
GROUNDWATER CHEMISTRY FOR SHALLOW ALLUVIAL WELLS AND SPRINGS IN THE UINTA BASIN, UTAH

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ABSTRACT

The Uinta Basin in Utah generally lacks sufficient water-quality data to characterize the area's relatively shallow groundwater. To establish a baseline of water quality for springs and alluvial wells, I collected water samples representing a widespread distribution of sites throughout the Utah portion of the Uinta Basin. Groundwater chemistry from greater depths in the oil- and gas-producing zones (e.g., Wasatch and Mesaverde Formations) is well known and was not the focus of this study. Shallow groundwater-quality information will help to develop environmentally sound, water-management solutions for the potential advancement of an oil-shale and tar-sands industry in the area.

During summer of 2013, I collected 22 water samples from 12 water wells and 10 springs. A suite of water-quality constituents was analyzed, including: general chemistry (including total dissolved solids [TDS]), nitrate, dissolved metals (including lead, iron, and zinc), volatile organic compounds (VOCs), total petroleum hydrocarbons (TPH), and stable isotopes (¹⁸O and ²H). TDS concentrations for all samples range from 214 to 5532 mg/L and nitrate concentrations range from <0.1 to 5.32 mg/L for all samples. Dissolved-solids concentrations were highest from a spring along the White River and lowest from a shallow well located in the northern part of the Uinta Basin near recharge from the Uinta Mountains to the north. Most sites have nitrate concentrations below 0.1 mg/L (the detection limit) with the exceptions of one alluvial well near Evacuation Creek and one spring north of Duchesne, downgradient from an active gravel pit. Some samples had detectable VOCs, but all were below the U.S. Environmental Protection Agency's maximum contaminant levels, except for some sites having elevated chloromethane. No samples had detectable TPH (commonly called gasoline-range organics/diesel-range organics or GRO/DRO). Oxygen and deuterium isotopes in sampled water indicate multiple recharge locations, except for northern wells that may receive recharge from a common area from the nearby high-elevation Uinta Mountains.

If sound water management practices are not implemented, water-quality degradation may result from an increase in mining activity/energy resource development. This regional baseline water study provides information to help local planners and potential developers preserve the quality of groundwater and surface water by establishing best management practices through careful land-use planning.

INTRODUCTION

With the continued demand for U.S.-derived energy products, research and development for unconventional sources of oil and gas in Utah has increased, including research geared towards unlocking the vast oil-shale and oil-sand resources of the Uinta Basin. The basin also has great potential for further development of shale/tight-sand gas reservoirs. However, the Uinta Basin generally lacks sufficient water-quality data to characterize the relatively shallow groundwater. The primary objective of this study is to document water quality in potential hydrocarbon development (figure 1). This study is a small component of a broader project by the Utah Geological Survey (UGS) that addresses the production and disposal of water originating from the development of shale/tight-sand gas reservoirs (see <http://geology.utah.gov/resources/energy/oil-gas/produced-water/>). This so-called "produced water" is volumetrically the largest

waste stream associated with unconventional oil and gas plays. Production and disposal of this water has recently become a topic of much public debate as it affects the economics of gas resource development and has potential land-use impacts that may affect vulnerable aquifers of the Uinta Basin. The Uinta Basin produced water project is part of a collaborative effort to promote maximized produced-water reuse, which will minimize use of fresh-water in unconventional oil and gas development and production. Characterizing shallow groundwater chemistry will aid in the protection of critical Uinta Basin alluvial aquifers and springs by establishing baseline water quality.

Various proposals have been submitted by energy companies (Enfit American Oil, Red Leaf Resources, and U.S. Oil Sands) and accepted by Utah State regulatory agencies (Utah Division of Oil, Gas, and Mining [UDOGM] and the Utah Division of Water Quality [UDWQ]) to devel-

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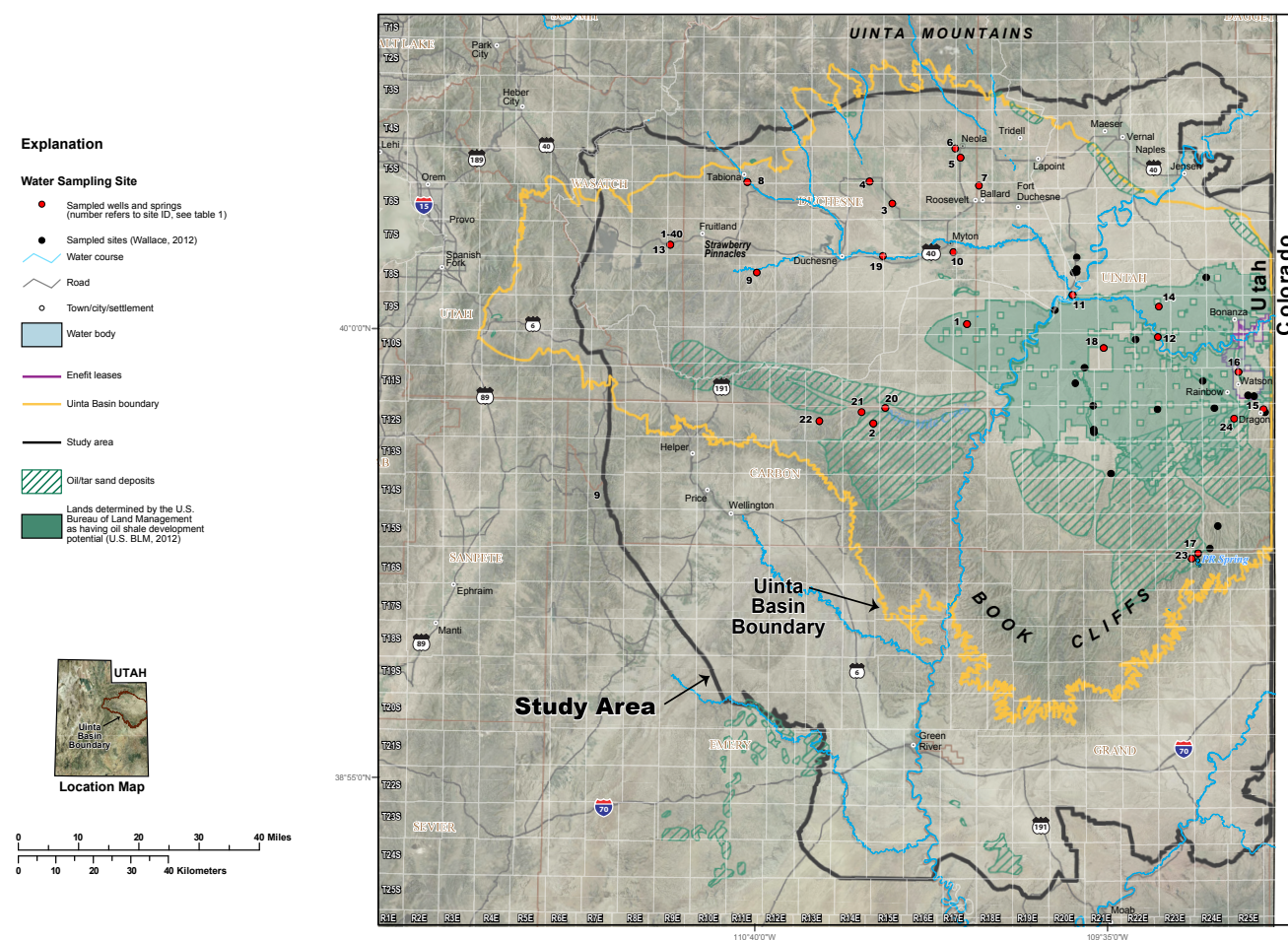


Figure 1. Location map of study area showing boundaries of shale oil/tar sands. Darker green areas highlight U.S. Bureau of Land Management land having oil shale development potential (U.S. BLM PEIS, 2012) (modified from Vanden Berg and others, 2013; Wallace, 2012). Numbered sites are wells/springs and their site IDs sampled for this study; black dots correspond to sites sampled during 2009-2011.

op unconventional energy resources in the study area. Enefit American Oil is preparing to develop an extensive surface/underground oil-shale mine and surface retort on private land near the old town site of Watson (figure 1). Enefit's commercial goal is to produce 50,000 barrels of shale oil per day, which corresponds to about 2.6 billion barrels of recoverable fuels from oil shale in the Uinta Basin in Utah and will require mining between 25 and 30 million tons of shale per year (Enefit American Oil, 2012). This operation will require significant disposal of spent shale. Red Leaf Resources has developed a unique surface mine and capsule retort technology to produce oil from oil shale on state land in the southern portion of the study area (T. 13 S., R. 23 E., Salt Lake Base Line and Meridian). Their commercial goal is to produce 9500 barrels of oil per day (Red Leaf Resources, 2012). The Oil Mining Company, Inc. (TOMCO) plans to use Red Leaf Resources' capsule retort technology to develop oil shale southeast of Rainbow (figure 1) (near perennial and ephemeral springs to the south). U.S. Oil Sands has commenced its phased development of oil-sands production in the PR Springs area near the southern border of Uintah County (figure 1). They plan to surface mine the oil sand, use a non-toxic bio-solvent derived from citrus

products to extract the bitumen, and dispose the leftover sand into lined pits (U.S. Oil Sands, 2012).

UDWQ has granted a groundwater discharge permit-by-rule based on conditions the operation has *de minimis* effect on groundwater quality for future drilling that attempts to delineate tar-sand areas for mining, especially around PR Springs (Mark Novak, UDWQ, written communication, January 2015). PR Springs will be sampled seasonally during the development of tar sands in this area as part of a U.S. Bureau of Land Management (BLM)-UDWQ cooperative Sampling and Analysis Plan (SAP) (Scott Hacking, personal communication, Utah Department of Environmental Quality [UDEQ], July 2014).

The information collected in this study provides necessary background water quality information along with historic water-quality data to help create a vulnerability assessment of the Uinta Basin's shallow aquifers. Assessing the sensitivity and vulnerability of the alluvial aquifers on BLM lands will help regulators develop environmentally sound, water-management solutions for responsible oil-shale and/or oil-sand resource extraction in the Uinta Basin.

PREVIOUS WORK

Hydrogeology

Groundwater in the Uinta Basin occurs in both unconsolidated valley-fill material and consolidated rocks. In the southeastern Uinta Basin, the principal productive consolidated aquifers are in the Green River and Wasatch Formations (Holmes, 1980). Price and Miller (1975) provided a reconnaissance of groundwater conditions in the southern Uinta Basin. Water is generally unconfined in the unconsolidated deposits and confined in the consolidated aquifers.

Recharge to the shallow groundwater system, including imported Duchesne River water, in the southern Uinta Basin for the 1935–1970 period was estimated at 120,000 acre-feet per year; discharge was estimated at 118,000 acre-feet per year (Price and Miller, 1975). Holmes (1980) indicated the amount of basin-wide recharge was 630,000 acre-feet per year, of which only 20% was derived from the southern half of the basin. Most recharge generally occurs during winter when more widespread and longer-duration snowstorms occur. The fine-grained, low permeability rocks found throughout the recharge area result in slow percolation rates; about 3% of estimated average annual precipitation (~100,000 acre-feet) is recharged (Price and Miller, 1975).

In a later study, groundwater discharge was estimated to be equal to recharge (Holmes and Kimball, 1987) with discharge occurring in the southeastern Uinta Basin mostly from shallow, alluvial aquifers within valley drainages of the Green and White Rivers and their tributaries. Most discharge occurs from streams, springs, evapotranspiration, and well withdrawal. The hydrologic budgets for the alluvial aquifer and the bedrock aquifers within the Green River Formation vary (Holmes and Kimball, 1987). Recharge for deep groundwater aquifers is primarily from precipitation and stream inflow but can also originate from leaking overlying formations. Shallow, alluvial aquifer recharge originates from stream infiltration and locally from upward migration of underlying, consolidated aquifer water. Groundwater movement in both unconsolidated and consolidated aquifers typically follows the slope and direction of the major streams (e.g., Strawberry, Duchesne, Green, and White Rivers) (Price and Miller, 1975). Water leaves the basin via the Green River and diversions to the Great Basin region (Holmes, 1985).

The total water volume consumed in the entire Uinta Basin is estimated by taking the difference between the inputs (surface-water and precipitation inflows) and the outputs (surface-water outflow and diversions to the Great Basin). The water volume consumed in 1985 was about 7.4 million acre-feet (Holmes, 1985). Today, annual consumption is most likely greater due to an increased number of water users. For shallow, alluvial aquifers in the southeastern Uinta Basin, the estimated volume of recoverable storage water is about 200,000 acre-feet with maximum yields for individual wells of more than

1000 gallons per minute (Holmes and Kimball, 1987).

A 1987 study by Holmes and Kimball of the U.S. Geological Survey (USGS) on groundwater in the southeastern Uinta Basin examined water quality from the alluvial and bedrock aquifers. They documented variable water quality throughout the southeastern Uinta Basin; their data are from the easternmost part of the study area. Total-dissolved-solids (TDS) concentrations ranged from 440 to 27,800 mg/L for water in the alluvial aquifers, from 870 to 5810 mg/L in the eastern portion of the Birds Nest aquifer (much higher salinities are found in the western Birds Nest), and from 640 to 6100 mg/L in the Douglas Creek aquifer. They attributed the changes in water quality to several physiochemical processes, including mineral precipitation and dissolution, oxidation and reduction, mixing, ion exchange, and evaporative concentration. Water quality is much poorer in the alluvial aquifers than in the bedrock aquifers. Based on 72 samples from four alluvial aquifers in the southeastern Uinta Basin, average TDS was 5432 mg/L. Average TDS concentration (80 water samples) for the eastern Birds Nest aquifer was 2700 mg/L, and average TDS concentration (12 samples) for the Douglas Creek aquifer was 1098 mg/L. Water quality in the deeper part of the basin, especially in the Birds Nest aquifer, has TDS concentrations of more than 100,000 mg/L (Vanden Berg and others, 2013).

Another study in the northwestern Uinta Basin, within the Altamont-Bluebell oil and natural-gas field, examined the impacts to drinking-water wells from oil and gas waste-water injection into deeper parts of the aquifer (Steiger, 2007). Twenty monitoring wells penetrating alluvial and/or shallow bedrock aquifers of the Duchesne River and Uinta Formations were analyzed for water quality with emphasis on bromide, chloride, and stable isotopes (^{18}O and ^2H). The study monitored the wells on a rotating basis from 1993 to 2004 to determine whether saline water disposed in the deeper aquifers (3100 to 10,500 feet below the surface) was influencing the shallow aquifers. Any increase in either bromide or chloride concentrations in the monitoring wells over time could indicate mixing of the two waters, but based on these constituents, no mixing was documented. Stable isotopes from the shallow wells plotted on or near the meteoric water line whereas those from the deep aquifer wells plotted well below the meteoric water line. Based on these chemical results, Steiger (2007) concluded that the deeper groundwater was not reaching the drinking-water aquifers.

Kenney and others (2009) evaluated water quality in the greater Upper Colorado River Basin, including the rivers and tributaries within the Uinta Basin, to determine the impact of land-use practices on water quality using TDS concentrations. Using a Spatially Referenced Regressions on Watershed Attributes (SPARROW) model, they compared relative contributions of dissolved solids from natural sources, agricultural practices, and industrial development (oil and gas fields). Based only on measured dissolved solids in rivers and streams, the authors concluded the greatest source of TDS is from natu-

ral geologic sources (~57%) and agricultural practices (45%) whereas the oil and gas industry contribution was statistically insignificant.

Previous Water-Quality Data

Several water-quality studies were conducted in the southeastern Uinta Basin on land designated by the BLM as having oil shale development potential. These studies are mainly of water sampled from oil and gas wells during well installation. In 1970, the USGS drilled six monitoring wells into the shallow, alluvial aquifer and Green River Formation in areas considered for oil-shale development and reported water-quality data from the Douglas Creek and Birds Nest aquifers within the Green River Formation (Holmes, 1980; Wallace, 2012). The UGS compiled water-quality data for springs and wells sampled during the 1970s (Wally Gwynn, former UGS geologist, written communication, May 2009). A study by Zhang and others (2009) provided water-quality data from 57 wells completed in several different formations. The UGS conducted studies on water-related issues affecting conventional oil and gas recovery and potential oil shale development in the Uinta Basin (Anderson and others, 2012; Wallace, 2012; Vanden Berg and others, 2013).

Wells and springs dominantly penetrating or issuing from the Green River Formation (and a few in the Wasatch Formation) indicate variable water quality (Wally Gwynn, former UGS geologist, written communication, May 2009). TDS concentrations from 39 springs range from 292 to 23,900 mg/L with an average of 1999 mg/L, and TDS concentrations from 50 wells range from 494 to 9870 mg/L with an average of 2443 mg/L (Wally Gwynn, former UGS geologist, written communication, June 2009). Zhang and others' (2009) data show 5% of the wells have TDS between 0 and 1000 mg/L, 4% between 1000 and 3000 mg/L, 5% between 3000 and 10,000 mg/L, 68.5% between 10,000 and 50,000 mg/L, and 17.5% greater than 50,000 mg/L. Water samples from the Birds Nest aquifer (from ~200 oil/gas wells, oil-shale wells, and disposal wells) have TDS values that range from 1100 to 205,286 mg/L; 35% of the wells have TDS concentrations less than 3000 mg/L (mainly in the southeast), 28% between 3000 and 10,000 mg/L (south and east) and 37% greater than 10,000 mg/L (north and west) (data provided by several oil and gas industry sources; see Vanden Berg and others, 2013). Anderson and others (2012) re-mapped the base of the moderately saline water (BMSW) in the Uinta Basin using 10,000 mg/L TDS as the "boundary" between non-saline (TDS <10,000 mg/L) and saline (TDS >10,000 mg/L) water from data provided by cooperating oil and gas operators (data from ~8000 wells drilled after a report by Howells and others (1987) who mapped the original BMSW).

Wallace (2012) evaluated water quality from 24 locations in the southeastern Uinta Basin to assess the alluvial and bedrock aquifers on lands proposed by the BLM as having oil shale development potential. Data from 85 water samples were analyzed from water wells

and surface-water sites (figure 2) over three different sampling seasons from 2009 to 2011. The actual number of samples obtained each season/year varied depending on the condition of the well/spring. A suite of water-quality constituents was analyzed including general chemistry (including TDS), nutrients (including nitrate, phosphorous, and ammonia), dissolved metals, and volatile organic compounds (VOCs).

Groundwater quality in Wallace (2012) was variable, and generally good with TDS concentrations primarily below 3000 mg/L; some sites showed elevated nitrate, arsenic, lead, selenium, barium, boron, and gross alpha particle emitter concentrations in the aquifers. Seasonal changes in water chemistry were minimal for most sampling sites. TDS concentrations for all samples range from 172 to 2832 mg/L. The highest TDS value of 2832 mg/L was from Evacuation Creek during spring 2009; the lowest value (172 mg/L) was from the Green River near Ouray during flood stages in spring 2010. Nitrate concentrations range from <0.1 to 18.8 mg/L for all sampling seasons. Most sites had nitrate concentrations below 0.1 mg/L except alluvial wells downgradient from irrigated fields and a cattle ranch operation in the northwestern part of the study area, and a well penetrating bedrock in the central part of the study area. Twelve different types of VOCs had detectable concentrations, but all were below U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCL). Besides VOCs and boron, only the chemical constituents exceeding EPA standards are discussed below (see Wallace, 2012).

More recently, sites around the Greater Natural Buttes oil and gas development area have been and continue to be sampled quarterly as part of a long-term water-resource monitoring project for shallow alluvial and surface water administered by a subsidiary of Anadarko Petroleum Company (InterTech Environmental and Engineering, LLC, 2014). In the most recent monitoring report, TDS concentrations ranged from 820 to 11,800 mg/L for alluvial wells and 331 to 13,500 mg/L for surface water sites (InterTech Environmental and Engineering, LLC, 2014). Detectable VOC concentrations above detection level include: vinyl chloride, acetone, trichlorofluoromethane, trichloroethane, toluene, styrene, pyridine, p-isopropyl-toluene, methyl ethylketone, bis (2-ethylhexyl) phthalate, and total petroleum hydrocarbon (TPH) (as diesel-range organics [DRO]).

WATER-QUALITY SAMPLING FOR SPRINGS AND ALLUVIAL WELLS

During summer 2013, I sampled water from 12 shallow wells and 10 springs, representing a widespread distribution without land use bias, to characterize the alluvial aquifers in the Uinta Basin, Utah. During summer 2014, two additional springs were discovered and sampled (figure 1). A suite of water-quality constituents was analyzed, including TDS, specific conductance, bicarbonate, hydroxide, carbonate, sulfate, chloride, nitrate, dissolved metals/metalloids (including calcium, magnesium,

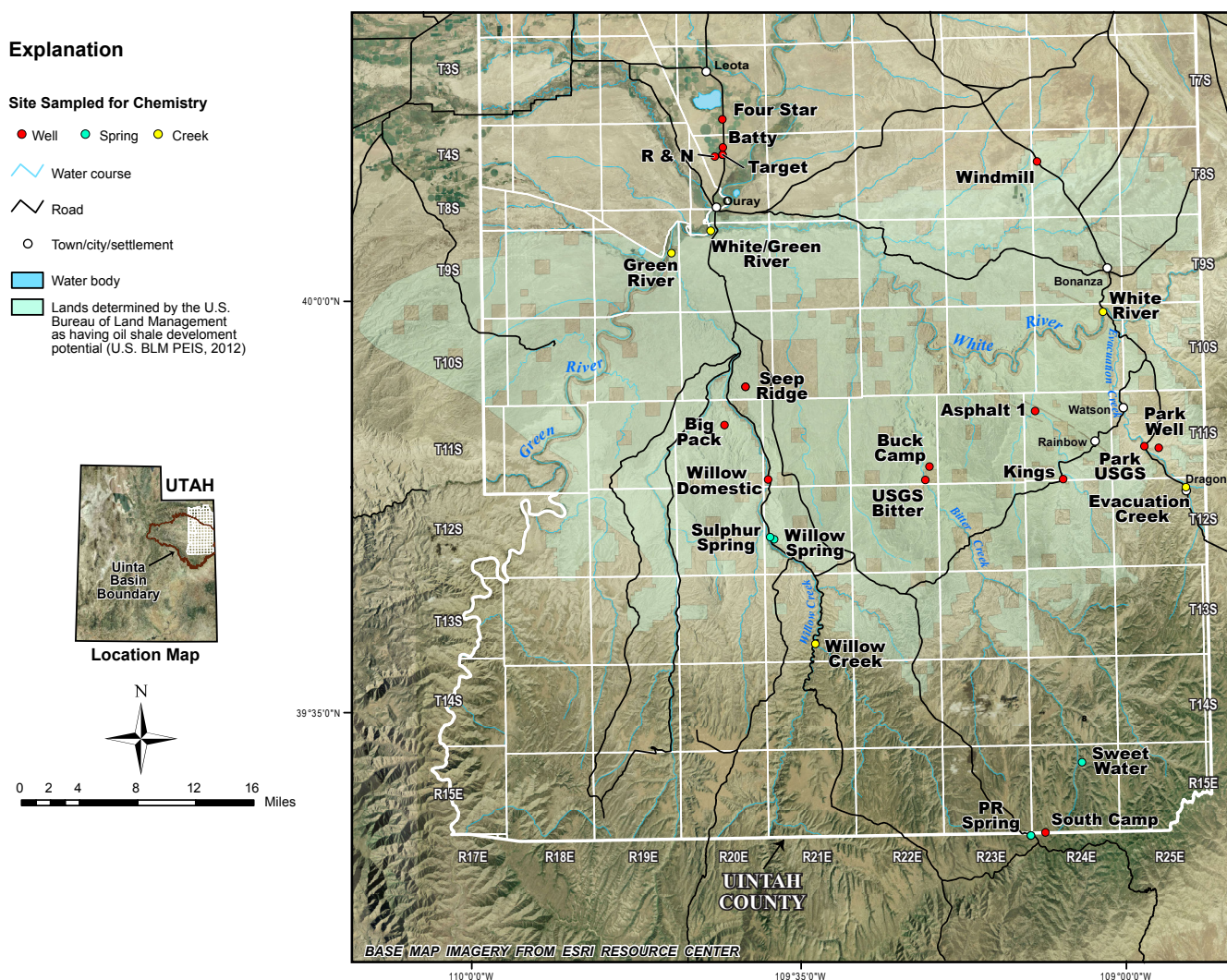


Figure 2. Sample site locations from a previous baseline water quality study for southeastern Uinta Basin. Well, spring, and surface water sites were sampled seasonally from 2009 to 2011 (from Wallace, 2012).

potassium, sodium, arsenic, aluminum, barium, cadmium, chromium, copper, mercury, manganese, mercury, silver, lead, iron, selenium, boron, and zinc), VOCs, TPH, and stable isotopes (^{18}O and ^2H). One well (site 18) was not analyzed for dissolved metals.

WATER-QUALITY RESULTS

Total-dissolved-solids concentrations for all wells and springs sampled range from 214 to 5532 mg/L, and nitrate concentrations range from <0.1 to 5.32 mg/L. Piper and Stiff water chemistry diagrams uniquely show variations in ion concentrations from water wells and springs throughout the study area. Piper diagrams indicate overall water chemistry is variable throughout the area with dominantly sodium-potassium-bicarbonate-, sodium-potassium-sulfate-, and calcium-magnesium-bicarbonate-sulfate-type groundwater (figure 3). Stiff diagrams show solute chemistry data for sites sampled in 2012–2014 (all but one site have solute chemistry data) (figure 4).

Total-Dissolved-Solids Concentrations

The average total-dissolved-solids concentration from samples in this study is 1229 mg/L, and the median is 747 mg/L. The highest TDS concentration is 5532 mg/L from a spring (site 12) near the White River, and the lowest is 214 mg/L from a water well near the Uinta Mountains recharge area (site 5). Additional TDS data were gathered from 32 public supply sources (water wells and springs). The average TDS for public supply sources is 427 mg/L. Figure 5 shows a graduated-symbol TDS concentration map for sites sampled during 2013 and 2014 (this study), the 2009 to 2011 sampled sites, and public supply sources (data from 1978 to 2013). The poorest quality water shown in figure 5 is an outlier compared to the rest, in terms of high TDS, and is from a spring (site 12) issuing from the Uinta Formation exposed at the surface near the White River (photo figure 6). The highest quality water is from wells (sites 3, 4, 5, 6, 7, 8) located proximal to the Uinta Mountains recharge area in the north (figure 5). Elevated TDS concentrations are possibly due to long residence time in the

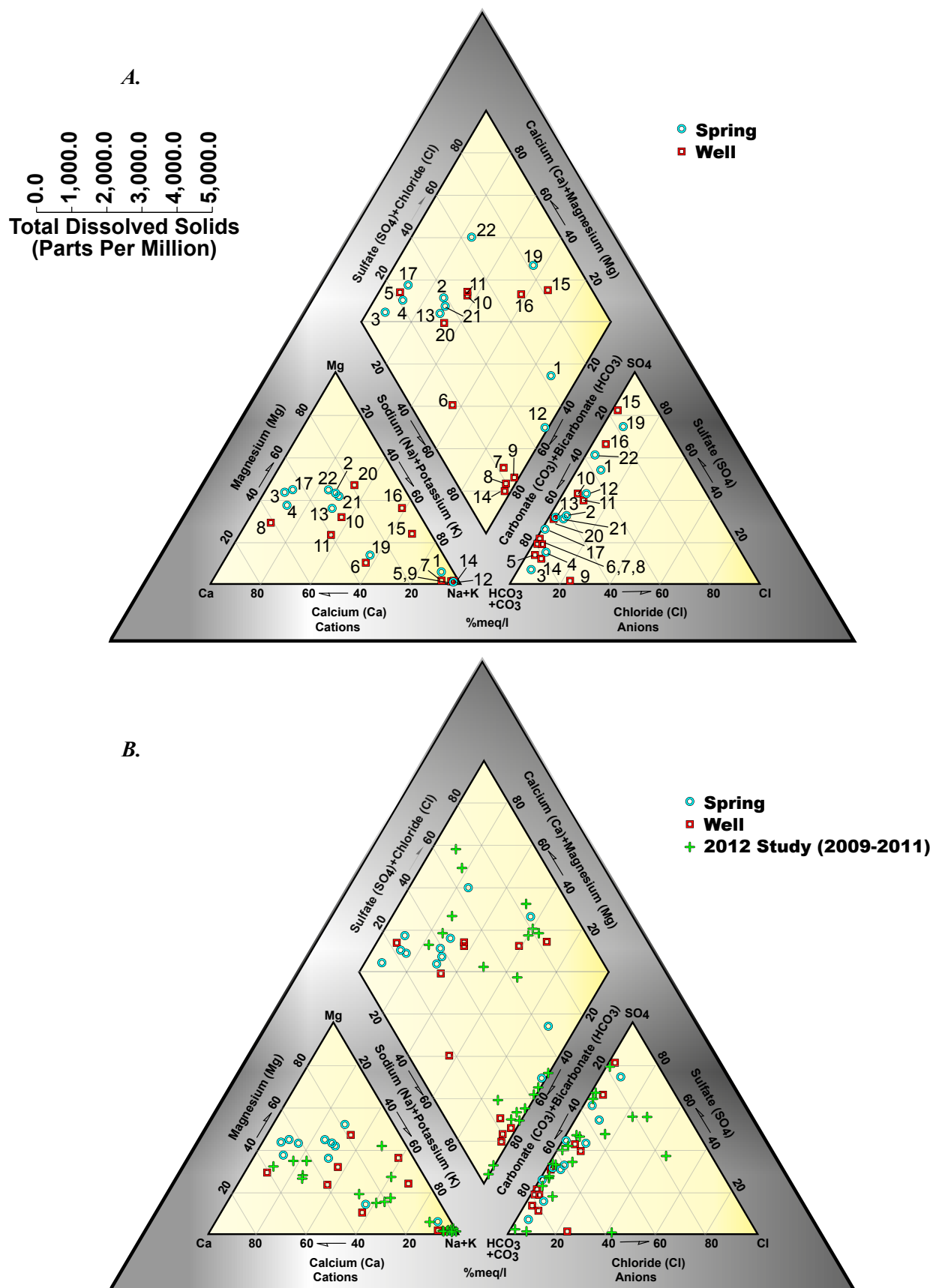


Figure 3. General solute chemistry for sampling sites in the Uinta Basin; A) Piper plot of samples collected for this study; numbers correspond to site IDs in table 1 and figure 1, B) Piper plot of all samples collected from a previous study (seasonal samples collected from 2009 to 2011; Wallace [2012]) and this study.

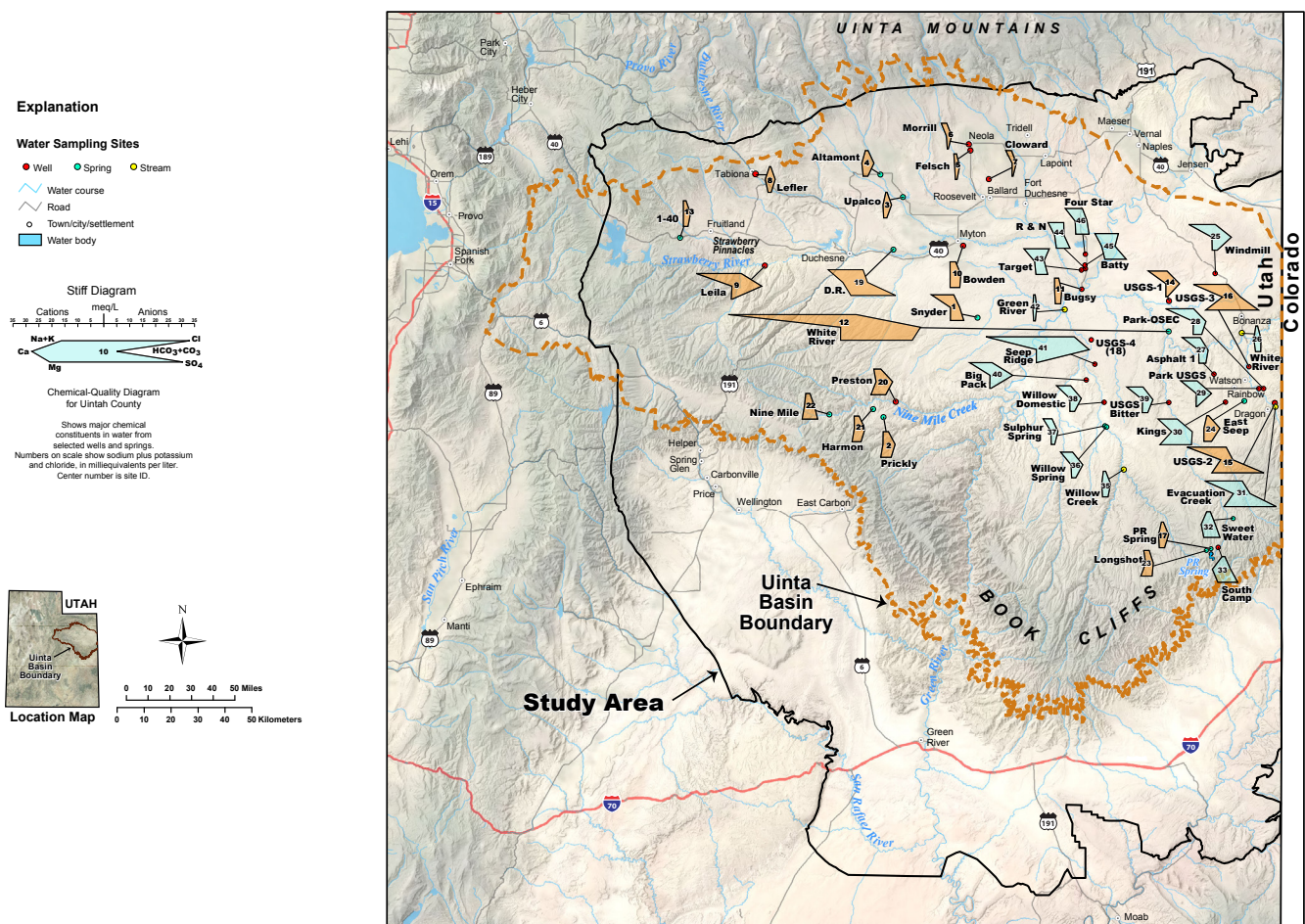


Figure 4. Stiff diagrams for solute chemistry in the Uinta Basin. Stiff plots shown in blue are from data collected during 2009–2011 (sites 25 through 46; Wallace, 2012); orange Stiff plots (Site IDs 1–22) are from data collected during 2013, but include sites 23 and 24 collected by the Utah Division of Water Quality during 2014.

bedrock aquifers, associated with drilling fluids (reported “lost” circulation driller’s mud due to the pervasive vugs within the Birds Nest aquifer), or wastewater disposal from wells drilled in the Green River Formation (though many disposal wells are upgradient from this spring, which warrants additional analysis, discussed below).

Nitrate Concentrations

Nitrate concentrations in groundwater range from less than 0.1 mg/L to 5.32 mg/L (table 1). The majority of samples (91%) had nitrate concentrations that were less than 1 mg/L. One spring (site 19) and one well (site 15) had nitrate concentrations of 4.3 and 5.3 mg/L. Both samples are below the EPA MCL of 10 mg/L. Average nitrate concentration is 0.59 mg/L and median concentration is 0.08 mg/L.

The highest nitrate concentrations of 5.3 and 4.3 mg/L are in different areas in the basin; site 15 is a shallow monitoring well drilled in the 1970s near Evacuation Creek (figure 7) and site 19 is a spring near the Duchesne River downgradient from a gravel pit. No other nearby land use commonly identified as a nitrate source (septic tanks, feed lots, and fertilized cropland) exists in either area.

Arsenic

Arsenic values from sampling sites ranged from less than 1 µg/L to 13 µg/L (table 1). One site (2), near an oil/gas development site, exceeds the 10 µg/L EPA MCL, and ten sites had arsenic concentrations between 1 and 9 µg/L. Forty-three percent of the sites had concentrations below detection level (< 1 µg/L); the average concentration is 2.5 µg/L and the median is 3.6 µg/L. Overall, arsenic concentrations in the basin aquifers are variable, and the source of arsenic is unknown.

Boron

Boron was analyzed in all but one sample (table 1) and ranges from <30 µg/L (site 23, E seep spring) to a high of 28,300 µg/L (site 12, White River spring). The average of all samples, excluding site 23, is 2319 µg/L and the median is 178 µg/L (table 1). Boron may be associated with dissolution of minerals (feldspar) in the Green River Formation (Desborough and others, 1974; Desborough and others, 1976) or derive from drilling fluid loss in the Birds Nest aquifer. Clerico (this UGA publication) reports elevated boron concentrations in the Birds-Nest aquifer which may be indicative of a perched aquifer in

Table 1. Water quality data for shallow well and spring sample sites in the Uinta Basin collected during summer 2013 (sites 1-22) and summer 2014 (sites 23 and 24).

			Solids,								
	Lab, Specific Conductance (umhos)	residue @180°C, dissolved	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Bicarbon-ate (mg/L)	Boron, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chloride (mg/L)	Chromium, dissolved (µg/L)	Iron, dissolved (µg/L)	
SITE ID	Site Name										
1	Snyder	2300	1476	1.25	<100	470	1760	<0.1	71.8	5.24	125
2	Prickly	1131	754	13	<100	478	797	<0.1	27.5	3.86	22.6
3	Upalco	532	304	4.51	292	294	70.8	<0.1	8.88	3.27	<20
4	Altamont	788	470	3.03	138	405	132	<0.1	19.5	3.68	22.1
5	Felsch	373	214	1.22	104	179	160	<0.1	3.81	<2	<20
6	Morrill	527	308	<1	<100	229	89.5	<0.1	1.79	<2	<20
7	Cloward	624	366	<1	<100	269	86.7	<0.1	1.61	2.59	29.9
8	Lefler	572	332	<1	110	284	72.4	<0.1	6.87	<2	38.8
9*	Leila	3570	2056	<1	391	1140	4460	<0.1	311	6.64	43.1
10	Bowden	1122	740	<1	<100	388	712	<0.1	24.4	<2	1890
11	Bugsy	715	468	<1	346	238	145	<0.1	25.3	<2	129
12	White River	8370	5532	8.89	1730	3510	28300	<0.2	537	11.5	59
13	I-40	593	392	<1	<100	276	156	<1	4.69	<2	21.9
14	USGS-1	1616	982	6.18	<100	825	846	<0.1	37.2	<2	52.5
15	USGS-2	4430	3364	<1	<100	469	178	<0.1	31.4	<2	26.5
16	USGS-3	4200	3168	4.98	<100	860	8510	<0.1	87.9	<2	2520
17	PR Spring	690	408	<1	<100	330	61.3	<0.1	**J2.49	<2	25.1
18	USGS-4	1586	1060	-	-	802	-	-	70.9	-	-
19	D.R.	4180	3250	2.33	<100	513	1520	0.135	137	<2	438
20	Preston	640	976	2.484	<100	702	577	0.165	10.2	<2	832
21	Harmon	1036	634	3.597	<100	442	259	<0.1	24	<2	<20
22	Nine mile	1214	854	<1	<100	284	92.9	<0.1	16.2	<2	20.5
23	longshot	719	554	-	-	292	2040	-	3.25	-	-
24	e. Seep Cyn	1174	832	-	-	633	<30	-	7.96	-	-
AVERAGE ¹			1229	2.5			2319				
MEDIAN ¹			747	3.6			178				

*well owner indicated no water treatment filter existed, VOC data suggest otherwise; **J is above detectable levels; u is undetected, - is no sample collected, ¹ available for some data

Table 1. continued. Water quality data for shallow well and spring sample sites in the Uinta Basin collected during summer 2013 (sites 1-22) and summer 2014 (sites 23 and 24).

SITE ID	Lead, dissolved (µg/L)	Nitrate as N (mg/L)	Selenium, dissolved (µg/L)	Sodium, dissolved (mg/L)	Sulfate (mg/L)	Zinc, dissolved (µg/L)	Benzene (µg/L)	Bromomethane (µg/L)	Bromodi- chlorometha- ne (µg/L)	Bromoform (µg/L)	Chlorobenz- ene (µg/L)
1	0.182	0.142	<1	463	565	<10	u	u	u	u	0.21
2	<0.1	0.086	<1	90.7	201	<10	u	1.4	u	u	u
3	<0.1	0.205	<1	9.2	19.6	<10	u	0.25	u	u	u
4	0.259	0.053	<1	24.4	65.2	44.9	u	0.36	u	u	u
5	0.265	0.275	<1	52	24.4	<10	u	u	u	u	u
6	0.132	0.061	<1	112	48.5	34.3	u	u	u	u	u
7	<0.1	0.043	<1	135	64.4	<10	u	0.25	u	u	u
8	<0.1	0.385	<1	12.9	55.5	12.3	u	u	u	u	u
9*	0.192	0.067	<1	808	35.5	<10	u	6.7	27.9	1.8	u
10	<0.1	0.041	<1	102	253	29.1	u	u	u	u	u
11	<0.1	0.077	<1	60.9	147	15.5	u	u	u	u	u
12	<0.2	0.033	8.687	2520	3390	<20	1.2	u	u	u	u
13	0.103	0.043	<1	46.6	103	11.6	u	u	u	u	u
14	0.291	0.019	<1	401	86.6	154	u	u	u	u	u
15	1.45	5.32	<1	837	1820	473	u	u	u	u	u
16	0.56	0.001	<1	718	1550	57.4	u	u	u	u	u
17	0.949	0.213	<1	18.9	94.7	35.2	u	u	u	u	u
18	-	0.001	-	-	126	-	u	u	u	u	u
19	4.89	4.33	<1	682	1710	822	u	u	u	u	u
20	3.498	0.338	<1	144	271	100.55	u	u	u	u	u
21	0.858	0.953	<1	86.4	174	44.896	u	u	u	u	u
22	0.999	0.195	<1	82.2	381	38.243	u	u	u	u	u
23	-	-	-	101	185	-	-	-	-	-	-
24	-	-	-	30.8	148	-	-	-	-	-	-
AVERAGE ¹	0.59										
MEDIAN ¹	0.08										

*well owner indicated no water treatment filter existed, VOC data suggest otherwise; **J is above detectable levels; u is undetected, - is no sample collected, ¹ available for some data

Table 1. continued. Water quality data for shallow well and spring sample sites in the Uinta Basin collected during summer 2013 (sites 1-22) and summer 2014 (sites 23 and 24).

SITE ID	Chloromethane (µg/L)	Chloroethane (µg/L)	Chloroform (µg/L)	Chlorodibromomethane (µg/L)	Vinyl chloride (µg/L)	Total xylene (µg/L)	Toluene (µg/L)
1	0.9	u	u	u	u	u	0.24
2	18	u	u	u	u	u	u
3	2.1	u	u	u	u	u	u
4	14.3	u	u	u	u	u	u
5	0.98	u	u	u	u	u	u
6	2.8	u	u	u	u	u	u
7	13.4	u	u	u	u	u	u
8	u	u	u	u	u	u	u
9*	17.5	u	82	12.1	u	u	u
10	tr	u	u	u	u	u	u
11	3.9	tr	u	u	u	u	u
12	u	u	u	u	-	tr	u
13	1.6	u	u	u	u	u	u
14	u	u	u	u	u	u	8.1
15	*J0.25	u	u	u	6.6	u	10.2
16	*J0.29	u	u	u	u	u	1.1
17	*J0.21	u	u	u	u	u	u
18	u	u	u	u	3	u	3.2
19	4.6	u	u	u	u	u	u
20	u	u	u	u	u	u	u
21	u	u	u	u	u	u	u
22	u	u	u	u	u	u	u
23	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-
AVERAGE ¹							
MEDIAN ¹							

*well owner indicated no water treatment filter existed, VOC data suggest otherwise;

**J is above detectable levels; u is undetected, - is no sample collected, ¹ available for some data

the area underlying Enefit's lease area near Evacuation Creek in the southeastern part of the Uinta Basin (figure 1). All but one of the boron concentrations were above the detection level of 30 µg/L. Boron does not have an EPA-designated MCL, and is not known to pose a threat to human health. However, the UDWQ has classified the nearby Green River as Class 4 Water and has set a maximum boron concentration of 0.75 mg/L for this class. Eight of the sample sites had boron concentrations that exceed the maximum concentration for Class 4 Waters.

Other Constituents of Concern

Water from seven of 21 sites analyzed for metals concentrations had some constituents with concentrations with detection levels above the reporting level but below the drinking water EPA MCL. The chromium concentrations ranged from <2 to 11.5 µg/L, and may be associated with

drilling fluids. Lead levels for 14 sites were above the detection level, ranging from 0.103 µg/L to 4.89 µg/L, but did not exceed the EPA Treatment Technique Action Level of 15 µg/L. Barium was detected at seven sites and concentrations ranged from 104 to 1730 µg/L, but no sites exceeded the EPA MCL of 2000 µg/L.

Volatile Organic Compounds and Total Petroleum Hydrocarbons

Total petroleum hydrocarbons (TPH) and volatile organic compounds (VOCs) were analyzed for all sample sites. No samples had detectable TPH (table 1). A total of twelve different VOCs were detected. Chloromethane was the most commonly occurring VOC (14 sites), and toluene and bromomethane were the second most common (5 sites each). Chloromethane concentration ranged from trace amounts to 18 µg/L. Toluene concentrations range

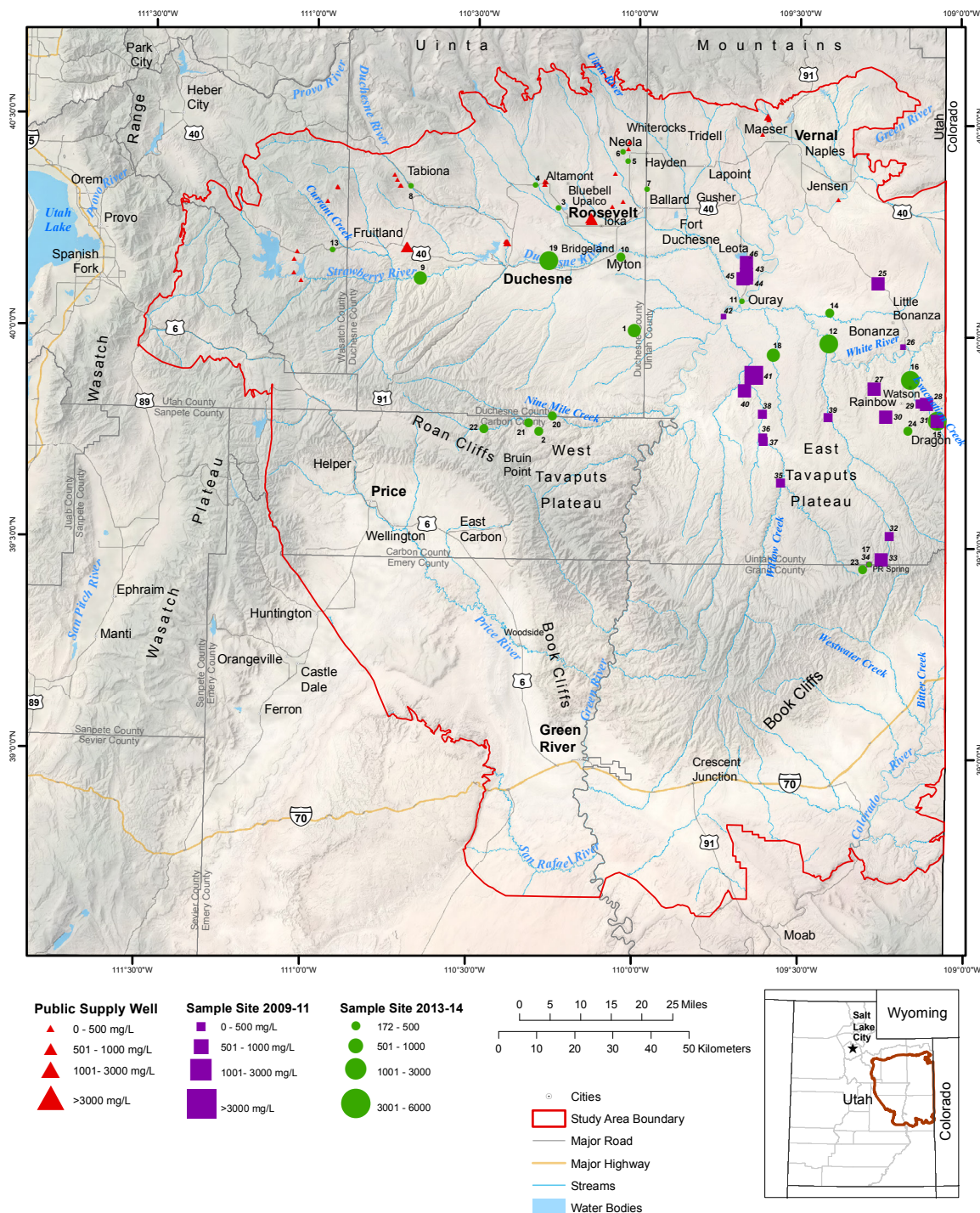


Figure 5. Total-dissolved-solids concentrations for samples collected for a previous baseline water quality study (samples collected from 2009 to 2011 [Wallace, 2012]), for this study, and from public supply wells taken from various years. Site IDs 1-24 are samples collected for this study (see table 1), site IDs 25-46 are from samples collected from 2009-2011.

from 0.24 to 10.2 $\mu\text{g/L}$. Vinyl chloride was detected in two wells (6.6 $\mu\text{g/L}$ at site 15 and 3 $\mu\text{g/L}$ at site 18) above the EPA MCL of 2 $\mu\text{g/L}$. These shallow alluvial monitor wells were drilled by the USGS during the 1970s and are not used for drinking water. Other detectable VOCs include benzene, bromoform, chlorodibromomethane, bromodichloromethane, chlorobenzene, chloroethane, and total xylene (table 1).

Chloromethane is on the EPA Contaminant Candidate List 3 but is currently unregulated by the EPA. The Drinking Water Health Advisory, Office of Water, has issued a report on the chemical properties of chloromethane as it is used in the production of other chemical products (U.S. EPA, 2014, accessed December 3, 2014). Toluene is a regulated organic liquid that has been known to cause problems with the nervous system, kidneys, or



Figure 6. White River spring (site 12) is located along the White River in the central part of the study area. The spring issues into pools that likely enter the White River and mix with White River overbank flood water during spring runoff.



Figure 7. Monitoring well (site 15) drilled by the U.S. Geological Survey during the 1970s for a study to examine water quality in shallow alluvium in the southeastern Uinta Basin. Nitrate concentration for this well is 5.3 mg/L.

liver when consumed in concentrations that exceed the MCL over long periods of time. Exposure to vinyl chloride in drinking water can cause long-term problems to the human nervous system and liver cancer (U.S. EPA, 2014, accessed December 3, 2014).

Secondary Constituents

National Secondary Drinking Water Standards set by the EPA were exceeded in 12 samples (table 1). The sulfate standard (250 mg/L) was exceeded at seven sites; iron standard (0.3 mg/L) was exceeded at four sites; and chloride standard (250 mg/L) was exceeded for one site. These constituents are not known to be deleterious to human health but may impart an unpleasant taste, odor, or color to the water.

Oxygen and Deuterium Stable Isotopes

Isotope hydrology uses the isotopes of water molecules to trace water sources and can be used to determine the contributions of old and new water in a groundwater system. Factors such as altitude, latitude, location within a continent (and proximity to a mountain range), and the amount of rainfall affect the enrichment factor of precipitation isotopes (Kendall and Caldwell, 1998). Heavier isotopes of oxygen and deuterium are associated with lower altitudes (on windward mountain sides), decreasing latitude, coastal versus inland areas, and smaller rainfall amounts (not applicable to snowfall) (Kendall and Caldwell, 1998).

Table 2. Isotope data for 22 sites in the Uinta Basin collected during 2013.

SITE ID	SITE NAME	Conductivity ($\mu\text{mos/cm}$)	Temperature (degrees C)	$\delta^{18}\text{O}$	+/-	δD	+/-
1	Snyder	2370	20	-14.06	0.4	-111.2	1
2	Prickly	1260	19.9	-15.01	0.4	-117.5	1
3	Upalco	570	10.9	-14.79	0.4	-110.9	1
4	Altamont	3170	10.2	-15.22	0.4	-113.3	1
5	Felsch	2700	13.3	-16.53	0.4	-120	1
6	Morrill	2440	13.6	-17.87	0.4	-133.8	1
7	Cloward	3590	13.8	-17.12	0.4	-126.5	1
8	Lefler	3300	11.6	-16.9	0.4	-126.3	1
9	Leila	3210	13.7	-17.32	0.4	-133.7	1
10	Bowden	1080	14.4	-13.66	0.4	-112.3	1
11	Bugsy	650	16.1	-14.83	0.4	-116.4	1
12	White River	9150	24	-16.34	0.4	-128.6	1
13	I-40	590	12.8	-17.38	0.4	-130.5	1
14	USGS-1	1700	23.5	-14.45	0.4	-109.8	1
15	USGS-2	4610	27	-13.7	0.4	-104.2	1
16	USGS-3	4260	14.3	-14.27	0.4	-110.1	1
17	PR Springs	690	12.7	-15.24	0.4	-111.4	1
18	USGS-4	1450	20.5	-15.14	0.4	-114.7	1
19	D.R.	3700	14.4	-15.07	0.4	-115.7	1
20	Preston	1390	17.3	-14.07	0.4	-107.7	1
21	Harmon	950	12.5	-14.36	0.4	-110.2	1
22	Nine Mile	1160	21	-15.07	0.4	-112.9	1

*highlight in yellow are spring sites

Twenty-two sites were sampled for oxygen isotopes and deuterium in 2013. The isotopic ratios in water range from -13.66 to -17.87‰ for oxygen and -134 to -104‰ for deuterium (table 2). The stable isotope results indicate that most water in the study area was recharged from different sources: some at moderate elevations and moderate climatic temperatures and others from higher elevations and cooler temperatures. Some locations have anomalous or ambiguous sources.

A plot of the oxygen and deuterium data is shown in figure 8. The global meteoric water line (GMWL) is from Clark and Fritz (1997). Most of the groundwater data collected from the area plot on or below the GMWL; groundwater is slightly enriched in ^{18}O relative to deuterium. Enrichment of ^{18}O (less negative isotopic signatures) in groundwater in the western United States has been attributed to paleoclimate effects (White and Chuma, 1987) such as arid conditions and extensive evaporation prior to recharge. Samples that are more enriched in ^{18}O (more positive) include the central wells, northern springs, and southern springs (including around Ninemile Creek). The enrichment of ^{18}O in the groundwater shown on figure 8 indicates evaporation of surface/soil water or snow subli-

mation prior to infiltration at these sites. If groundwater is recharged by more ephemeral heavy precipitation, then data for the groundwater may plot on the GMWL (which some of the data do). The lighter, or more depleted isotopes include the northernmost wells, the spring in the westernmost part of the study area (site 13), northern wells near Tabiona (site 8), Strawberry Pinnacles (site 9), and sites near the communities of Neola and Ballard (sites 5, 6, and 7) (figure 4; table 2). The outlier site 10 (another northern well near Myton; figure 1) has recharge water likely from another source. The isotopes from the White River spring (site 12) have a unique isotopic signature that likely relates to a different source(s) of recharge water, either connate brine water, hydraulic-fracturing (fracking) fluid, disposal water, or lost (circulation) drilling fluids, or a mixture of these; the White River spring and its unique water characteristics warrant future investigation (see below).

The isotopic signature for the shallowest well sampled in the northern basin near Myton (site 10) also stands out and likely receives recharge locally from the high water table associated with the nearby Duchesne River. For samples having enriched ^{18}O , spring runoff may be a

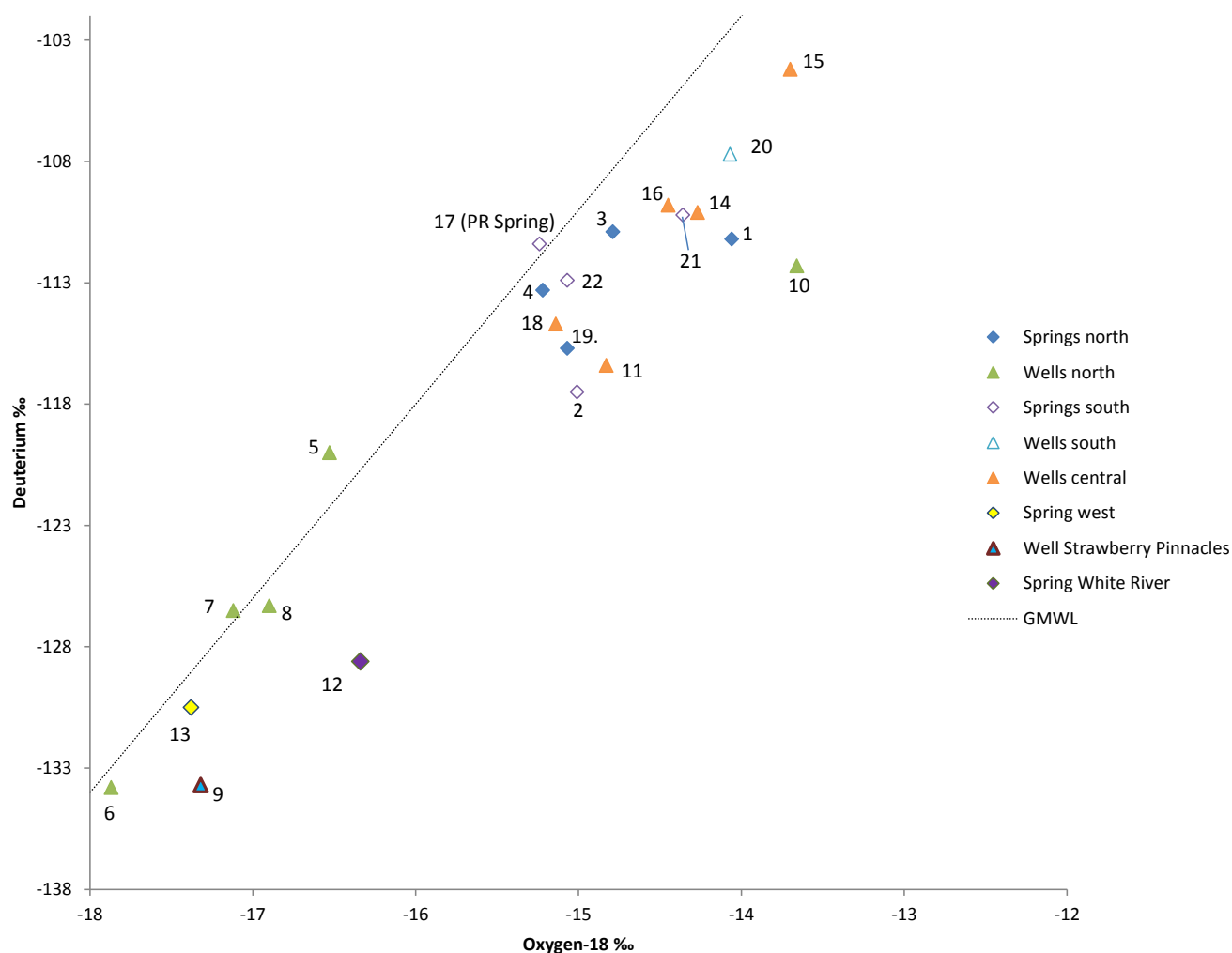


Figure 8. Plot of deuterium versus oxygen isotope for 22 samples in the Uinta Basin. The global meteoric water line (GMWL) is from (Clark and Fritz, 1997). See figure 1 for site ID locations and table 2 for isotope data for each site.

significant component of recharge in the study area, so the enrichment is most likely a result of sublimation of snow and/or evaporation of water during runoff but prior to recharge. Samples with the more depleted isotopic signatures may have a recharge source from the relatively nearby Uinta Mountains where recharge may take much longer to reach these sites.

WHITE RIVER SPRING COMPLEX

The spring/seep complex issuing from the Uinta Formation, along the White River exhibits anomalous chemistry data and suspect gases warranting further discussion (site 12, figures 4, 9a, and 9b). Informal reports from the public (strange odors [rotten egg] and unusual colors [black and pink]) alerted the BLM and UDEQ to further investigate the water quality of this spring/seep complex (Scott Hacking, UDEQ, personal communication, 2013), which is along a popular recreational corridor. The TDS concentration (5532 mg/L) is the highest from the 2012 and 2013 studies (Wallace, 2012). Anomalous high chemical constituents include arsenic, barium, bicarbonate, boron, chromium, selenium, sodium, sulfate, benzene,

and trace xylene (table 1); some of these constituents (boron, selenium, sodium, sulfate, and oil/grease) have been reported in streams and streamflow in the Uinta Basin and environs by other investigators (Lindskov and Kimball, 1984; Gerner and others, 2006; Wingert and others, 2010; Wallace, 2012). No constituent exceeds EPA MCL for drinking water standards, and the elevated TDS concentration, which is above the Utah Division of Drinking Water's MCL of 2000 mg/L for public-supply sources, does not apply in this case. The source of the relatively high TDS is unknown and needs further investigation, but may be sourced from natural, connate water or long-residence time along a complex groundwater flow path. TDS concentrations from the Uinta Formation for 102 wells in the Uinta Basin range from 165 mg/L to 222,060 mg/L with an average of 10,900 mg/L and a median of 1615 mg/L (Stephanie Carney, UGS, personal communication, May 2015, unpublished data). Water from the White River has low TDS concentrations typically near 500 mg/L (Wallace, 2012); the water in this spring likely is not sourced from the White River. A second field test of water from the spring complex (located about 50 feet from the laboratory-analyzed sample, taken in a

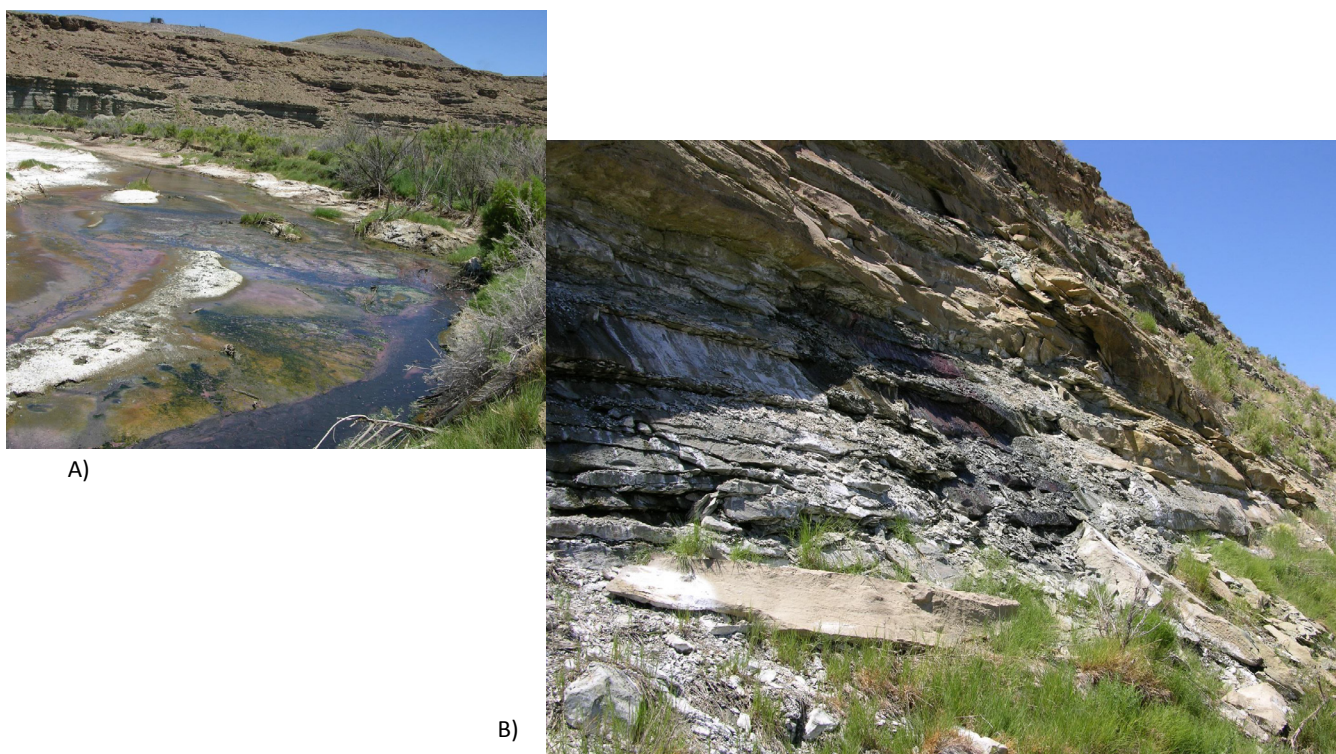


Figure 9. White River spring complex along the White River recreational corridor. Pink color may be bacteria/biologic activity; some of the black-colored residue is likely pervasive Uinta Basin gilsonite. A) spring pools, B) seep in bedrock above spring.

nearby stagnant pool of water) had a TDS of 25,452 mg/L and specific conductance of 38,912 $\mu\text{mhos/cm}$ (Ammon McDonald, DOGM, personal communication, 2014). The presence of some of the constituents, such as selenium, boron, and zinc may be from natural sources inherent in the bedrock as reported in previous investigations from wells, seeps, and surface water within Green River Formation watersheds (Desborough and others, 1974; Gerner and others, 2006; Wingert and Adams, 2010).

A black powder (noted by recreationists) exists as a substrate in pools in the spring system and contains what is most likely finely ground gilsonite (Taylor Boden and Peter Nielsen, UGS, personal communication, 2012). Gilsonite is a natural, chemically inert, and mechanically very friable hydrocarbon resin. The source of gilsonite in these pools is unknown but may be related to nearby gilsonite veins (Boden and Tripp, 2012). The stretch of the White River at this location trends along the same northwest-southeast direction as the mapped gilsonite veins (Boden and Tripp, 2012), though no vein has been documented at this location (perhaps due to small size, erosion by the river, or cover by alluvium or the river itself). Gilsonite veins in the area may serve as a conduit for groundwater carrying fluids from the subsurface (Vanden Berg and others, 2013).

During July 2014, staff with UDEQ, BLM, and EPA had the spring water re-analyzed. The analyses yielded results similar to the UGS sampling, with a TDS of 7430 mg/L, 1800 $\mu\text{g/L}$ for barium, 31,500 $\mu\text{g/L}$ for boron,

2970 mg/L sodium, 587 mg/L chloride, 3770 mg/L bicarbonate, and above-detection levels for benzene and TPH (DRO) (Joyel Dhieux, EPA, written communication, July 21, 2014). No samples were taken to determine the chemical constituents of the bubbling gas.

In order to evaluate the source of the dissolved constituents and gases in the White River spring complex, and whether there may be a link to current or historic oil and gas drilling activity, I recommend the following actions:

- Compare water chemistry of the Birds Nest aquifer, produced water from nearby gas wells, and records of mud-water compositions used during drilling of older wells, with the spring complex.
- Collect and analyze produced water and spring-complex water samples for oxygen, hydrogen, strontium, boron, radium, and lithium isotopes.
- Collect water and gas samples to analyze for methane, propane, ethane, hydrogen sulfide, and $\delta^{13}\text{C}$ of methane, to reveal potential sources of gases associated with the spring.

Integration of mapping and analyses of the geochemical and isotopic tracers listed above may help determine the source(s) and possibly the groundwater transport mechanism (A. Vengosh, Duke University, personal communication, June 2014). For example, previous investigations near the Book Cliffs along the Green River show

that integration of the geochemical and isotopic tracers using boron and strontium can help determine sources of dissolved solids (Gerner and others, 2006).

DISCUSSION

The water-sampling sites for this study were selected without bias to land use and are widespread throughout the study area. Stiff diagrams show variable water quality throughout the 2012 and 2013 study areas. The variations among sampling sites indicate water is likely from multiple aquifers that are not connected, with the exception of wells and springs in the northernmost area of the basin near the Uinta Mountains recharge area.

Arsenic, boron, chromium, barium, sulfate, iron, and chloride were identified in many of the sampled sites. Some samples had concentrations of arsenic and boron that exceeded limits set by the EPA and UDWQ. Sulfate, iron, and chloride concentrations at some sites exceed the EPA Secondary Drinking Water Quality Standards. As land use changes in the basin and more oil/gas wells are developed, continued sampling of these sites may show any water quality changes.

This baseline study was conducted to establish the current water quality of shallow aquifer(s) and springs in the Uinta Basin. The overall chemistries of most samples are of good quality. The recommendation to continue to sample wells and springs is a cautionary measure in response to potential and existing energy-resource development. To prevent future degradation and preserve the relatively good quality of water resources in the Uinta Basin, the locations sampled should be monitored for changes in water chemistry that may herald contamination. The public-supply source at PR Springs has an existing recommendation of seasonal sampling as part of a BLM-UDWQ cooperative Sampling and Analysis Plan. Because of the sensitive location along a popular recreational corridor, I recommend a similar sampling plan be established near the seep/spring along the White River.

SUMMARY

The Uinta Basin in eastern Utah generally lacks sufficient water-quality data from alluvial wells and springs to characterize the area's shallow groundwater. As part of a two-year project studying water-related issues affecting potential shale/tight-sand gas development in the Uinta Basin, this component of the study establishes baseline water quality and provides some background data that will help underscore the potential vulnerability of the area's shallow alluvial wells and springs.

This study was conducted to document water quality for lands proposed for unconventional energy-resource development, particularly those designated and/or leased as potential tight-gas and tar-sand development. During summer 2013, I collected 22 water samples from alluvial water wells and springs, and augmented the data from

two springs sampled by the UDWQ in the Uinta Basin. A suite of water-quality constituents was analyzed, including general chemistry (including TDS), nitrate, dissolved metals, volatile organic compounds, TPH, and stable isotopes. Dissolved solids were highest from an out-crop spring in the Uinta Formation flowing to the White River and they were lowest from the wells and springs in the northern part of the area proximal to recharge in the Uinta Mountains. Overall, samples show variable water quality throughout the study area indicating there are multiple aquifers that are not connected. Two sites have notable nitrate concentrations (though below the EPA MCL): a shallow monitor well near Evacuation Creek and a spring downgradient from a gravel pit near Duchesne, Utah. Some sites have detectable VOCs including benzene, vinyl chloride, bromomethane, chlorobenzene, chloromethane, and toluene.

All of the sites sampled vary in terms of their water resource value. Some are perennial springs, some are water supply sources for the oil/gas industry, some supply water for wildlife, and a few are domestic water supply sources. Most of the water, if treated properly, could be used as drinking water; all but three of the sampling sites have TDS concentrations below the upper limit (3000 mg/L) set by the Utah Water Quality Board as "Drinking Water Quality." None of these three sites is used as a public supply source, which deems a TDS of less than 2000 mg/L to meet Utah Division of Drinking Water's MCL requirement. To ensure good water quality is preserved, I recommend sampling most of the sites annually or every three years at the least.

Potential water-quality degradation may result from an expected increase in oil and gas activity if sound water-management procedures are not implemented. This project provides supporting data for a complementary study to examine aquifer vulnerability to potential contamination from VOCs (Wallace and others, this publication). Together these studies can help to implement integrated management of water production and disposal for shale/tight-sand gas development in the Uinta Basin. This regional water study will provide GIS-based information to help local planners and potential developers preserve the quality of shallow groundwater and springs by establishing best-management practices through careful land-use planning.

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