BASELINE WATER QUALITY AND ESTIMATED QUANTITY FOR SELECTED SITES IN THE SOUTHEASTERN UINTA BASIN, UTAH

by Janae Wallace

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Cover photo: *View from Seep Ridge overlooking Willow Creek drainage in the southeastern Uinta Basin.*

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CONTENTS

FIGURES

TABLES

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by Janae Wallace

ABSTRACT

The southeastern portion of the Uinta Basin, Utah, generally lacks sufficient water-quality data to characterize the area's surface water and relatively shallow groundwater. To establish a baseline of water quality, the Utah Geological Survey (UGS) collected biannual water samples over a three-year period from near-surface aquifers and surface sites. Groundwater 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. The near-surface and relatively shallow groundwater quality information will help in the development of environmentally sound water-management solutions for a possible future oil shale and oil sands industry and help assess the sensitivity of the alluvial and near-surface bedrock aquifers on U.S. Bureau of Land Management land having oil shale development potential. A minor component of this study was to try to quantify the volume of water in aquifers in the southeastern Uinta Basin, especially for the thinly mantled and disconnected alluvial aquifers and the Birds Nest and Douglas Creek aquifers with the understanding that creating a groundwater flow model and performing aquifer tests on wells are beyond the scope of study. U.S. Geological Survey online data and information from previous studies provide the best estimates for storativity in these aquifers. For the alluvial aquifers, the volume of recoverable water in storage is estimated at 200,000 acre-feet. Based on a saturated thickness range of 200 to 1000 feet, estimated water quantity for the Douglas Creek ranges from 60,000 to 300,000 cubic meters per hectacre. The Birds Nest aquifer is estimated to range from 33 to 110 feet thick with an estimated water quantity range of 25,000 to about 84,000 cubic meters per hectacre.

During spring and autumn of 2009 and 2010, and spring and summer of 2011, the UGS collected 85 water samples from up to 24 water wells and surface-water sites. A suite of water-quality constituents were analyzed including general chemistry (including total dissolved solids), nutrients (including nitrate, phosphorous, and ammonia), dissolved metals (including arsenic, lead, iron, and boron), and volatile organic compounds (VOCs). Total-dissolved-solids concentrations for all samples range from 172 to 2832 mg/L and nitrate concentrations range from <0.1 to 18.8 mg/L for all sampling seasons. Dissolved-solids concentrations were highest from Evacuation Creek during spring 2009 and lowest during flood stages in spring 2010 from the Green River near Ouray, Utah. Most sites have nitrate concentrations below 0.1 mg/L (the detection limit) with the exception of alluvial wells in the northwestern part of the study area downgradient from irrigated fields and a large cattle operation, and one bedrock well in the central part of the study area. Some samples had detectable VOCs, but all were below the U.S. Environmental Protection Agency's maximum contaminant levels. Seasonal change in water chemistry is minimal for most sites.

Potential water-quality degradation may result from an increase in mining activity/energy resource development if sound water management practices are not implemented. This regional baseline water study provides GIS-based 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 has increased, including research geared towards unlocking the vast oil shale and oil sand resources of the Uinta Basin (figures 1, 2, and 3). In particular, the southeastern Uinta Basin has been recognized by the U.S. Bureau of Land Management (BLM) as having oil shale development potential; however, this area generally lacks sufficient water-quality data to characterize the area's surface water and relatively shallow groundwater. The primary objective in this study is to establish baseline water quality in these areas.

Various proposals have been submitted by energy companies (Enefit American Oil, Red Leaf Resources, and U.S. Oil Sands) to develop unconventional energy resources in the area. Enefit American Oil is looking to develop an extensive surface/underground oil shale mine and surface retort on private land near the old town site of Watson. Enefit's commercial goal is to produce 50,000 barrels of shale oil per day, which will require mining between 25 and 30 million tons of shale a year (Enefit American Oil, 2012). This operation will also require significant disposal of spent shale.

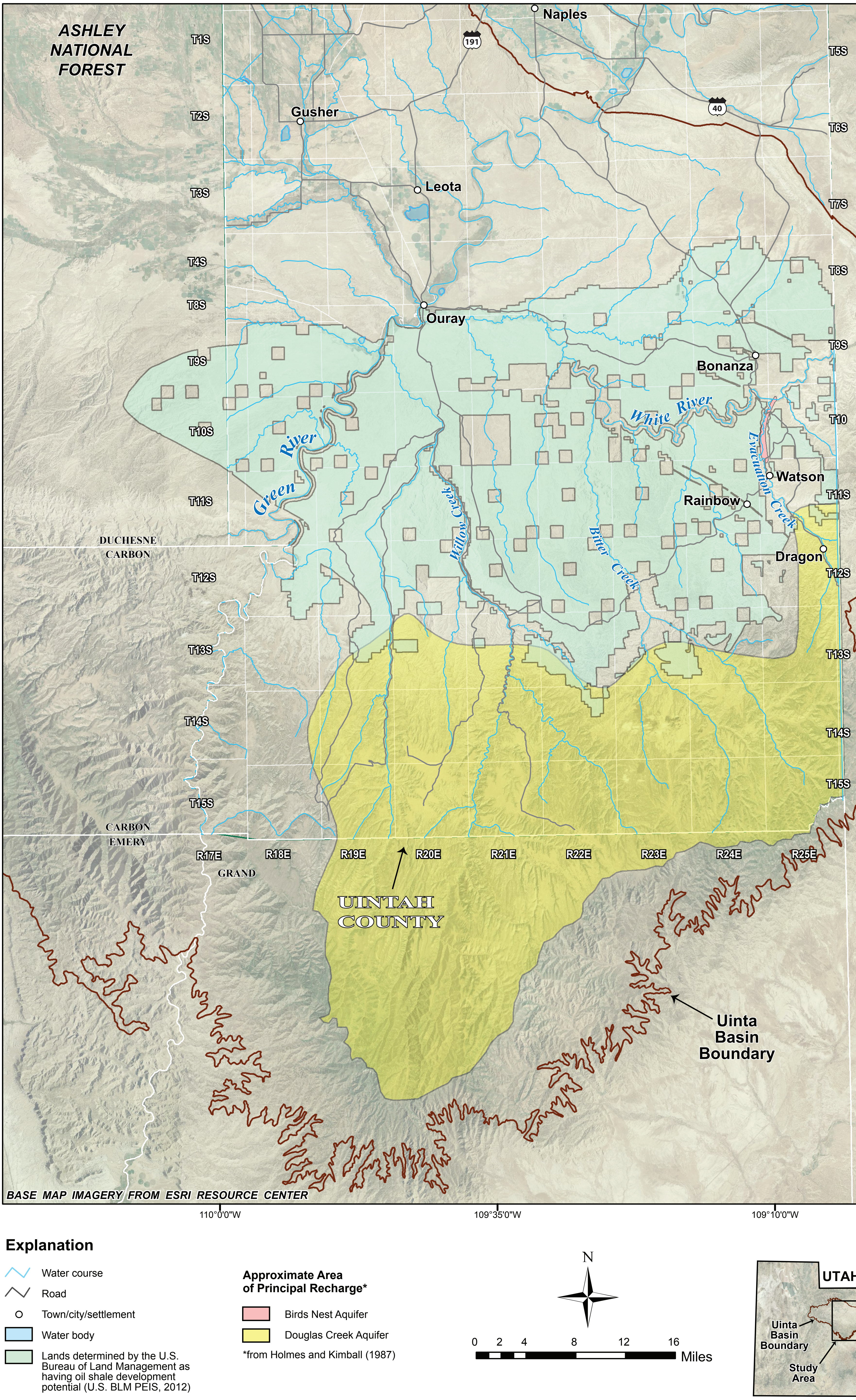

Figure 1. Location map of the southeastern Uinta Basin study area.

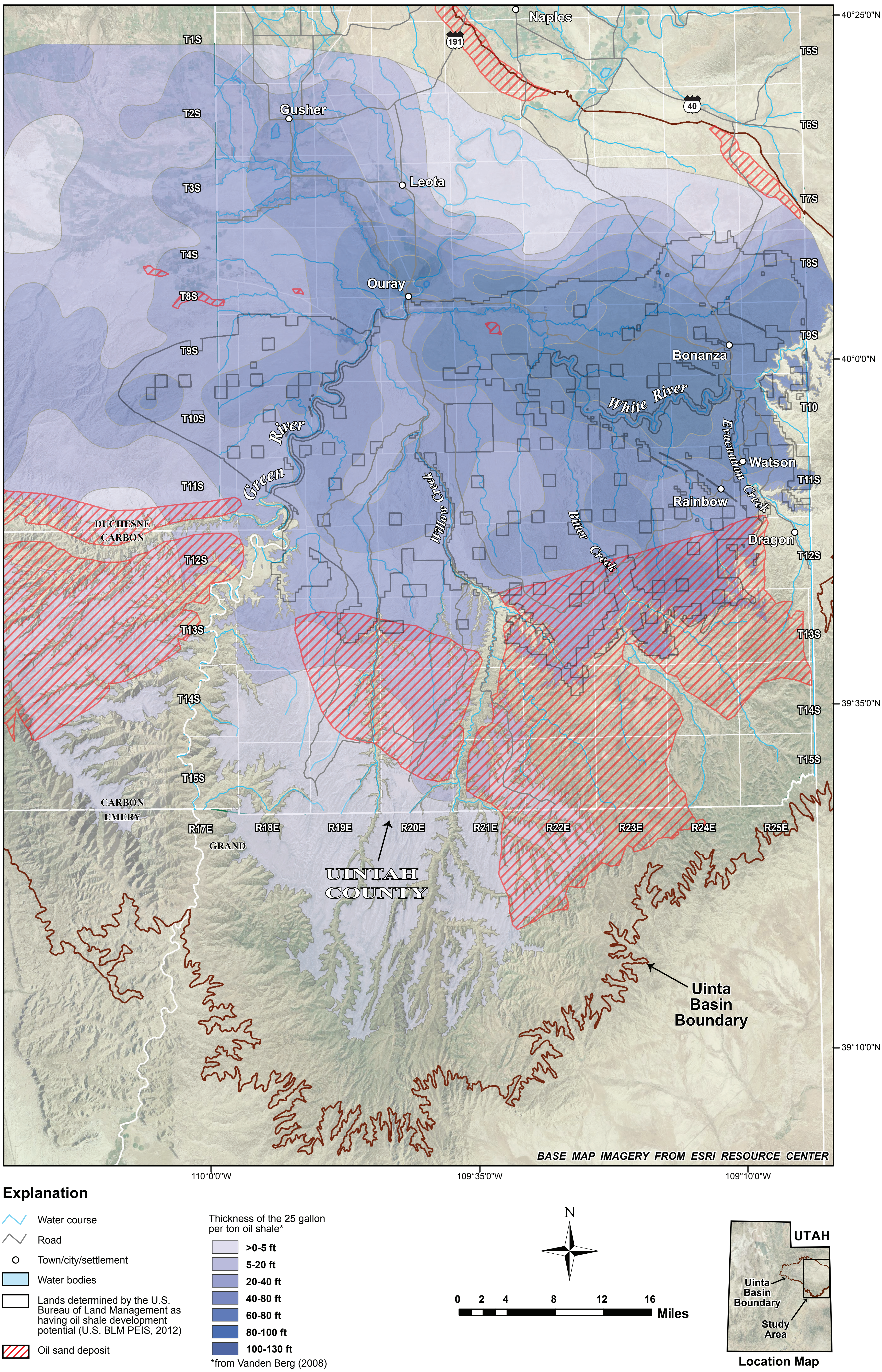

Figure 2. Oil shale and oil sand deposits in the eastern Uinta Basin.

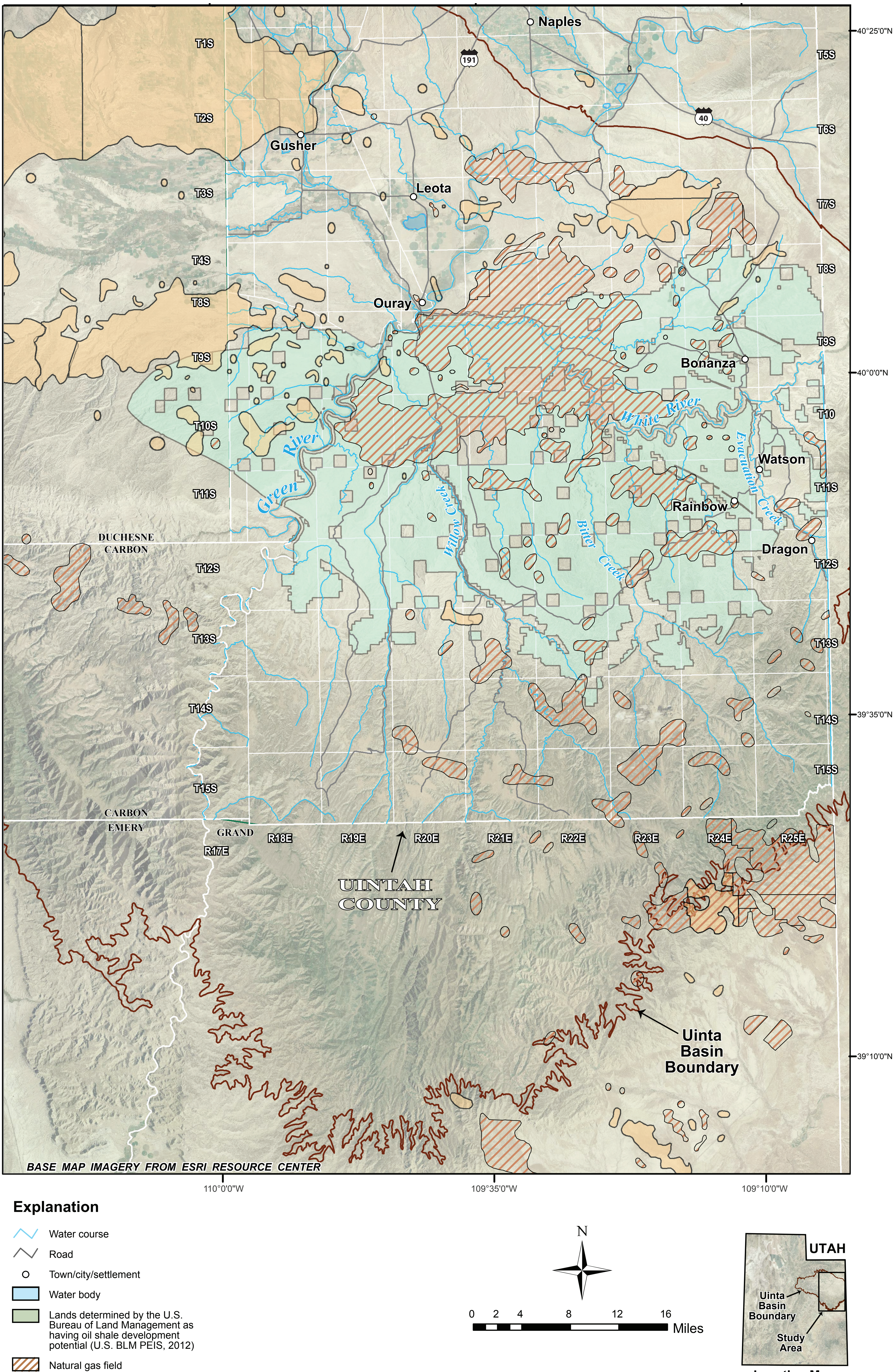

Figure 3. Natural gas and crude oil fields in the eastern Uinta Basin.

Red Leaf Resources plans to use their 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 from several capsules running simultaneously (more information on Red Leaf's unique technology can be found on their website) (Red Leaf Resources, 2012). Reclamation will include sealing the spent shale within the capsule retort. U.S. Oil Sands is an energy development company looking to produce oil from oil sands in the PR Spring area near the southern border of Uintah County (southern portion of the study area). Their proposal is to surface mine the oil sand and use a bio-solvent to extract the bitumen, disposing the leftover sand into lined disposal pits (U.S. Oil Sands, 2012).

The information collected in this study will help regulators develop environmentally sound water-management solutions for a possible oil shale and/or oil sand industry by assessing the sensitivity of the alluvial and near-surface bedrock aquifers on BLM lands having oil shale development potential in the southeastern Uinta Basin.

A second objective of this study is to estimate the volume of water in aquifers in the southeastern Uinta Basin, especially for the thinly mantled and disconnected alluvial aquifers and within the Green River Formation. Creating a groundwater flow model and performing aquifer tests on wells are beyond the scope of this study and are cost/time prohibitive, hence U.S. Geological Survey data provide the best estimate of storativity in these aquifers based on their easily accessed data provided online (U.S. Geological Survey, 2011) and information from previous studies (Holmes, 1980; Holmes and Kimball, 1987) within the Uinta Basin in Utah, dominantly in the southeastern part of the 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 under water-table conditions in the unconsolidated deposits and under confined conditions in the consolidated aquifers. Estimates of recharge in the southern Uinta Basin for the 1935-70 period was 120,000 acre-feet per year (including inflow from imported water) and 118,000 acre-feet per year for discharge (Price and Miller, 1975). A later study indicated the amount of recharge basin-wide was 630,000 acre-feet per year, with only 20% of the recharge derived from the southern half of the basin (Holmes, 1980). Most recharge generally occurs during winter when more widespread and longer-duration snowstorms occur; due to the dominant fine-grained nature and low permeability of recharge-area rocks and slow percolation rates, about 3% of estimated average annual precipitation (~100,00 acre-feet) becomes groundwater recharge (Price and Miller, 1975).

Groundwater discharge was estimated to be the same as recharge (Holmes and Kimball, 1987), with discharge in the southeastern Uinta Basin from the alluvial aquifers, mostly within valley drainages of the Green and White Rivers and their tributaries. Most discharge is to streams, springs, evapotranspiration, and withdrawal from wells. The hydrologic budgets for the alluvial aquifer and the bedrock aquifers within the Green River Formation vary (Holmes and Kimball, 1987). Recharge for the Douglas Creek aquifer is from precipitation and inflow from streams. For the Birds Nest aquifer and alluvial aquifer, most recharge is from infiltration of streams and for the Birds Nest aquifer, recharge is also from leakage from the overlying Uinta Formation. The alluvial aquifer also receives recharge locally from leakage from the underlying consolidated aquifer. Water leaves the basin by transbasin outflow in the Green River and from diversions to the Great Basin region (Holmes, 1980). 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). The total volume of water consumed in the entire Uinta Basin is the difference between surface-water inflow combined with precipitation and the surface-water outflow plus the diversions to the Great Basin. The volume of water consumption in 1985 was about 7.4 million acre-feet (Holmes, 1980); today, annual consumption is most likely greater due to an increased number of water users. For the alluvial aquifers in the southeastern Uinta Basin, the estimated volume of recoverable water in storage is about 200,000 acre-feet, with maximum yields for individual wells at less than 1000 gallons per minute (Holmes and Kimball, 1987).

A 1987 study by the U.S. Geological Survey (USGS) on groundwater in the southeastern Uinta Basin examined water quality from the alluvial and bedrock aquifers (Birds Nest and Douglas Creek aquifers within the Green River Formation). Holmes and Kimball (1987) 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 that include 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 for the eastern Birds Nest aquifer, based on water from 80 samples, was 2700 mg/L, while average TDS for the Douglas Creek aquifer was 1098 mg/L from 12 samples. 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 (Anderson and others, 2012).

Another study in the northwestern Uinta Basin, within the Altamont-Bluebell oil and natural gas field, examined the impact on drinking-water wells from injection of wastewater from oil and gas wells 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 ^{2}H). 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 having an influence on the shallow aquifers. Any increase in either bromide or chloride concentrations in the monitoring wells over time could indicate mixing of the two waters. No indication of mixing based on these two constituents was documented; stable isotopes from the shallow wells plotted on or near the meteoric water line compared to the deep aquifer wells, which plotted well below the meteoric water line. Based on these chemical results, the study showed that the deeper groundwater was not reaching the drinking-water aquifers (Steiger, 2007). The same would be expected in the southeastern part of the basin. Water disposed in deep oil and gas-producing zones is unlikely to migrate to alluvial or near-surface aquifers.

More recently, 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, with emphasis on dissolved solids. Using a Spatially Referenced Regressions on Watershed Attributes (SPARROW) model, Kenney and others (2009) compared relative contributions of dissolved solids from natural sources, agricultural practices, and industrial development (oil and gas fields). The USGS SPARROW surface water-quality model relates measured chemical constituent transport at monitoring stations to upland catchment attributes (Kenney and others, 2009). Based only on measured dissolved solids in rivers and streams, Kenney and others (2009) concluded the greatest source of TDS is from natural geologic sources and agricultural practices, while the contribution from the oil and gas industry is statistically insignificant.

Previous Water-Quality Data

Previous water-quality studies in the southeastern Uinta Basin on land designated by the BLM as having oil shale development potential are mainly based on data from oil and gas wells that were sampled for water during the drilling phase of well installation. To augment data for this study, several oil and gas operators provided data (figures 2 and 3) from hundreds of oil/gas wells (appendix A; figures 4, and 5). In addition, a previous study by Zhang and others (2009) provided water-quality data from 57 wells and several different formations; their data are summarized on figure 6. Water-quality data were also compiled by the Utah Geological Survey (UGS) for springs and wells sampled during the 1970s (Wally Gwynn, written communication, May 2009). In 1970, the USGS drilled six monitoring wells in 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 (Holmes, 1980; appendix B).

Water chemistry data from the Birds Nest aquifer (~200 oil/gas wells, oil shale wells, and disposal wells) have TDS values that range from 1100 to 205,286 mg/L with 35% of the wells having TDS 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 from several sources provided by the oil and gas industry; see appendix A, compiled by Anderson and others, 2012). Zhang and others' (2009) data show 5% of the wells having 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. Wells and springs dominantly penetrating or issuing from the Green River Formation (a few in the Wasatch Formation) indicate variable water quality (Wally Gwynn, written communication, May 2009). Total-dissolved-solids concentrations from 39 springs range from 292 to 23,900 mg/L with an average of 1999 mg/L, while TDS concentrations from 50 wells range from 494 to 9870 mg/L with an average of 2443 mg/L (Wally Gwynn, written communication, June 2009).

BASELINE WATER QUALITY

This study evaluated water quality from 24 locations in the southeastern Uinta Basin as a means to assess the alluvial and bedrock aquifers on lands proposed by the BLM as having oil shale development potential. The original plan was to sample 50 sites throughout the study area without bias to land use or well depth (figure 7); however, after searching through the Utah Division of Water Rights' database and conducting extensive field reconnaissance, the number of sites was reduced to 24 for various reasons (e.g., misplotted, defunct well, dry well, or dry spring).

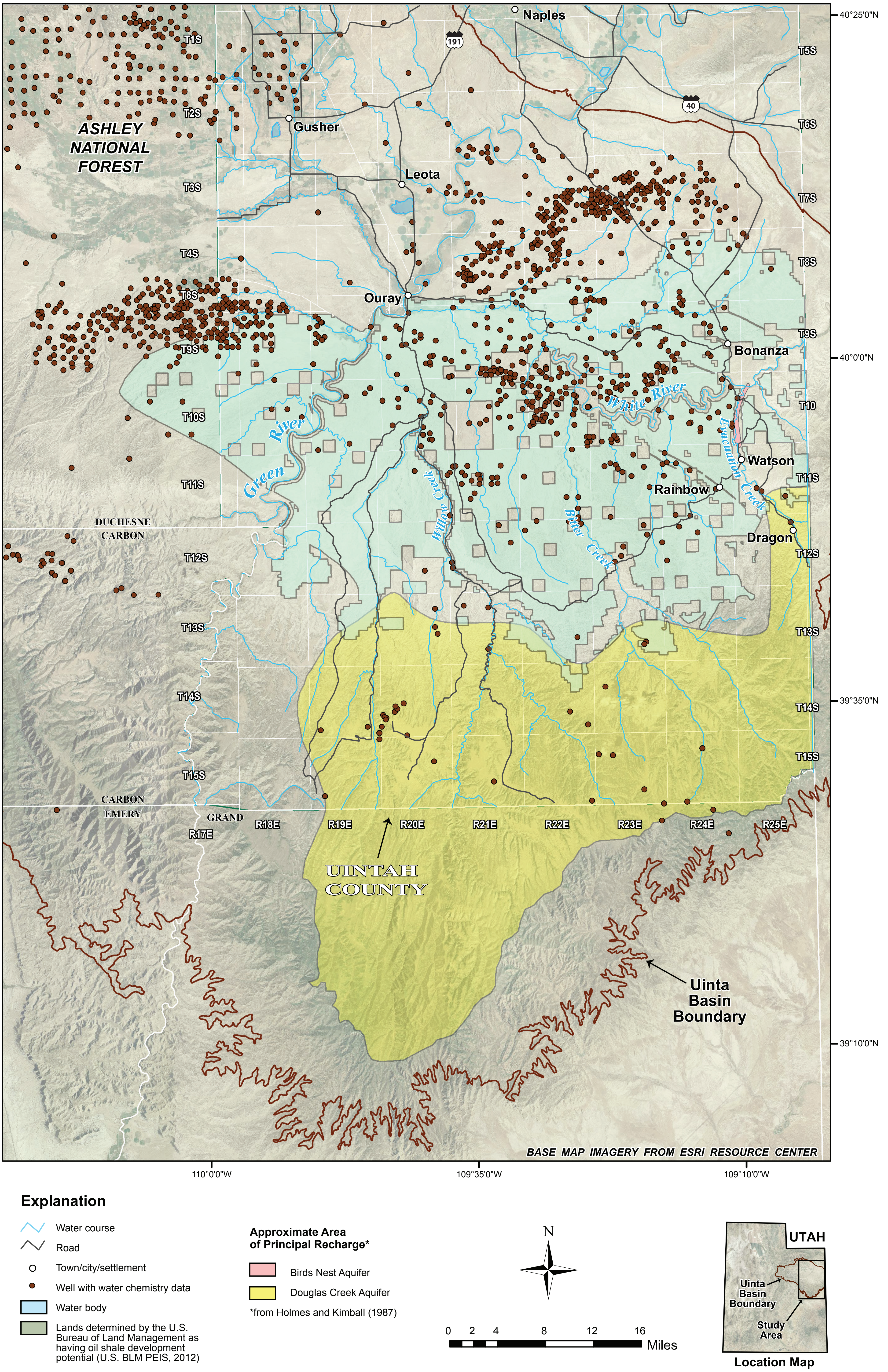

Figure 4. Location of wells with water-quality data in the eastern Uinta Basin (wells listed in appendix A).

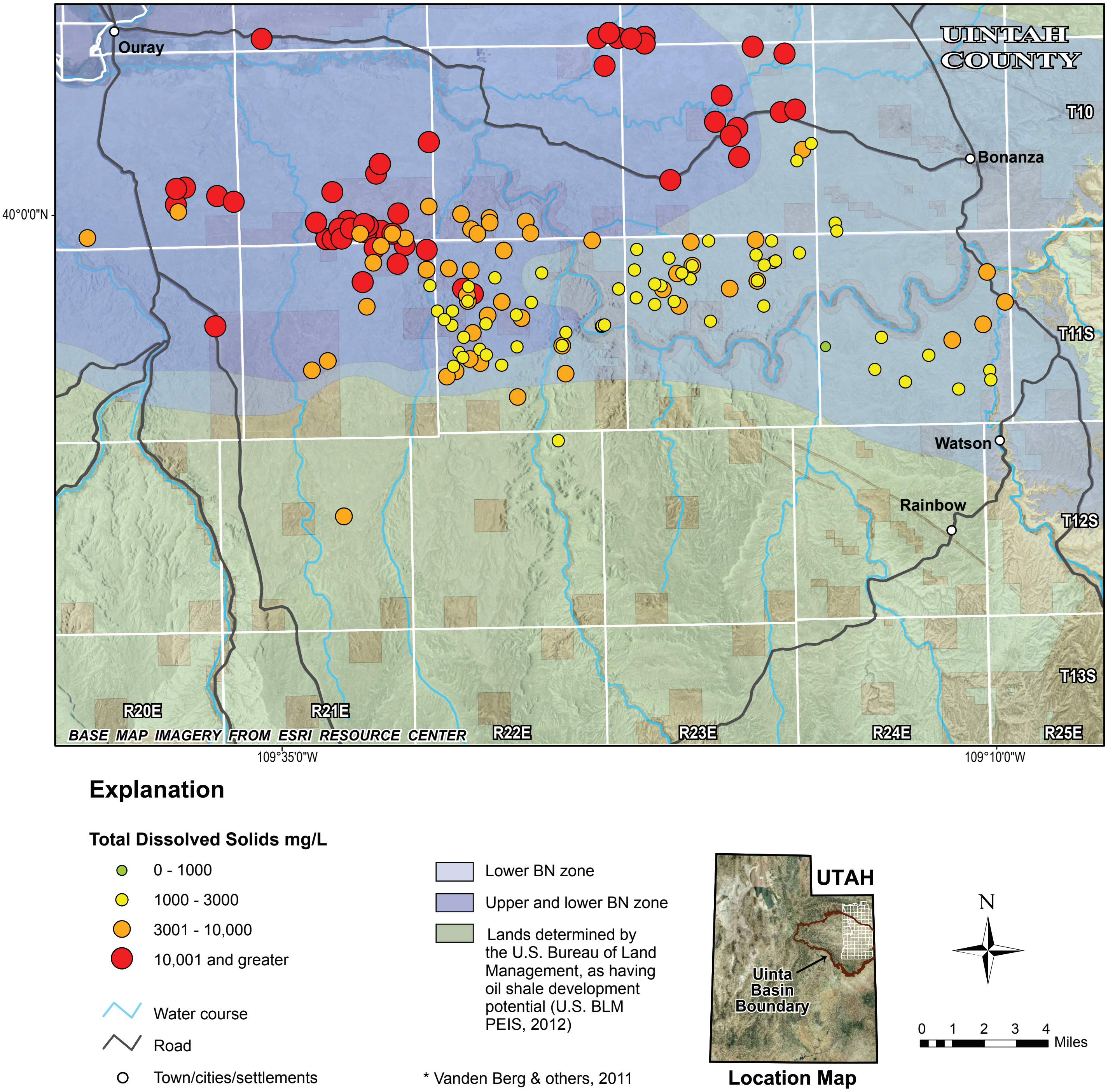

***Figure 5.** Total-dissolved-solids concentrations for water in the Birds Nest (BN) aquifer (Vanden Berg and others, 2010).*

Some of the sites sampled were identified during preliminary research and others were discovered during field investigations through serendipity or word of mouth from local land users. Table 1 summarizes general information for each site. The sites are identified by their location and/or well owner or formal name (e.g., Sulphur Spring) and are listed geographically in a generally clockwise direction from northeast (site 1) to northwest (site 24) as they exist in the study area (figure 7). For example, if a site is located in Park Canyon, part of its identification is "Park" and has an arbitrarily assigned site number according to its clockwise geographic location. Detailed descriptions of each sample site and accompanying photographs for some sites are presented in appendix C.

During spring and autumn of 2009 and 2010 and spring/summer of 2011, 85 water samples were collected from water wells and surface-water sites (figure 8; appendix D). The actual number of samples obtained each season/year varied depending on the condition of the well/spring. For

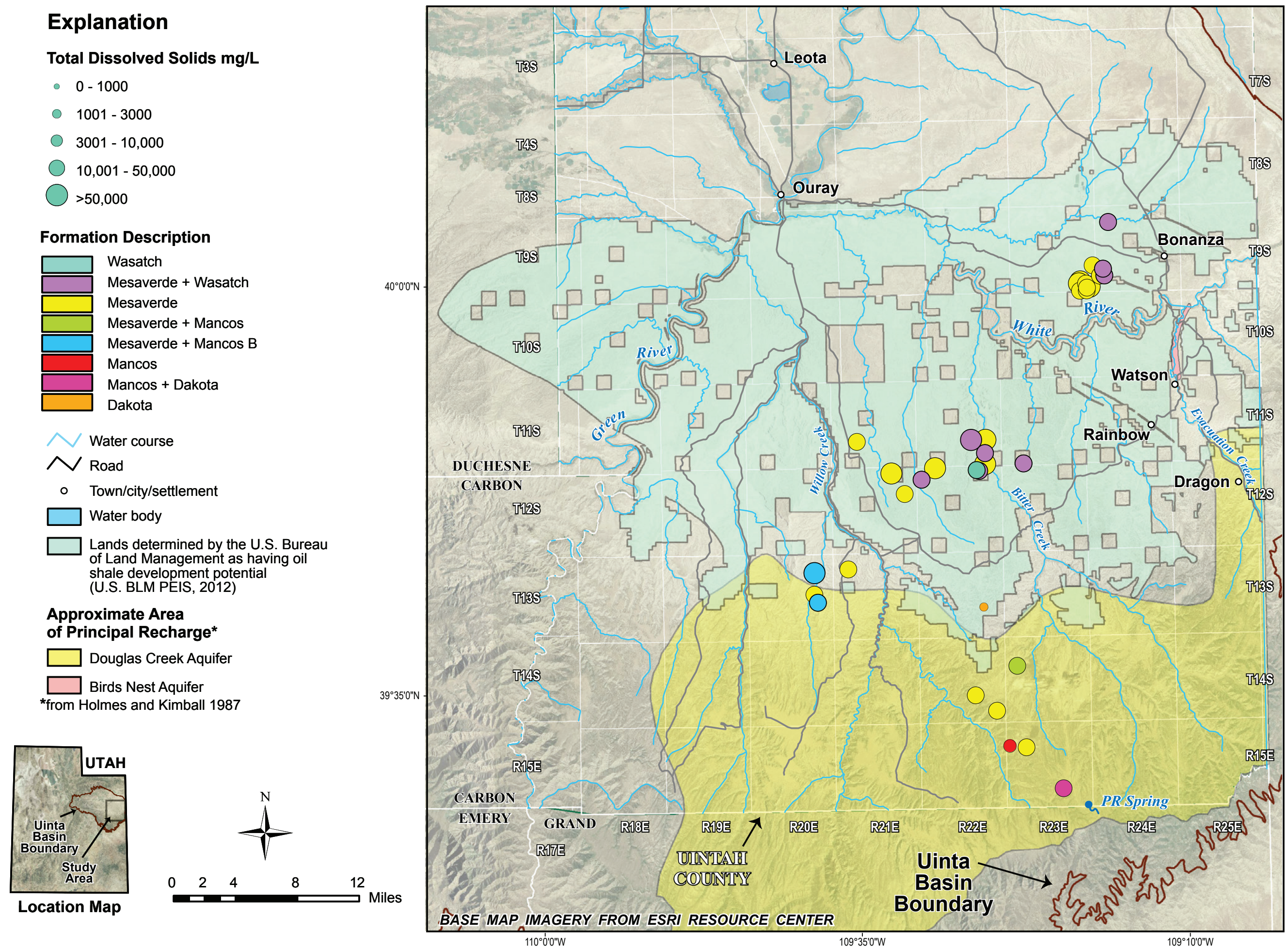

Figure 6. *Total-dissolved-solids concentrations for water in the Birds Nest aquifer (modified from Zhang and others, 2009).*

example, some wells that were available during the initial sampling stage were no longer operable during later stages in the study and likewise, during subsequent sampling events, additional wells/springs were discovered from field observation and word of mouth from local sources. One well drilled as a water source for an oil/gas supply well in Park Canyon was not sufficiently purged to obtain a quality sample due to equipment constraints (site 4 Park-OSEC) (at the time of sampling, well depth and depth to water were unknown). Two of the wells are former oil/gas wells that were eventually plugged, but remained active as flowing water wells to service wildlife via accumulation of pond water (site 17 Big Pack and site 18 Seep Ridge). Similarly, two of the test wells drilled by the USGS were subsequently modified to be used as a source of water for wildlife via pond collection through underground piping systems (site 3 Asphalt 1-USGS and site 15 Bitter-USGS). Some sites were sampled only once, while others were sampled during all five sampling rounds. A suite of water-quality constituents were analyzed including general chemistry (including TDS), nutrients (including nitrate, phosphorous, and ammonia), dissolved metals, total organic carbon (TOC), and volatile organic compounds (VOCs).

WATER-QUALITY RESULTS

Groundwater quality in the study area varies and is generally good with TDS concentrations primarily below 3000 mg/L, although elevated nitrate, arsenic, lead, selenium, barium, boron, and alpha gross concentrations exist in the aquifers at some locations. Total-dissolved-solids concentrations for all samples range from 172 to 2832 mg/L and nitrate concentrations range from <0.1 to 18.8 mg/L for all sampling seasons. An anomalously high TDS concentration of 3056 mg/L was initially taken from site 18 (Seep Ridge) from a distal location in a pond sourced from the flowing former oil/gas well. Subsequent samples from this site were obtained near the wellhead where water enters the pond from a pipe and have lower TDS concentrations more representative of groundwater from the well than the initial more distal pond sample. The highest reliable TDS value of 2832 mg/L was from Evacuation Creek during spring 2009, and the lowest value (172 mg/L) was from the Green River near Ouray during flood stages in spring 2010. Most sites have nitrate concentrations below 0.1 mg/L, with the exception of alluvial wells in the northwestern part of the study area downgradient from irrigated fields and a cattle ranch operation, and a well penetrat-

Table 1. *Overview of water sampling sites. Appendix C describes sites in detail accompanied by photographs.*

SITE #	SITE ID	Depth (ft)	Level (ft)	Formation	# sampling events
1	Windmill[4]	1382+?	flowing?	Green River?	3
2	White River[3]	surface	surface	Alluvial	4
3	Asphalt 1–USGS[8]	2650	?	Green River	3
4	Park–OSEC	750	57/350	Bird's Nest	1
5	Park–USGS	193+	flowing	Green River	5
6	Kings well[1]	80?	67?	Green River	4
7	Evacuation Creek	surface	surface	Alluvial	5
8	Sweet Water Spring[8]	spring	flowing	Green River	3
9	South Camp[3]	98	61	Green River?	4
10	PR Spring[3]	spring	flowing	Green River?	4
11	Willow Creek	surface	surface	Alluvial	5
12	Willow Spring[9]	spring	surface	Green River	1
13	Sulphur Spring	spring	flowing	Green River?	5
14	Willow–domestic	711	flowing	Green River?	5
15	Bitter–USGS[8]	1497	?	Green River	3
16	Buck Camp–Bitter[10]	?	?	?	2
17	Big Pack	6900	flowing	Wasatch	5
18	Seep Ridge	>2510	flowing	Green River	5
19	Green River[8]	surface	surface	Alluvial	4
20	White/Green R.[3,7]	surface	surface	Alluvial	1
21	Target[2]	53	23	Alluvial	4
22	R&N[5]	60 & 80	23 & 49	Alluvial	4
23	Batty[2,6]	83	28	Alluvial	1
24	Four Star	172	70	Alluvial	4

[1]No access to site in fall 2009 due to weather conditions
[2]Not sampled in fall 2009 due to time constraints
[3]New site sampled in fall 2009
[4]Well not operational in spring 2010 or spring 2011
[5]Unable to sample spring 2010
[6]Well no longer in use starting spring 2010
[7]Not sampled after spring 2010
[8]New site sampled in spring 2010
[9]New site sampled in spring 2011
[10]Research by BLM staff indicate water source is same as site #15

ing bedrock in the central part of the study area. Twelve different types of VOCs had detectable concentrations but were all below U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCL). Besides VOCs and boron, only chemical constituents exceeding EPA standards are discussed below (for example, chromium was sampled for the sites, but did not exceed the EPA MCL [and is listed in appendix D]). Seasonal change in water chemistry was minimal for most sampling sites.

Both Piper and Stiff water chemistry diagrams show how the ion concentrations from water wells, springs, and creeks vary throughout the study area. Piper diagrams showing general chemistry for water samples over different years indicate overall water chemistry is variable throughout the area with dominantly sodium-potassium-bicarbonate-type and calcium-magnesium-bicarbonate-sulfate-type groundwater (figure 9), but maintains similar quality for the same sampled site over the three-year period (compare figure 9A, 9B, and 9C). Figure 10 shows Stiff diagrams for sampled sites having solute chemistry data collected from the most recent sampling event; most data are from 2011, except for those sites where data were collected once or twice earlier in the study. Overall, the Stiff diagrams show variable water quality throughout the study area with water likely from multiple aquifers that are not connected, except locally (e.g., shallow alluvium in the northwesternmost part of the study area). Total-

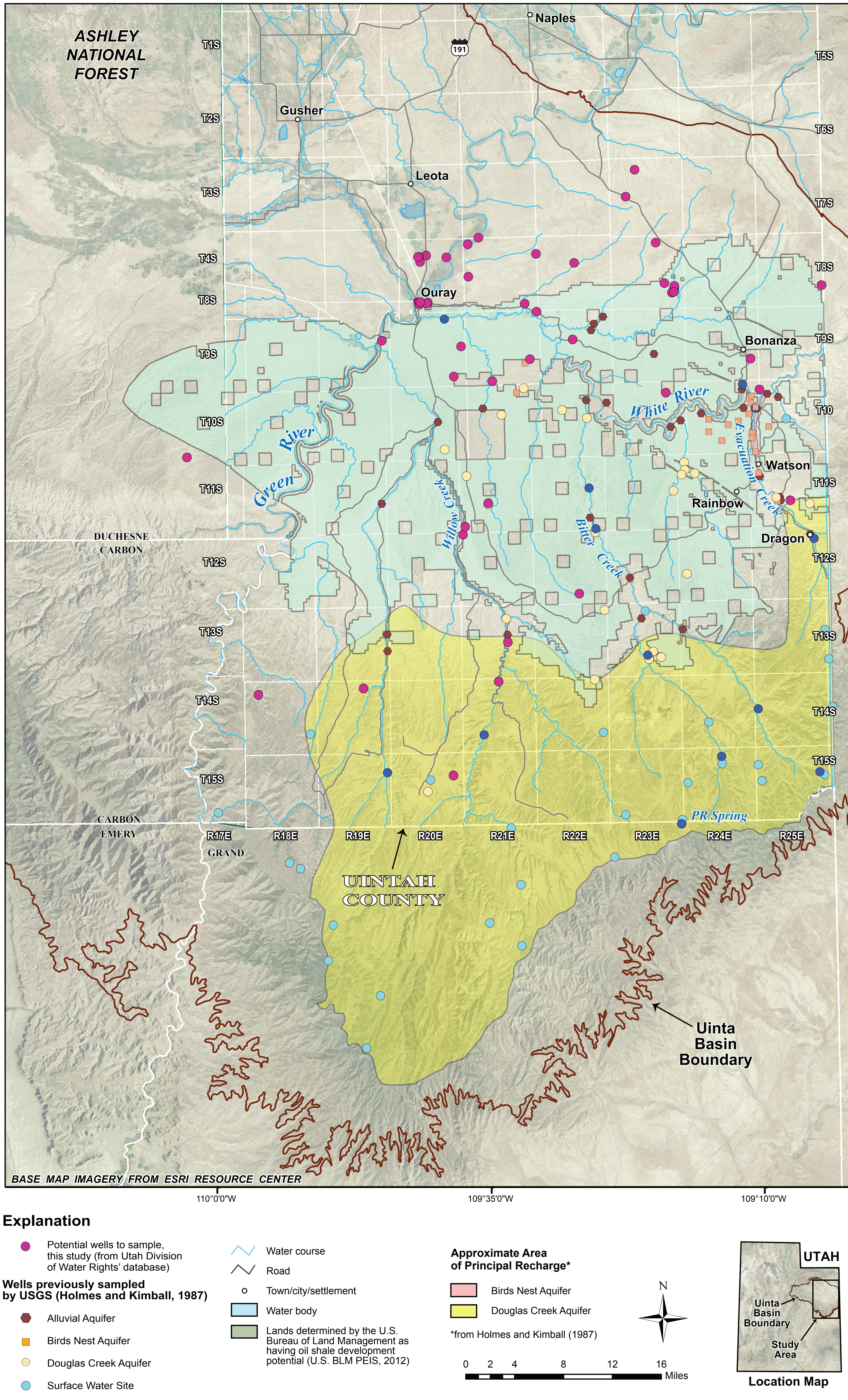

Figure 7. Pre-study map showing potential wells, and other surface sampling sites; field investigation discovered most of the sites are unavailable.

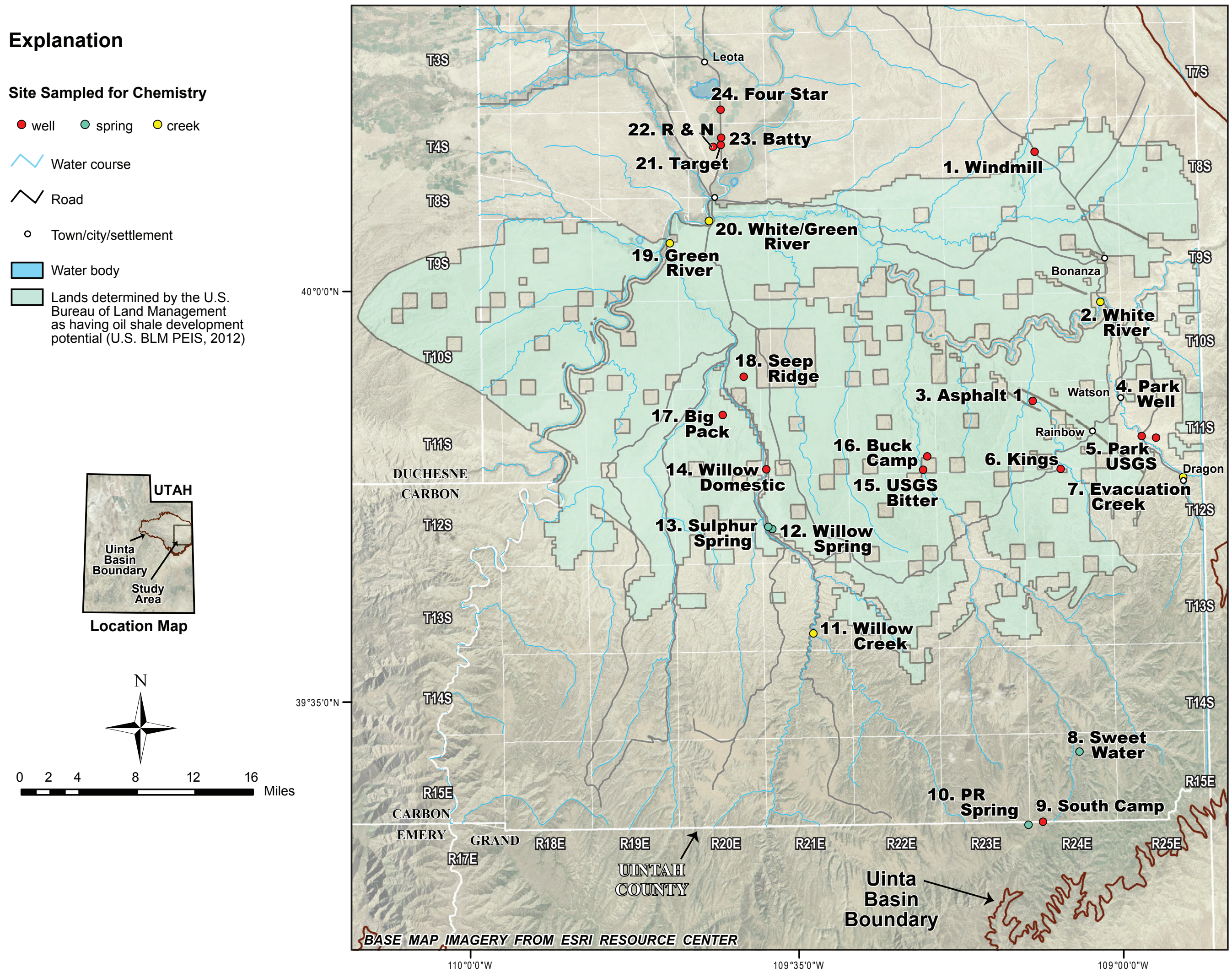

Figure 8. Sampling sites for this study.

dissolved-solids concentration data are from 4 springs, 13 wells, and 5 surface-water sites. Appendix D summarizes the chemistry data.

Total-Dissolved-Solids Concentrations

Total-dissolved-solids concentrations in the study area range from 172 to 2832 mg/L. The average seasonal TDS concentrations range from 1030 to 1470 mg/L, with the highest concentrations from spring 2009 and the lowest from spring/summer 2010. Figure 11 shows a graph of TDS versus sample site for all sampling events. Most seasonal sampling events had at least eight samples with TDS concentrations exceeding 1000 mg/L. The poorest quality water, in terms of high TDS, exists in the bedrock wells penetrating the Green River Formation and from low-flow waters of perennial Evacuation Creek (Evacuation Creek flows along outcrop of the Birds Nest zone of the Green River Formation which contains significant saline mineral deposition and subsequent dissolution [Vanden Berg and others, 2010]). The highest quality water (less than 500 mg/L) was from PR Spring, the Green and White Rivers, and one sample obtained during spring runoff from Willow Creek in 2011 (figure 11; appendix D). Seasonal samples from all sites had similar TDS concentrations, with about half consistently less than 1000 mg/L and the other half consistently greater than 1000 mg/L. Water with TDS greater than 3000 mg/L exists in one sample (distal pond sample for site 18 Seep Ridge), but this value is considered anomalous as discussed above. Elevated TDS concentrations are likely due to long residence time in the bedrock aquifer, surface contamination in shallow alluvial wells, and from dissolved constituents contributed from the Green River Formation.

Nitrate Concentrations

Nitrate concentrations in groundwater range from less than 0.1 mg/L to 18.8 mg/L (appendix D). For all seasonal sampling events, the majority of wells (>50% and up to 70%) had nitrate concentrations that were less than the detection level. For alluvial samples, average seasonal

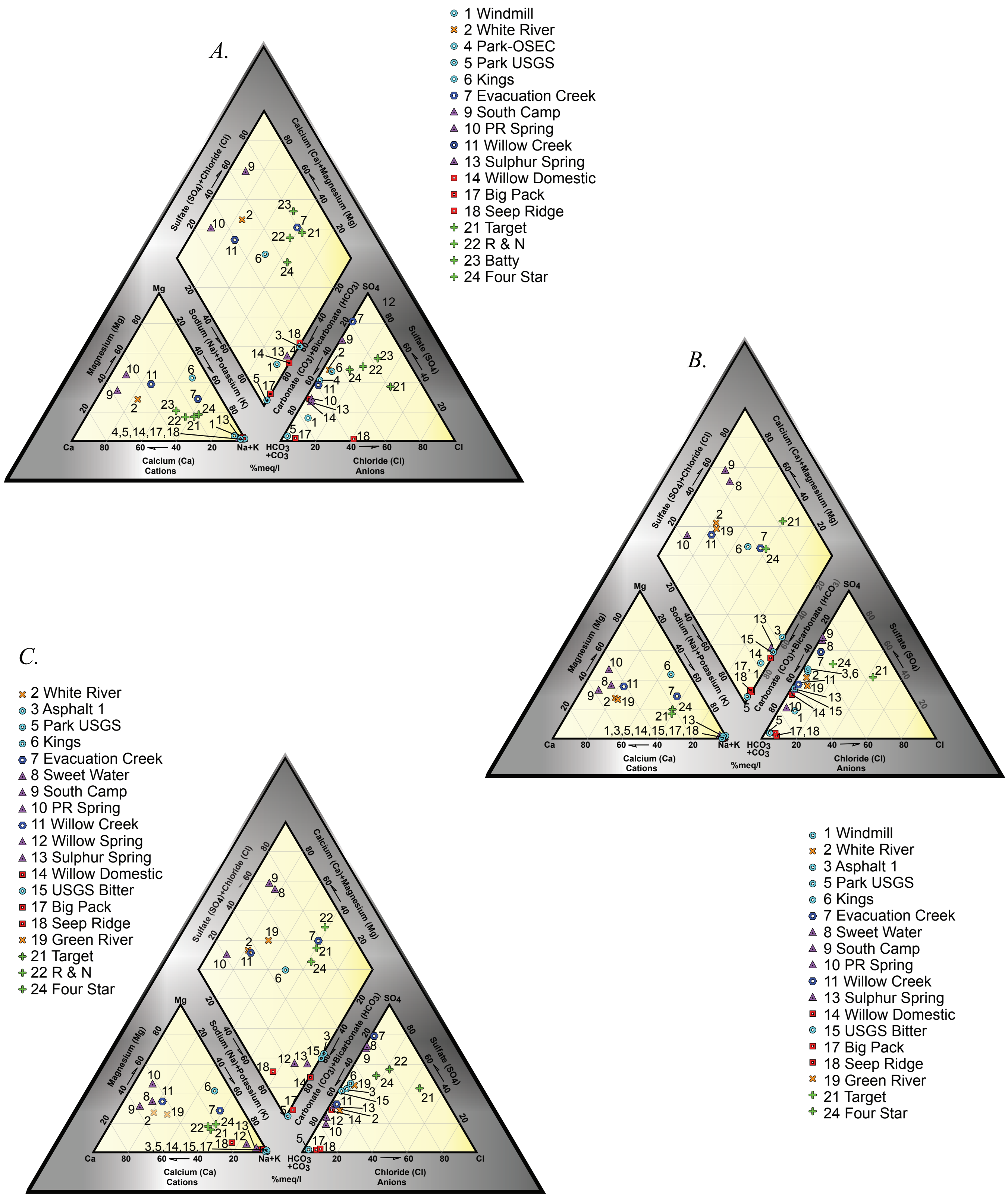

Figure 9. *General solute chemistry for sampling sites for three different years. A) 2009 data or 17 sites, B) 2010 data for 18 sites, and C) 2011 data for 19 sites sampled in the southeastern Uinta Basin. Overall solute chemistry is variable throughout the study area but relatively consistent for each site collected over three years.*

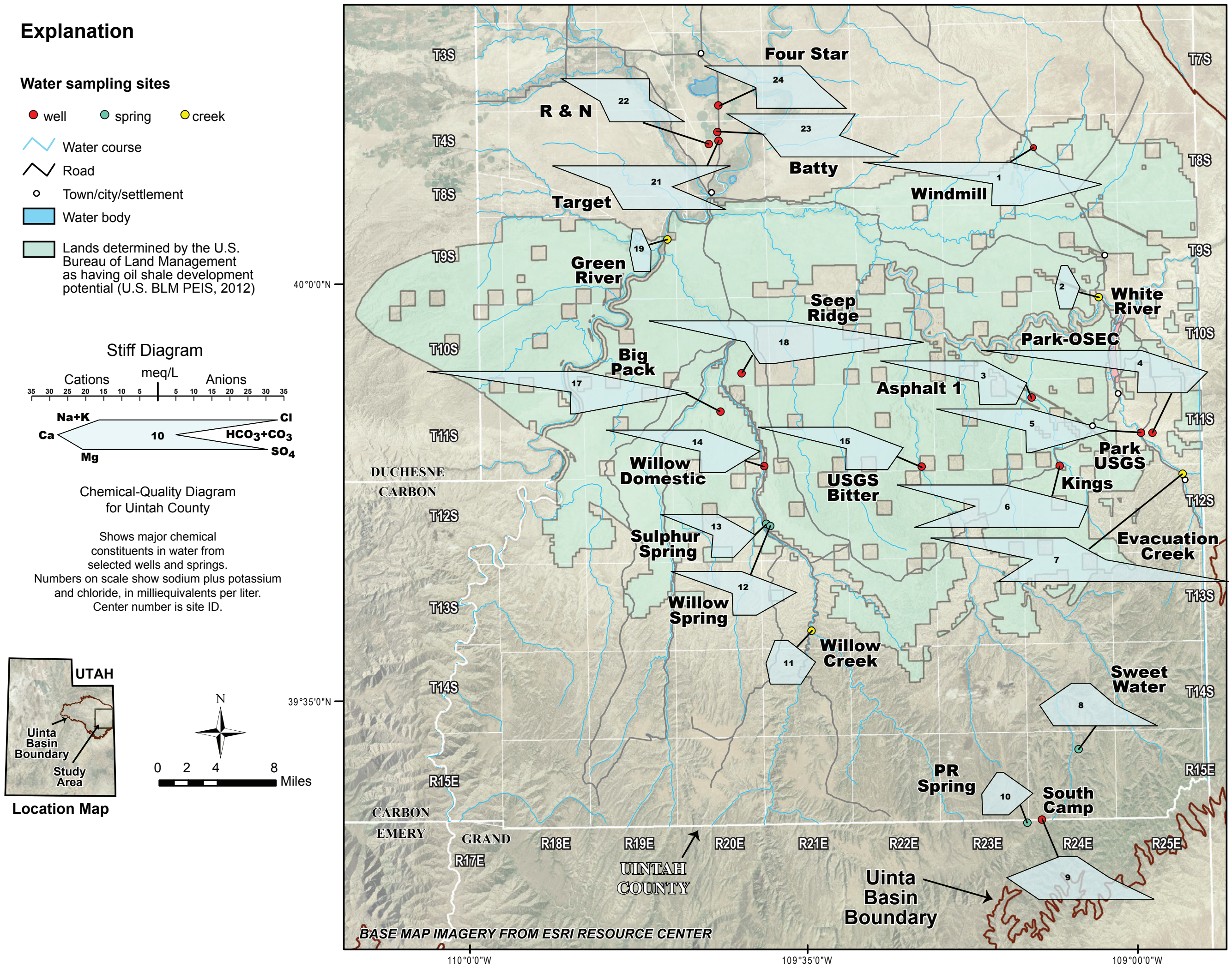

***Figure 10.** Stiff diagrams for solute chemistry in the southeastern Uinta Basin. Most data are from 2011, except sites 1, 4, and 23, which were sampled in 2009.*

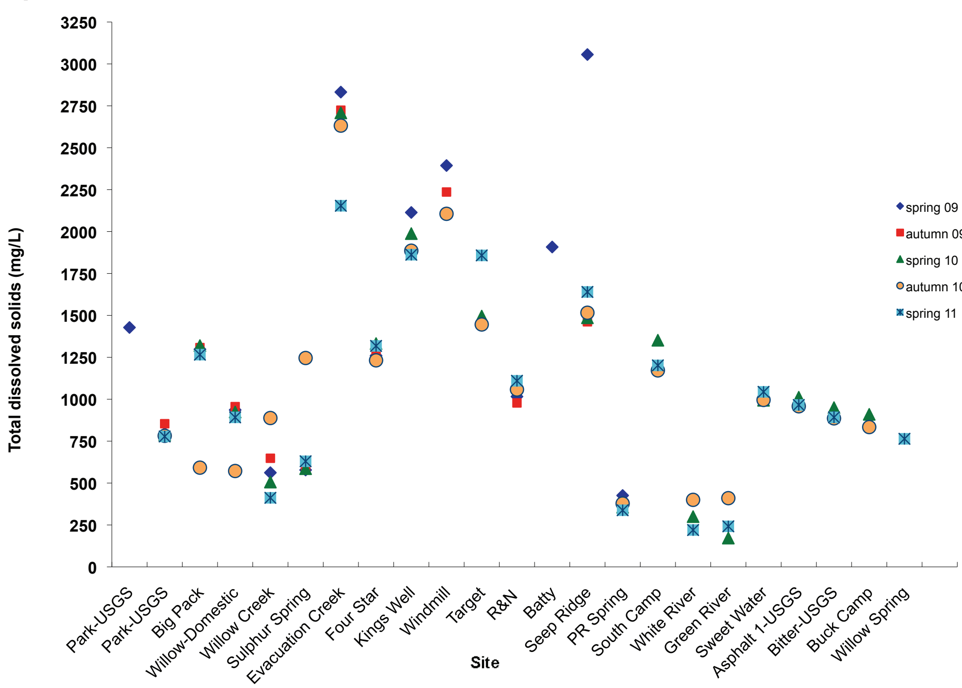

***Figure 11.** Total-dissolved-solids concentrations for each sample site for up to five different seasons.*

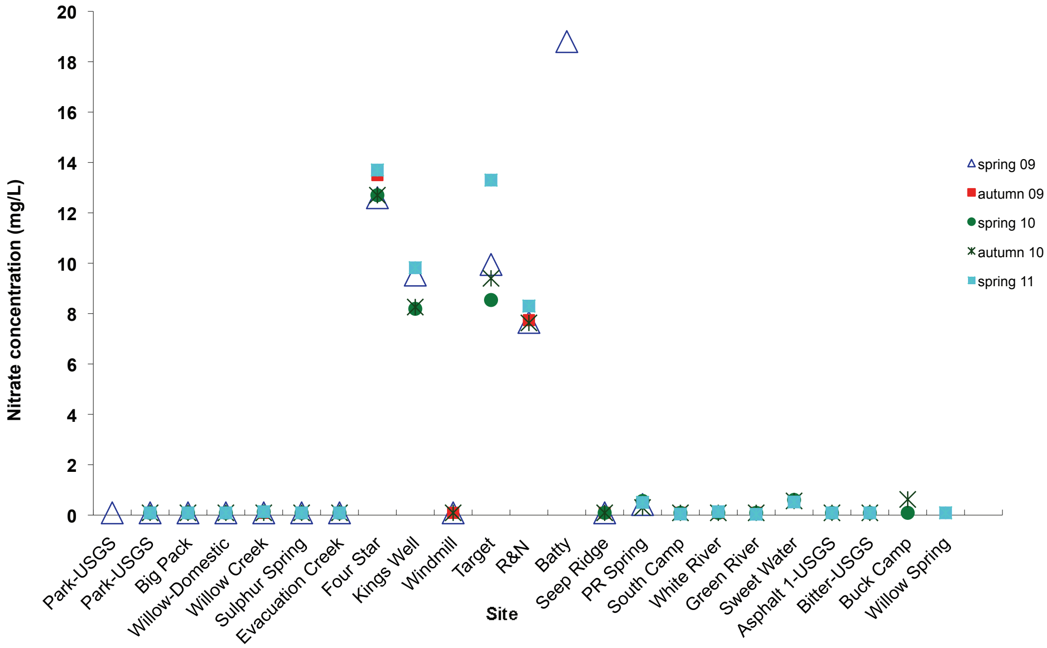

Figure 12. *Nitrate concentration over five different sampling seasons. Points plotting at "0" on the x-axis indicate a lab analysis report of <0.1 mg/L nitrate concentration.*

nitrate concentrations ranged from 9.4 to 12 mg/L, with most averages exceeding the 10 mg/L EPA MCL. Only site 6 (Kings well) had nitrate concentrations in water from bedrock that exceeded 10 mg/L; the majority of other bedrock samples had nitrate concentrations below the detection level (<0.1 mg/L). Figure 12 plots nitrate concentration for all sampling seasons and years these data were collected. Sixty to 80% of all nitrate seasonal samples were less than 1 mg/L.

The highest nitrate concentrations (>10 mg/L) exist in relatively shallow wells located on agricultural lands in the northern part of the study area (appendix C, figure C.16). Kings well, the one bedrock well that had high nitrate concentrations (figure 12), is near a gilsonite vein (figures 13 and 14) (Verbeek and Grout, 1993; Boden and Tripp, 2012). Gilsonite is a relatively insoluble asphaltic solid hydrocarbon containing nitrogen. No other nearby land use commonly identified as a nitrate source (septic tanks, feed lots, and fertilized cropland) exists in the area; however, an ephemeral pond adjacent to Kings well serves wildlife and seasonal sheep grazing, both of which could be a potential source of nitrate. The gilsonite vein may act as a conduit (Vanden Berg and others, 2010) for potentially contaminated surface water to reach the relatively shallow water level (less than 80 feet deep) in Kings well, elevating the nitrate concentration. Confirming this hypothesis would require further research, but it should be recognized that land use, such as livestock grazing, near gilsonite veins could increase the risk of near-surface aquifer contamination.

Two samples were also analyzed for total Kjeldahl nitrogen (TKN). A TKN analysis measures total organic nitrogen and ammonia. One sample from site 6 (Kings well) had a TKN concentration of 2.0 mg/L and one sample from site 9 (South Camp) had a concentration of 0.4 mg/L. Surface-water samples with suspect gilsonite contamination show relatively high TKN values (41 mg/L; Robin Hansen, Vernal Office BLM, and Scott Hacking, UDEQ, written communication, May 2011). The low TKN value for Kings well suggests that gilsonite is probably not the source of the nitrogen.

Arsenic Concentrations

Arsenic values from sampling sites for all seasons ranged from less than 1 µg/L to 31 µg/L (appendix D) and exceeded the 10 µg/L EPA drinking water-quality standard at two different sampling sites (site 1 Windmill [two times] and site 6 Kings well [four times]). The percentage of sites each season with samples having arsenic concentrations below detection level (<1 µg/L) ranged from a low of 33% to a high of 47%. Overall, arsenic concentrations in the basin-fill and bedrock aquifers are variable. The source of arsenic in the two wells exceeding EPA standards is unknown.

Boron

Boron was analyzed in samples during all seasons (figure 15; appendix D) and ranges from less than 30 µg/L (the detection level) to a high of 6020 µg/L (from site 6 Kings well). Boron may be associated with dissolution of minerals in the Green River Formation. Most of the boron concentrations were above the detection level but below the MCL (not a primary drinking water standard, but a surface water-quality standard based on the Utah Division of Water Quality's criterion for maximum boron concen-

Figure 13. *Mined-out gilsonite vein in the southeastern Uinta Basin near Rainbow (photo courtesy of Taylor Boden).*

tration of 0.75 mg/L for Class 4 "Beneficial Use Designation" for the nearby Green River). On figure 15, the boron concentrations that plot on the x-axis have concentrations below the 30 µg/L detection level (they are not "0" values). Boron is not known to pose a threat to human health.

Selenium

At Lower Ashley Creek and Ouray National Wildlife Refuge, selenium was identified as a constituent of concern in a report by the Utah Division of Water Resources (2011) that indicated the source is from groundwater flow into these areas. Three wells have selenium concentrations that exceed the 50 µg/L drinking water standard (appendix D; site 6 Kings well, site 22 R & N, and site 24 Four Star).

Lead

Lead was analyzed at most sites and had concentrations exceeding the EPA drinking water-quality standard of 15 µg/L in two samples, neither of which is a public supply source, but are sources for wildlife. Lead levels for site 1 (Windmill) (15.4 and 16.3 µg/L) and a former oil/gas well (site 18 Seep Ridge) (16.9 µg/L) that currently supplies water to wildlife as a flowing well, had concentrations near the EPA standard.

Barium

Barium was analyzed at most sites and had concentrations exceeding the EPA drinking water-quality standard of 2000 µg/L in three samples: 2070 µg/L for site 17 (Big Pack) and 2160 and 2490 µg/L for site 18 (Seep Ridge). These wells are not a public supply source, but are abandoned oil/gas wells currently piped into a pond and used as a water source for wildlife.

Radiologics

Alpha gross was sampled for eight different randomly selected sites throughout the study area (appendix D). All samples had detectable alpha gross concentrations ranging from 2.4 to 36.1 pCi/L; four of the samples exceed the MCL of 5 pCi/L and one sample from the Green River near Ouray during summer 2011 had a concentration of 4.97 pCi/L, near the MCL. Sites that had concentrations exceeding the MCL include site 21 (Target) which supplies water to the oil and gas industry and sites 6, 13, and 17 (Kings well, Sulphur Spring, and Big Pack, the latter of which is a former oil/gas well) which all currently serve wildlife via a pond system.

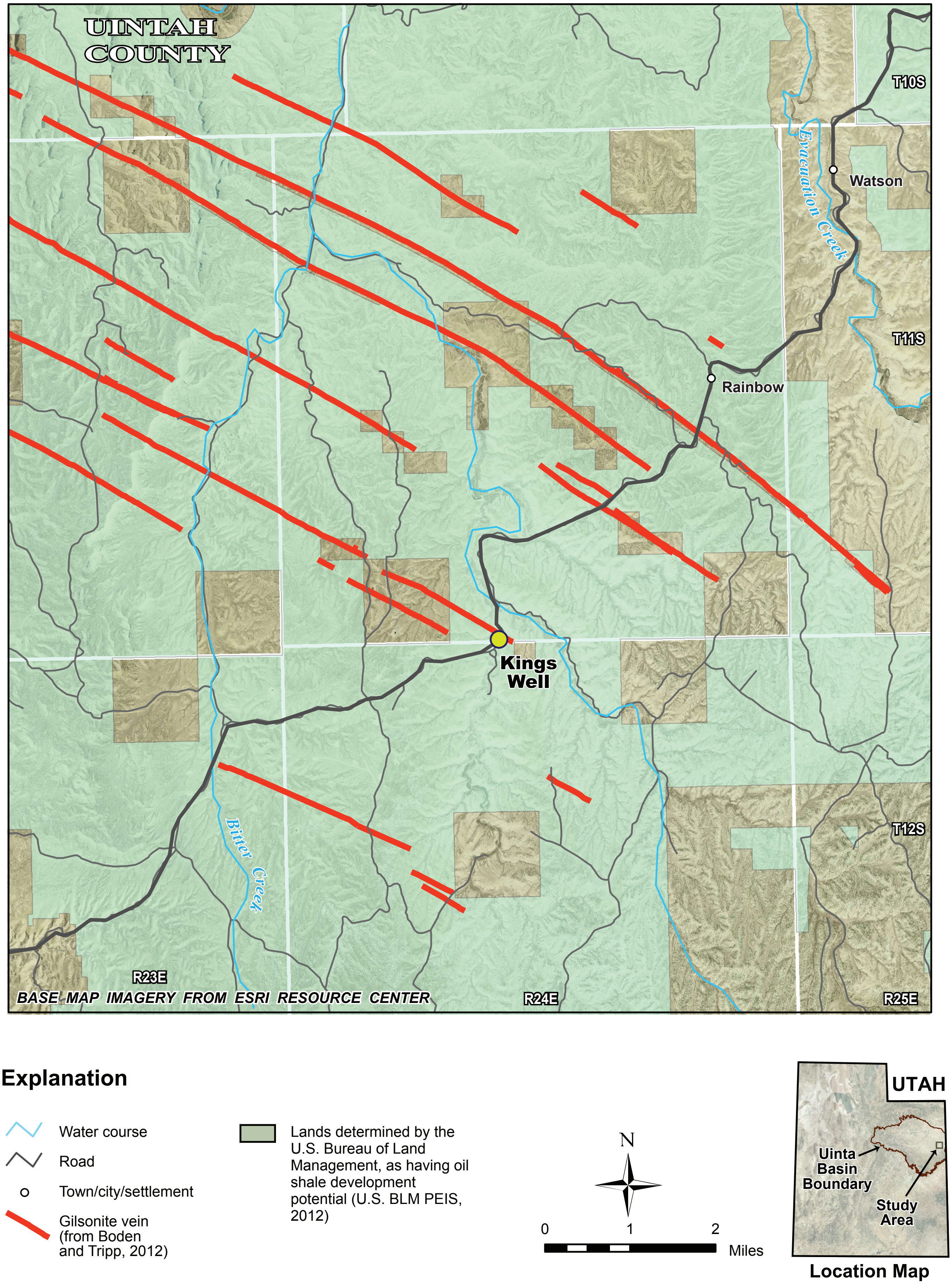

Figure 14. *Gilsonite vein map showing the location of Kings well (site 6) near a gilsonite vein (modified from Boden and Tripp, 2012).*

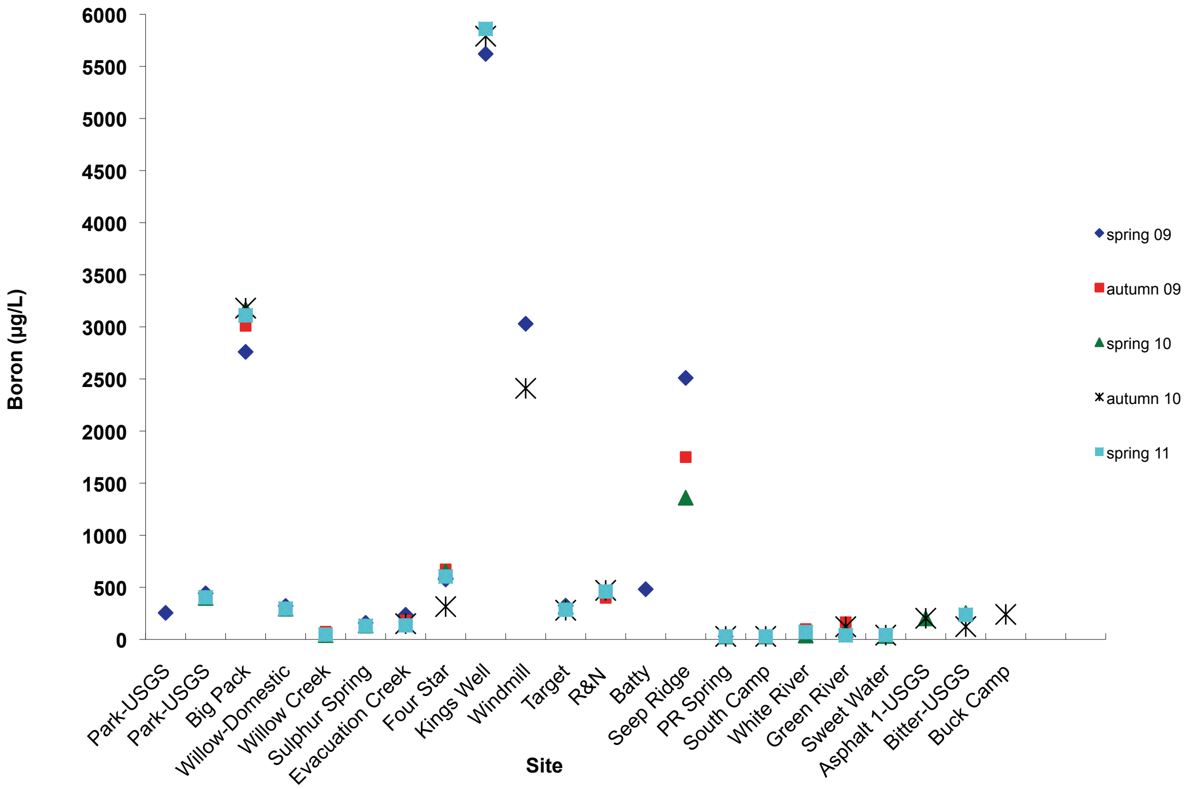

Figure 15. *Boron concentration for each sample site over five different sampling seasons. Points plotting on "0" on the x-axis have concentrations below the detection level of 30 µg/L.*

Volatile Organic Compounds

Volatile organic compounds (VOCs) were analyzed annually for all sample sites and resampled during autumn for selected sites. No VOC exceeded EPA MCL, but some sample sites had detectable levels of certain VOCs. Chlorobenzene, the most commonly occurring VOC, was detected in 18 samples over all sampling intervals, followed by chlorethane (detected in 6 samples), xylene (5 samples), and ethylbenze (3 samples). Other VOCs include benzene, bromoform, bromoethane, toluene, naphthalene, chloro di-bromomethane, bromo dichloromethane, and 1,2,4-Trimethylbenzene (all of these VOCs were detected at least once and some of these VOCs up to two times) (appendix D). The range of concentrations for detected chlorobenzene is 0.5 µg/L (the detection limit) to 1.1 µg/L, well below the MCL of 100 µg/L. Chlorobenzene is used in the manufacture of other organic chemicals, dyestuffs, and insecticides and can be deleterious to human health, potentially causing liver or kidney problems, and may be derived from chemical and/or agricultural industries (U.S. EPA, 2011). Chlorobenzene was detected in both surface water (the White River) and groundwater from a well located in the southernmost part of the basin that seasonally serves a scout camp (South Camp, figure C.6). Chloroethane, the second most commonly detected VOC, does not have a current EPA standard and is being evaluated as a hazardous pollutant. It is typically used as an industrial solvent, a chemical intermediate, and a blowing agent (e.g., in styrene plastic manufacturing) (U.S. EPA, 2011).

Other Chemical Constituents

Secondary drinking water standards were exceeded in 27 samples for all seasons. Sulfate levels were exceeded at seven different sites, iron content was exceeded in four samples at two sites, and chloride was exceeded for five samples at three sites for all seasons (appendix D). These constituents are not known to be deleterious to human health but may impart an unpleasant taste, odor, or color to the water (appendix D). In addition, as mentioned above, boron is present in many of the samples, but does not have a secondary drinking water standard.

WATER QUANTITY

A second objective of this study was to estimate the volume of water in aquifers in the southeastern Uinta Basin, especially for the thinly mantled and disconnected alluvial aquifers and the Birds Nest and Douglas Creek aquifers within the Green River Formation. Creating a groundwater flow model and performing aquifer tests on wells are beyond the scope of this study and are cost/time prohibitive, hence U.S. Geological Survey data provide the best estimate of storativity in these aquifers based on their easily accessed data provided online (U.S. Geological Survey, 2011) and information from previous studies (Holmes, 1980; Holmes and Kimball, 1987) within the Uinta Basin in Utah, dominantly in the southeastern part of the basin.

The volume of water consumption was about 7.4 million acre-feet per year in 1985 for the Uinta Basin in Utah (Holmes, 1985). In 1985, the population of Uintah County was 24,900 people and the population of Duchesne County was 14,700; by 2010, the population of Uintah County had increased to 32,588 and Duchesne County had increased to 18,607 (Utah Governor's Office of Planning and Budget, 2011). The increase in population likely has resulted in an increase in water use beyond the 1985 water consumption rate of 7.4 million acre-feet per year.

Most public water supply is from surface water, dominantly the Green and White Rivers, with only minor supply from groundwater wells. For the alluvial aquifers in the southeastern Uinta Basin, the volume of recoverable water in storage is estimated at 200,000 acre-feet, with maximum yields for individual wells estimated at less than 1000 gallons per minute (Holmes and Kimball, 1987; Utah Division of Water Resources, 2011).

Test holes drilled by the USGS during the 1970s to determine hydraulic properties of the aquifer(s) in the area provide local estimates for the Birds Nest and Douglas Creek aquifers in six areas of the eastern Uinta Basin, coinciding with water-quality samples taken as part of this study (Holmes, 1980; appendix B). All six wells penetrated the Green River Formation. The Birds Nest was encountered in two wells and the Douglas Creek Member was penetrated in all six wells. Only three wells penetrated alluvium with thicknesses ranging from 0 to 190 feet; 40 feet near Asphalt Wash (site 3 Asphalt-1 USGS), 190 feet in Willow Creek (near site 11 Willow Creek surficial sample), and 110 feet near Bitter Creek and Buck Camp (site 15 Bitter-USGS) (figure 8). The alluvial material consists of fine and coarse interlayered sediment (Holmes, 1980). At the time of drilling, the alluvial material was partially saturated to unsaturated. Based on an estimated maximum saturated thickness of 100 feet and minimum saturated thickness of 10 feet within the southeastern Uinta Basin, the estimated storage for alluvium ranges from 6000 to 60,000 cubic meters per hectacre based on methodology used by the American Institute of Mining Engineers (1915).

Hydraulic properties of the Douglas Creek aquifer include (1) transmissivity that ranges from 16 to 170 square feet per day with an average of 50 square feet per day—this was used to estimate a storage coefficient of 5×10^{-4}, and (2) maximum discharge from each of the six wells that does not exceed 200 gallons per minute (Holmes, 1980). The measured thickness of the upper Douglas Creek member ranges from 200 to 1000 feet and the lower Douglas Creek ranges from 0 to 300 feet thick (the upper and lower parts of the member are separated by the Renegade Tongue of the Wasatch Formation; Hintze, 1973; Anderson and others, 2012). Based on a saturated thickness range of 200 to 1000 feet and a porosity of 0.1% (Vanden Berg, written communication, February, 2012), estimated water quantity for the Douglas Creek ranges from 60,000 cubic meters per hectacre to 300,000 cubic meters per hectacre. The Birds Nest aquifer is estimated to range from 33 to 110 feet thick for the upper Birds Nest and 30 to 100 feet thick for the lower Birds Nest (Mike Vanden Berg, written communication, February, 2012), thus an estimated water quantity, using a rough estimated porosity of 2.5% (Vanden Berg, written communication, February, 2012), ranges from 25,000 to about 84,000 cubic meters per hectacre. These calculated estimates simplify the actual aquifer characteristics and do not incorporate lateral or vertical variations in sedimentary thickness within the units. The Birds Nest aquifer, for the most part, is not a suitable drinking water resource due to its relatively high dissolved solids concentrations. Also, because it is under pressure, it is likely not saturated with water (Vanden Berg, written communication, February 2012).

The potential contribution of recharge water to the alluvial aquifers was estimated by evaluating the amount of discharge from flow at selected sites along Evacuation Creek, Bitter Creek, the White River, and the Green River using online data provided by the U.S. Geological Survey (U.S. Geological Survey, 2011) (figures 16–20) (most of these ephemeral streams are located near sampled wells). Evacuation Creek near Dragon Station and Bitter Creek near Bonanza (this is the formal USGS station name, not an exact geographic descriptive location) have discharge data records for the water years 1975 to 1983, with peak flows at both sites recorded in 1983 (an anomalously wet year) (figures 16 and 17). Overall, discharge is low for both creeks based on the annual data from the 1970s, which likely represents flow as it currently exists and was confirmed by field observation; recharge from these creeks to alluvium is likely minimal. Holmes (1980) describes discharge areas along the canyon bottoms within the Uinta Basin (where Evacuation Creek, Bitter Creek, and the White River flow) intersect water-bearing units of the Green River Formation (i.e., gaining streams). Both the White and Green Rivers near Ouray, Utah, have flows that fluctuate considerably depending on the season and year (figures 18, 19, and 20). The U.S. Geological Survey (2011) discharge data for these large rivers may indicate potentially negligible loss of streamflow to the groundwater system.

RECOMMENDATIONS

The water-sampling sites for this study were selected without bias to land use and are widespread throughout the study area. Most water-quality data, in terms of TDS, show the sites maintain similar water quality during different seasons and years. Subsequent sampling of these sites may show whether water quality has been impacted by changes in land use. Due to the likely increase in development from the oil and gas industry and potential

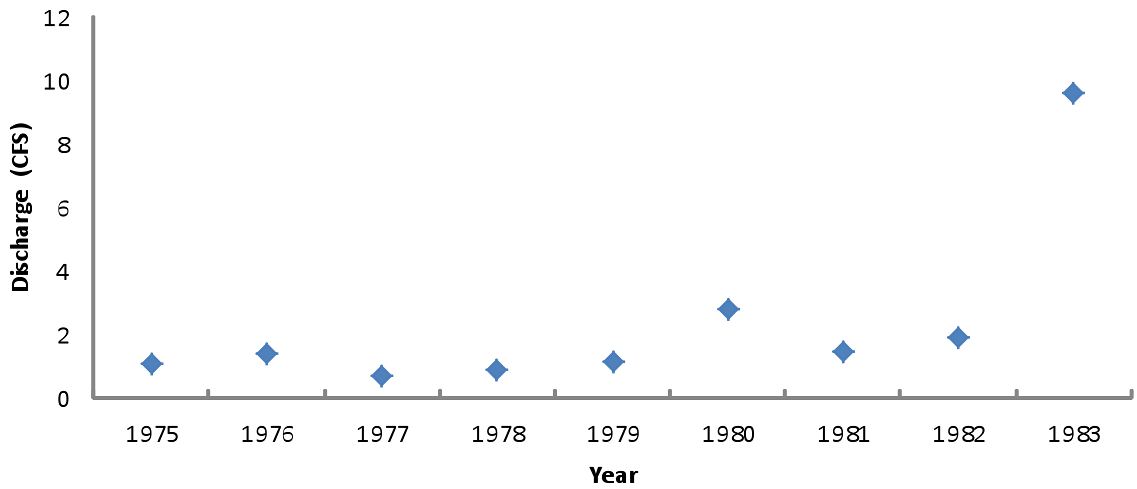

Figure 16. *Discharge versus year for Evacuation Creek; these dates are the only data available for this site (data and graph from the USGS, 2011).*

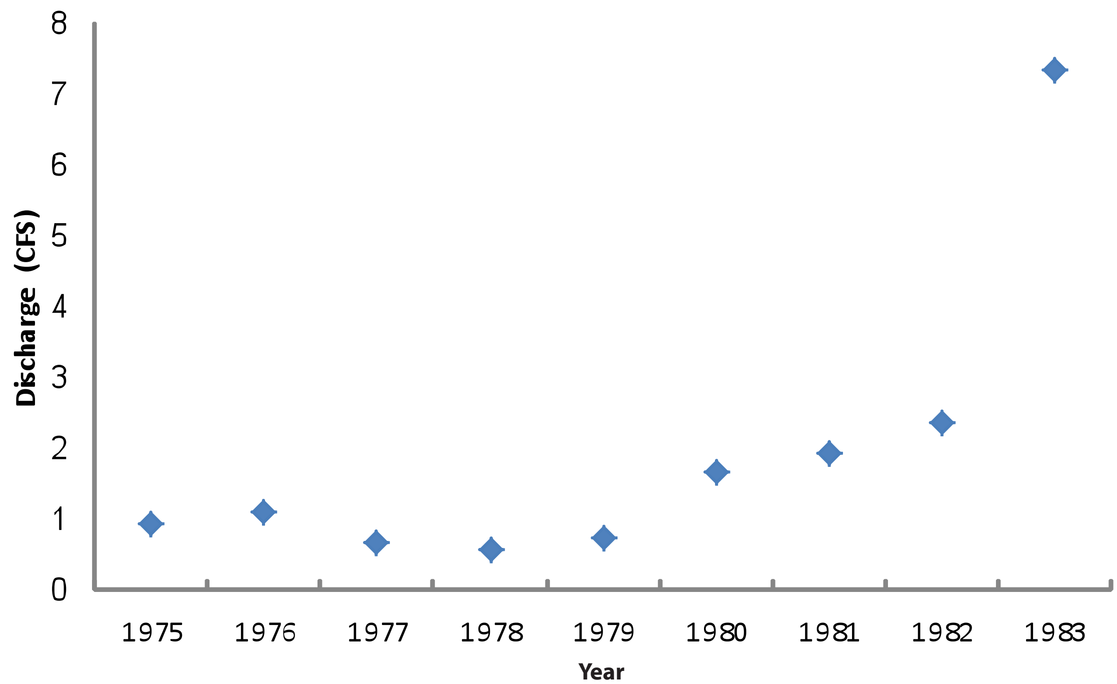

Figure 17. *Discharge versus year for Bitter Creek; these dates are the only available data for this site (data and graph from the USGS, 2011). The station name is formally designated by the USGS and does not indicate the water flows near the community of Bonanza.*

development of an oil shale and/or oil sands industry, it is recommended that these sites be sampled on a yearly basis, or every three years at a minimum, to determine if groundwater-quality degradation is occurring. The recommendations herein are not meant to impose regulatory measures for any current or future land-use development, but are a suggestion to track the quality of water at these sites; early detection of pollutants could help avoid costly cleanup.

Most samples collected during this study yielded relatively low nitrate concentrations except areas of shallow alluvial aquifers in the northwestern part of the study area. Nitrate is common in agricultural settings (Lowe and Wallace, 2001; Lowe and others, 2002), which is the land-use practice surrounding these alluvial wells (fertilizer and/or an animal waste source). Samples from site 6 (Kings well), located farther to the south, also have nitrate concentrations that exceed the EPA standard; however, no apparent source typically associated with nitrate exists in the area. Gilsonite, a nitrogen-rich hydrocarbon, is a relatively chemically stable, but mechanically unstable, hydrocarbon that is prevalent in the study area with a vein terminating near the Kings well. One future recommendation is to obtain nitrogen and oxygen isotopes from the Kings well water samples to try and determine the potential source of nitrate. Because the well is near a gilsonite vein, surface-water contamination via flow from the vein into the aqui-

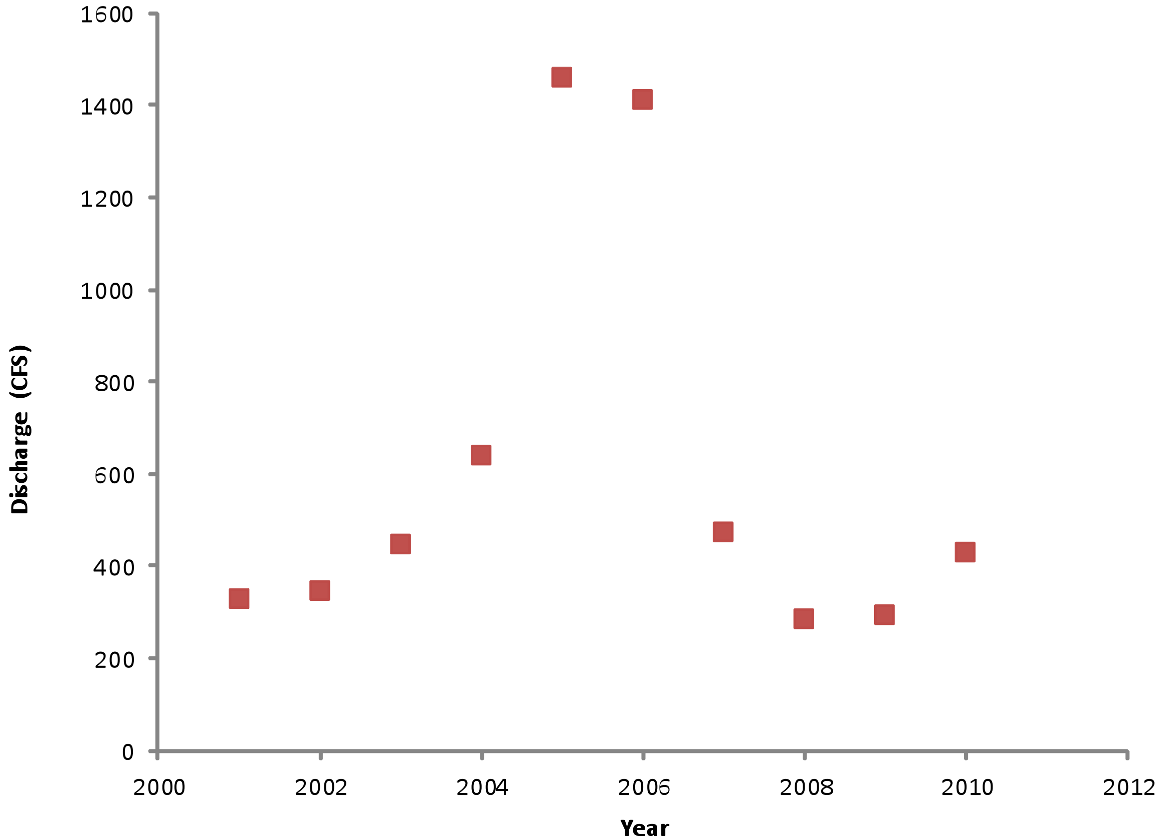

Figure 18. *Discharge versus year for the White River near Watson; the station name is designated by the USGS and does not indicate the water flows near the old site of Watson (data and graph from the USGS, 2011).*

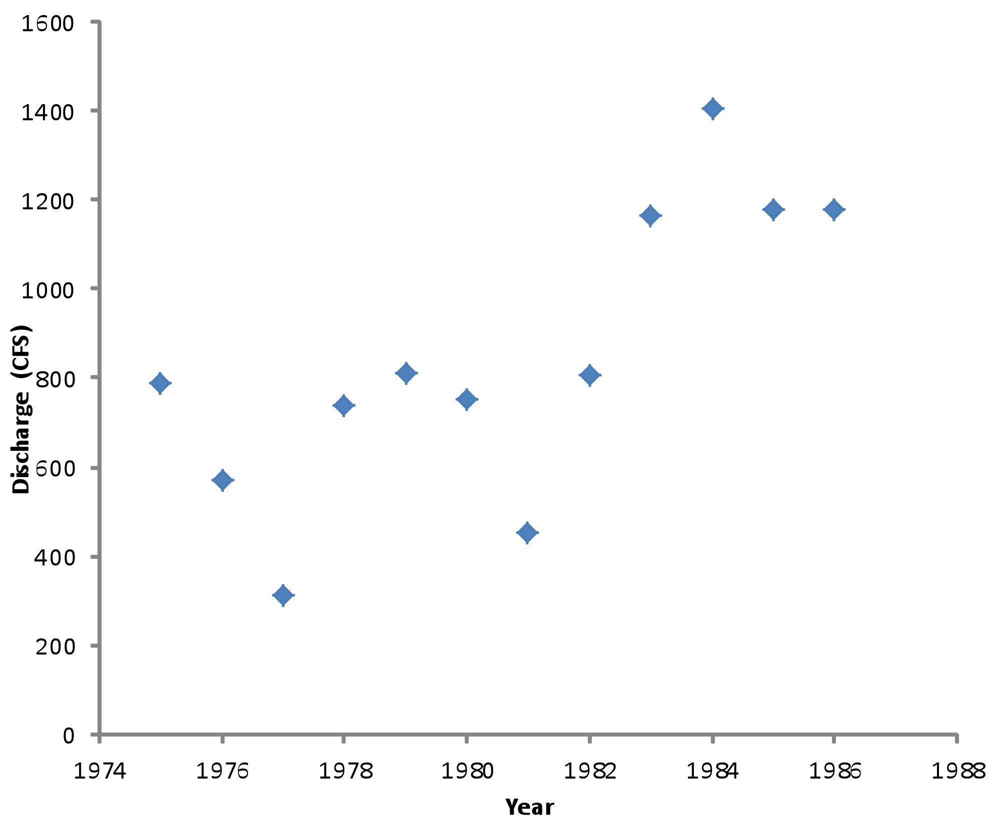

Figure 19. *Discharge versus year for the White River near Ouray (data and graph from the USGS, 2011).*

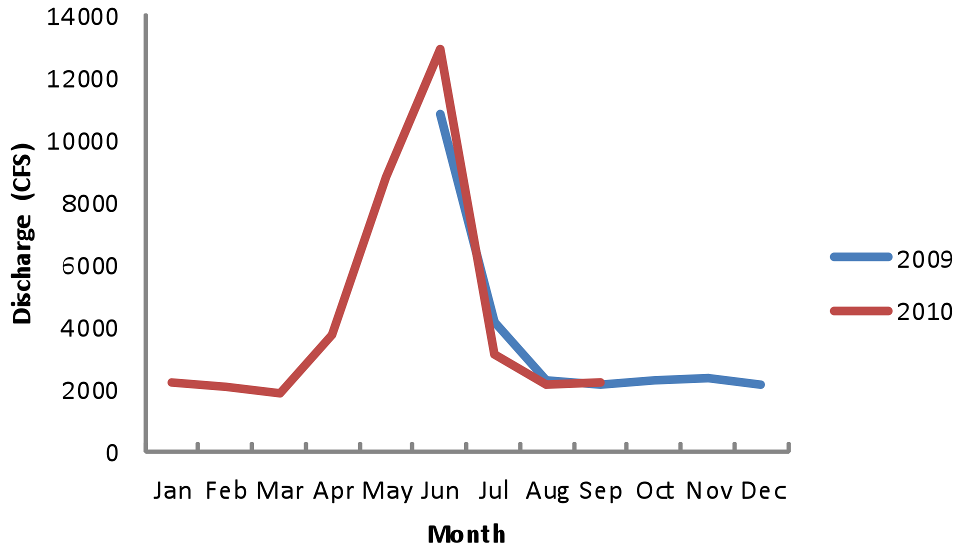

Figure 20. *Discharge versus month for two different years for the Green River near Ouray (data and graph from the USGS, 2011).*

fer is possible. Boron is also a common element contained in the Green River Formation and the use of boron isotopes can help delineate a nitrogen source (Leenhouts and others, 1998; Widory and others, 2005). Previous studies have shown that joint use of nitrogen and boron isotopes can help decipher the origin of nitrate in groundwater and allow a semi-quantification of the contributions of the respective pollution sources (fertilizers, wastewater, and animal waste) (Widory and others, 2005). With a high nitrate concentration, the Kings well may not be considered a viable drinking-water source. However, if the sources of nitrate are identified, concentrations could be reduced.

Future sampling for heavy metals is recommended to determine if a marked increase occurs, especially in barium, chromium, uranium, and zinc. These metals have been reported in other studies related to oil shale development (Bank, 2011). This would be particularly important if a large oil shale industry develops and spent shale stock piles are created—there is concern that spent shale could leach heavy metals into the groundwater (Bank, 2011). Concentrations measured during this study range from non-detect to a high of 2490 µg/L for barium, 13.3 µg/L for chromium, and 338 µg/L for zinc (all below the MCL). Uranium was not analyzed in this study, but eight samples had measurable alpha gross (radiologics), which may indicate uranium is present.

Because this is a baseline study to establish the current conditions of water quality in the southeastern Uinta Basin and because the overall chemistries of the sample sites did not vary much during this study, the recommendation to continue to sample wells, springs, and surface-water sites in the future is meant as a cautionary measure in response to potential energy development. An ultimate goal is to preserve the relatively good quality of water resources as they exist today and to prevent future degradation by examining any changes in chemistry that may herald contamination.

SUMMARY

This study was conducted to establish baseline water quality and estimate water quantity for lands proposed by the BLM as having oil shale development potential. During spring and autumn of 2009 and 2010, and spring of 2011, 85 water samples were collected from up to 24 sites including water wells and surface-water sites in the southeastern Uinta Basin. A suite of water-quality constituents were analyzed including general chemistry (including total dissolved solids), nutrients (including nitrate, phosphorous, and ammonia), dissolved metals, and volatile organic compounds. Total-dissolved-solids concentrations for all samples ranged from 172 to 2832 mg/L (with an anomalous concentration of 3056 mg/L) and nitrate concentrations ranged from <0.1 to 18.8 mg/L for all sampling seasons. Dissolved solids were highest from Evacuation Creek during spring 2009 and lowest from the Green River near Ouray, Utah, during flood stages in spring 2010. Overall, samples show variable water quality throughout the study area with water likely from multiple aquifers that are not connected except locally (e.g., shallow alluvium in the northwesternmost part of the study area). Most sites have nitrate concentrations below 0.1 mg/L with the exception of alluvial wells in the northwestern part of the study area downgradient from irrigated fields and a large cattle ranch, and one bedrock well in the central part of the study area that warrants future investigation to determine the source of nitrate.

A secondary objective of this study was to try to quantify the volume of water in aquifers in the southeastern Uinta Basin, especially for the thinly mantled and disconnected alluvial aquifers and the Birds Nest and Douglas Creek aquifers with the understanding that creating a groundwater flow model and performing aquifer tests on wells are beyond the scope of study. U.S. Geological Survey online data and information from previous studies provide the

best estimates for storativity in these aquifers dominantly in the southeastern part of the Uinta Basin. For the alluvial aquifers, the volume of recoverable water in storage is estimated at 200,000 acre-feet, with maximum yields for individual wells estimated at less than 1000 gallons per minute. Based on a saturated thickness range of 200 to 1000 feet, estimated water quantity for the Douglas Creek ranges from 60,000 to 300,000 cubic meters per hectacre. The Birds Nest aquifer is estimated to range from 33 to 110 feet thick for the upper Birds Nest and 30 to 100 feet thick for the lower Birds Nest, thus an estimated water quantity ranges from 25,000 to about 84,000 cubic meters per hectacre, but, because it is under pressure, it is likely not saturated with water.

All of the sites sampled vary in terms of their water resource value. Some are perennial streams or springs, some are water supply sources for the oil/gas industry, some supply water for wildlife, and a few are public water supply sources. Most of the water, in terms of being potable, could be used as a source for drinking if treated properly, with all having TDS concentrations below 3000 mg/L, the upper limit set by the Utah Water Quality Board as "Drinking Water Quality."

Water-quality degradation may result from an increase in development activity if sound water management procedures are not implemented. Recent proposals have been submitted by energy companies to develop oil shale and oil sands resources in the area. This regional baseline water study provides vital information to help local planners and potential developers to preserve the quality of groundwater and surface water by establishing best-management practices through careful land-use planning.

ACKNOWLEDGMENTS

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APPENDICES

APPENDIX A

Water Chemistry Database for Wells in the Uinta Basin, Uintah County, and Extended Areas in Surrounding Counties

(click to view in Excel)

APPENDIX B

Information on the U.S. Geological Survey's Six Uinta Basin Test Holes Drilled During the 1970s

Appendix B. *Information on the U.S. Geological Survey's six Uinta Basin test holes drilled during the 1970s (from Holmes, 1980).*

Test Hole	Operator	Well Name	Location	Twn	Rng	Sec	1/4 1/4	UTM E NAD 83	UTM N NAD 83	Date of Sample	Discharge (gal/min)	Depth to top of interval sampled (ft)	Depth to bottom of interval sampled (ft)	Water temperature (°C)
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/18/76	1	1,888	2,650	26.5
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/19/76	3.3	1,507	1,622	26
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/19/76	8.1	1,080	1,285	26
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/20/76	6	750	950	25
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	11/11/76	4	1,092	1,158	21.5
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	11/12/76	2	1,250	1,260	22
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	3/23/79	10	1,092	1,576	25
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	645054	4391298	6/29/77	0	0	40	15
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	645054	4391298	7/7/78	11	40	1,290	18.5
3	USGS	Test Hole 3	(D-13-21)10ada-1	13S	21E	10	NE SE NE	624780	4396546	3/22/78	211	250	1,092	16.5
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	647985	4402283	3/26/78	10	100	800	10
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	647985	4402283	3/28/78	42	800	1,402	22
5	USGS	Test Hole 5	(D-11-25)26aab-1	11S	25E	26	NE NE NW	663634	4410692	5/23/78	12	117	798	16.5
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	4/3/78	16	135	764	18
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	4/7/78	125	1,000	1,497	23.5
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	5/5/78	15	135	860	23.5

Test Hole	Specific conductance (µmho/cm)	pH (units)	Dissolved solids, residue at 180°C	Dissolved solids, sum of constituents	Dissolved calcium (Ca)	Dissolved magnesiun (Mg)	Dissolved sodium (Na)	Sodium-adsorption ratio	Dissolved potassium (K)	Bicarbonate as HCO3	Carbonate as CO3	Alkalinity as CaCO3
1	10,300	8.2	6,110	6,120	8.5	5.3	2,300	153	9.5	1,180		968
1	2,070	8.8	1,340	1,310	2.3	1	480	67	1.4	574	24	511
1	2,070	8.7	1320	1,310	2.2	0.9	480	69	1.6	607	19	530
1	1,970	8.6	1,260	1,230	3.2	1.2	450	54	1.8	602	12	514
1	1,800	--	--	965	1.1	0.2	360	83	0.8	611	--	501
1	1,720	--	--	974	1.3	0.2	350	76	0.7	481		395
1	1,800	9	--	1,080	1.3	0.5	390	74	0.9	--	--	430
2	9,000	8.7	--	4,920	3.4	4.5	2,300	193	3.8	2,430	200	2,330
2	1,130	7.2	927	906	54	44	190	4.7	0.7	240	0	200
3	900	8.1	--	651	17	15	190	8.1	0.9	280	--	230
4	4,000	9.2	--	2,350	15	79	760	17	4.6	1,270	--	1,040
4	1,300	8.6	--	948	4.5	1.8	340	34	1	370	--	300
5	3,680	7.4	3,030	3,070	130	140	690	10	1.9	490	0	400
6	10,900	9.2	--	9,870	6.6	300	3,100	38	10	1,200	1,250	3,070
6	1,370	--	--	959	4.5	0.7	360	42	1.5	620	--	509
6	1,350	9	--	921	1.7	0.4	60	65	0.8	700	15	599

all data reported in mg/L;
no API# listing for these wells

Baseline water quality and estimated quantity for selected sites in the southeastern Uinta Basin, Utah

Appendix B. *Information on the U.S. Geological Survey's six Uinta Basin test holes drilled during the 1970s (from Holmes, 1980).*

Test Hole	Dissolved carbon dioxide (CO2)	Total sulfide (S)	Dissolved sulfate (SO4)	Dissolved chloride (Cl)	Dissolved fluoride (F)	Dissolved bromide (Br)	Dissolved silica (SiO2)	Dissolved NO2 + NO3 as N	Dissolved ammonia as N	Dissolved ammonia as NH4	Ammonia + organic total as N	Total phosphorus as P	Total phosphor us as PO4
1	12	--	270	2,900	4.9	12	10	0	12	15	11	0.16	0.49
1	1.6	--	440	59	2	0.4	13	0	0.76	0.98	0.84	0.05	0.15
1	2.1	--	380	110	2.1	0.6	13	0	0.79	1	1.3	0.06	0.18
1	2.5	--	350	92	2.2	0.4	13	0	0.79	1	1.5	0.06	0.18
1	--	--	250	38	1.4	--	12	0.01	--	--	--	--	--
1	--	--	360	13	0.9	--	11	0.01	--	--	--	--	--
1	--	7.7	390	22	1.1	--	12	0.03	--	--	--	--	--
2	9.1	--	39	980	110	--	9.2	--	--	--	--	--	--
2	24	0.2	470	12	0.3	0.1	8.9	0.39	0.01	0.01	0.24	0.01	0.03
3	3.6	--	270	9.3	0.2	--	10	0.08	--	--	--	--	--
4	1.3	--	820	39	0.4	--	6.3	0.2	--	--	--	--	--
4	1.5	--	400	7.4	0.5	--	8.1	0.02	--	--	--	--	--
5	31	0	1,800	33	0.8	0.2	19	0.01	0.69	0.89	0.9	0.03	0.09
6	3.8	--	4,300	280	2.2	--	12	0.05	--	--	--	--	--
6	--	--	260	13	1.2	--	12	0	--	--	--	--	--
6	1.2	--	150	32	1.9	--	13	0.03	--	--	--	--	--

Test Hole	Dissolved orthophos phorus as P	Dissolved orthophosp hate as PO4	Dissolved aluminum (Al)	Dissolved arsenic (As)	Dissolved barium (Ba)	Dissolved boron (B)	Dissolved cadmium (Cd)	Dissolved chromium (Cr)	Dissolved copper (Cu)	Dissolved iron (Fe)	Dissolved lead (Pb)
1	--	--	280	3	300	3,200	1	0	2	160	5
1	0.06	0.18	30	1	0	310	0	0	0	70	5
1	0.05	0.15	140	1	0	380	0	0	1	130	4
1	0.07	0.21	10	1	0	430	1	0	2	140	13
1	0	0	--	--	--	370	--	--	--	--	--
1	0.01	0.03	--	--	--	140	--	--	--	--	--
1	--	--	50	--	--	200	--	--	--	--	--
2	--	--	--	--	--	70000	--	--	--	140	--
2	0.01	0.03	0	1	200	170	1	10	0	1,600	5
3	0	0	--	--	--	630	--	--	--	40	--
4	0	0	--	--	--	1,800	--	--	--	40	--
4	0	0	--	--	--	130	--	--	--	2100	--
5	0	0	0	5	0	770	1	0	5	2,100	4
6	--	--	--	--	--	12000	--	--	--	730	--
6	0.01	0.03	--	--	--	250	--	--	--	170	--
6	0.03	0.09	--	--	--	460	--	--	--	10	--

all data reported in mg/L;
no API# listing for these wells

Appendix B. *Information on the U.S. Geological Survey's six Uinta Basin test holes drilled during the 1970s (from Holmes, 1980).*

Test Hole	Dissolved lithium (Li)	Dissolved manganese (Mn)	Dissolved mercury (Hg)	Dissolved molybdenum (Mo)	Dissolved selenium (Se)	Dissolved strontium (Sr)	Dissolved vanadium (V)	Dissolved zinc (Zn)	Dissolved organic carbon (mg/L as C)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, dissolved (pCi/L, as Sr/Yt-90)
1	530	30	0	8	0	1,200	1.4	80	--	--	--
1	100	90	0	1	0	220	0	20	--	--	--
1	110	10	0	0	0	200	0	20	--	--	--
1	110	10	0	0	0	180	0	40	--	--	--
1	--	--	--	--	--	--	--	--	--	--	--
1	--	--	--	--	--	--	--	--	--	--	--
1	--	--	--	--	--	--	--	--	--	--	--
2	--	8	--	--	--	--	--	--	--	--	--
2	40	20	0	2	0	3,800	0	30	2.4	<3.4	<3.1
3	--	10	--	--	--	--	--	--	--	--	--
4	--	60	--	--	--	--	--	--	--	--	--
4	--	60	--	--	--	--	--	--	--	--	--
5	260	700	0	11	0	6,800	0	300	3.9	<8.5	--
6	--	40	--	--	--	--	--	--	--	--	--
6	--	20	--	--	--	--	--	--	--	--	--
6	--	10	--	--	--	--	--	--	--	--	--

all data reported in mg/L;
no API# listing for these wells

APPENDIX C

Sampling Site Descriptions

SAMPLING SITE DESCRIPTIONS
(see figure 8 for location of sample sites)

Site 1. Windmill: Named for the Bureau of Land Management (BLM) sign, Kennedy Station was a former stagecoach stop along the gilsonite route from the gilsonite mine at Dragon Station within the heart of the Uinta Basin. The well is powered by a windmill, and piping system underground from the fenced-in and welded wellhead to a pond is used to supply water for wildlife. Samples were obtained near the pipe outlet within the pond only when the wind was blowing; the windmill was broken during some sampling rounds and no sample was taken (figure C.1).

Site 2. White River: Named for the White River where samples were obtained near the banks of the river near the put in/take out for rafting trips below a bridge and near outhouses.

Site 3. Asphalt 1-USGS: Located in Asphalt Wash, this U.S. Geological Survey (USGS) well was drilled as test hole #1 (appendix B) during a 1976 study (Holmes, 1980). It is a flowing well with underground piping that allows water to flow into a pond used to supply water for wildlife. The spigot could be turned on to allow water to be collected during two sampling events, but was "frozen" shut the third sampling round. The third sample was obtained near the pipe entering the pond (figure C.2).

Site 4. Park-OSEC: Located in Park Canyon near an oil/gas well currently owned by OSEC. When we discovered this well in the field (with BLM and Division of Oil, Gas, and Mining [DOGM] staff), no information on well depth was available. I obtained the sample with the help of BLM staff using a submersible Hurricane Pump (which will pump water from a maximum depth of 170 feet). We bailed the samples, not knowing the depth, and purged water for about 50 gallons. After further investigation, I learned from OSEC staff of the well's characteristics, and that this well is too deep to obtain a proper sample with UGS equipment; the gray-colored water sample (having a strong petroleum odor) we collected was likely stagnant water and not representative of well water from greater depths (750').

Site 5. Park-USGS: Located near Park Canyon, this locked well has a welded label that identifies the well as "USGS G-16H" and is located in an inaccessible area shrouded in shrubs surrounding the wellhead. Piping is connected to the well and water flows from a pipe into a pond. Samples were obtained from the pipe-hose that drains into a pond that supplies water for wildlife (figure C.3).

Site 6. Kings Well: This well is located along King's Well Road identified by BLM signs within the basin (figure C.4). The initial well was a hand dug well that is covered with a large grate and is no longer in use. That well was replaced by a more modern well drilled approximately 80 feet deep according to Vernal BLM staff investigations. I pumped this well with a submersible Hurricane Pump and purged the well three times the volume to obtain a representative sample. I also took field measurements with a hand-held multiparameter instrument for specific conductance, temperature, and pH every 5-gallon-bucket interval.

Site 7. Evacuation Creek: Named from the samples taken from Evacuation Creek near Dragon Station within the basin. All samples were taken from the middle of the stream bed near the mouth of ephemeral Missouri Creek/canyon and above the confluence of these two streams.

Site 8. Sweet Water Spring: Named from the USGS topographic map of the same name. Spring water issues from bedrock and flows into the ephemeral creek in South Canyon in the southernmost part of the study area (figure C.5).

Site 9. South Camp: Named from the well drilled to supply water to a seasonal scout camp called Ward Jarman's South Camp. Samples were taken from a spigot near the wellhead that appears to be solar powered (figure C.6).

Site 10. PR Spring: Named from the USGS topographic map of the same name and popular camping spot, especially during hunting season. Samples were obtained from a spigot connected via piping and directly downhill from the source's spring box. This is considered a public-supply source.

Site 11. Willow Creek: Named for samples taken from Willow Creek in the Willow Creek drainage. The initial sample was obtained farther south than the later samples. I changed locations due to better efficiency (e.g., less amount of driving time and avoiding muddy roads during the spring runoff).

Site 12. Willow Spring: Named for an unnamed and unmapped (ephemeral?) spring within Willow Creek drainage. Sample was taken during the final round of sampling during the runoff/flooded spring season of 2011. The source of the spring likely issues from bedrock much farther from the where the pond sample was obtained along the road. The spring's area is represented by a wet/boggy wetland-type environment with vegetation and shrubs obscuring the spring's opening.

Site 13. Sulphur Spring: Named from the USGS topographic map of the same name. Most of the samples were obtained from the spring flowing over mossy sediments and flow was commonly low, at times making it difficult to obtain a sufficient sample (figure C.7.)

Site 14. Willow-domestic: Named for a flowing well located on former domestic property. The homes are now abandoned and condemned, but the sulfur-smelling gray-colored water flows from a pipe attached to the well that is submerged in a horse trough to provide water for horses that seasonally occupy a corral along the Willow Creek road (figure C.8).

Site 15. Bitter-USGS: Named for USGS test hole #6 well (appendix B) that was drilled in 1978 by Walt Holmes of the USGS and located in Bitter Creek drainage. This is a flowing well with attached below-ground piping that flows to a pond that supplies water for wildlife. The rusted spigot on this well functions and allows a trickle of water to flow from pressure (no pump) (figure C.9).

Site 16. Buck Camp-Bitter: This sample is named for the BLM sign located at temporary shelter that houses oil/gas employees in Buck Camp along the Bitter Creek drainage. Many spigots are located on the property along with corrals (figure C10). Vernal office BLM staff later verified this water source to be affiliated with underground piping from Site 15, the USGS test hole. Similar chemistry confirms the validity of their research.

Site 17. Big Pack: A plugged former oil/gas well that is used as a flowing well within the USGS topographic Big Pack Mountain area within the Willow Creek drainage area. The initial samples were taken from the wellhead flowing into a ponded/grassy area. Subsequent work on the site by field workers piped the water from the wellhead into a piping system that also feeds a pond system that supplies water for wildlife (figures C.11 and C.12). Subsequent samples were taken from the water flowing from the pipe into a smaller pond.

Site 18. Seep Ridge: Named for a former oil/gas well surrounded by other producing oil/gas wells near the road of the same name. This well is a flowing well where water seeps from a submerged pipe into a pond that provides water for wildlife. The water also contains hydrocarbon material and the pond system near the pipe is black and shiny with oil and grease that flows through a wetland into another cleaner water pond. The initial sample was taken from the clean pond (before I discovered the submerged pipe); subsequent samples were taken near the pipe issuing into the hydrocarbon-rich pond water to get a better representative sample of the water. Sampling from this piping system was not always possible due to the amount of black sticky hydrocarbon material (figures C.13 and C.14).

Site 19. Green River: Named for the samples taken from the Green River. The final sample was taken from near the bridge at Ouray due to flooding preventing any sampling from the previous sites.

Site 20. White/Green R.: Named for the sample taken from near the confluence of the White River before it reaches the Green River.

Site 21. Target: Named for the name on the water tank (Target Trucking) where sample was taken. The wellhead does not have a spigot; samples were taken from the holding tank used by truckers to supply water for the oil/gas industry in the basin (figure C.15).

Site 22. R&N: Named for the sign on the dirt road where the two wells are located. Two shallow wells (60 and 80 feet deep) are blended to provide water to water trucks that supply water for the oil/gas industry in the basin.

Site 23. Batty: Named for the property owner (Batty) housed in a well house with piping that flowed to storage tanks that served the water supply trucks for the oil/gas industry in the basin. The well was no longer operable during subsequent sample events.

Site 24. Four Star: Named for the Four-Star Ranch, this well is considered a public-supply well, although the well provides water for irrigation and for trucks that supply water for the oil/gas field in the basin. This water is not used as domestic water for the ranch. The wellhead has a pump in the well house and samples were obtained from a spigot within the well house adjacent to the well (figure C.16).

Figure C.1. *Site 1. Windmill well. Water in pond is pumped to the surface by power from the windmill; samples taken in 2009 when windmill was in operation. Site is located at Kennedy Station—a former stagecoach stop from the 1900-30s along a gilsonite mining "route."*

Figure C.2. *Site 3. Asphalt 1-USGS test hole in Asphalt Wash (see appendix B); runoff/piped water feeds pond for wildlife.*

Figure C.3. *Site 5. Park-USGS shows capped well and hose leading from well head to pond; samples were obtained from the pipe.*

Figure C.4. *Site 6: Kings well located in the central part of the study area is along King's Well Road; a battery powered submersible Hurricane Pump was used to sample and bail this well three times the volume of the well.*

Figure C.5. *Site 8. Sweet Water Spring located near South Camp; spring is bubbling just to the right of large rock in stream.*

Figure C.6. *Site 9. South Camp water well located in southernmost part of the study area near PR Spring and Sweet Water Spring; well is likely solar powered and serves as a seasonal camp.*

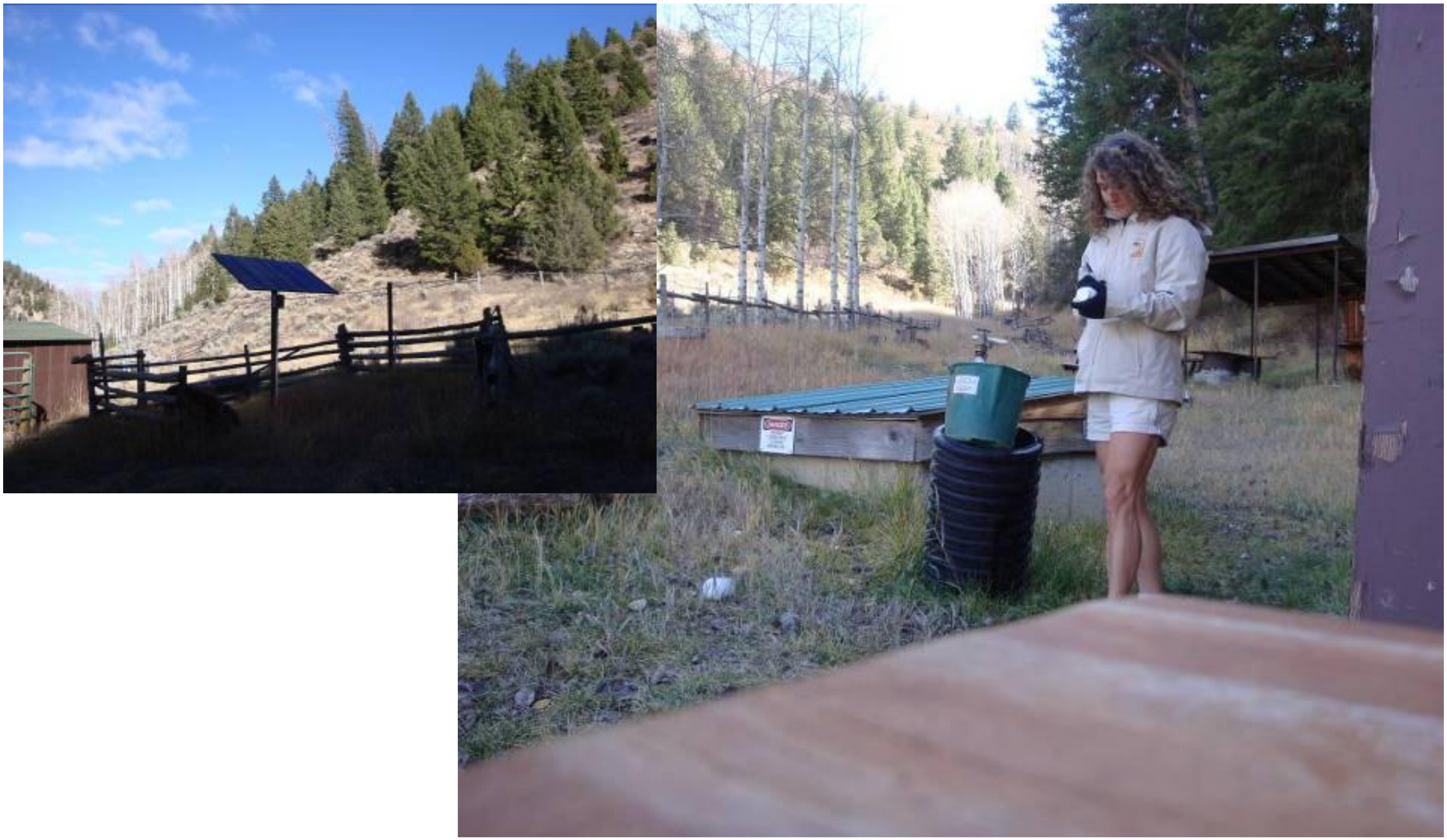

Figure C.7. *Site 13. Sulphur Spring during 2009 sampling season with a good water supply; during other sampling rounds, the water level was much lower which made it difficult to obtain a sufficient-sized sample to collect all water quality parameters.*

Figure C.8. *Site 14. Willow-domestic well: pipe from flowing well feeds into horse trough for temporary water supply in the corral, located along the road and near Willow Creek.*

Figure C.9. *Site 15: Bitter-USGS well near Buck Camp within Bitter Creek drainage area (see appendix B for hydrologic information).*

Figure C.10. *Site 16. Buck Camp spigot used to supply ephemeral use at corral and temporary housing at Buck Camp.*

Figure C.11. *Site 17. Big Pack: original well sampled from flowing well head; subsequent samples were from flowing pipe altered by well owner.*

Figure C.12. *Site 17. Big Pack: water flows into another pond to supply water for wildlife.*

Figures C. 13 and C.14. *Site 18. Seep Ridge: samples originally obtained from pond draining away through a wetland, subsequent samples obtained from pipe directly from well issuing into the pond; pond provides water for wildlife.*

Figure C.15. *Site 21. Target: named for the name on the water tank (Target Trucking) where sample was taken. The wellhead (red cap in photo) does not have a spigot, so samples were taken from the same holding tank used by truckers supplying water to the oil/gas industry in the Basin.*

***Figure C.16**. Land use around site 24 Four Star well shows irrigated land and cattle ranch in the northwesternmost part of the study area near Pelican Lake and the community of Leota, Utah.*

APPENDIX D

Water-Quality Data for Selected Sites for Five Different Sampling Intervals

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***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Field ID	Site Name	Cadastral Location	LAT	LON	water use (if known)	API # or DWRi#	Well Depth (feet)	Completion date
Spring/Summer 2009									
1	307	Windmill-Kennedy	(D-8-24)18bab	40.127418	-109.25903	wildlife/BLM	4304720084	1382+	1967?
4	295	Park-OSEC	(D-11-25)22cdc	39.841164	-109.1094	defunct- O/G	49-1557	750	1995
5	296	Park-USGS	(D-11-25)21cca	39.843449	-109.1287	wildlife	-	193+	pre 1987?
6	306	King's Well	(D-11-24)33dcc	39.811763	-109.23371	unknown/BLM?	near 43-047-15931	70-82	1997
7	304	Evacuation Creek	(D-12-25)2dad	39.801597	-109.07645	wildlife/ O&G?	-	creek	-
10	312	PR Spring	(D15-23)36ddd	39.462639	-109.28389	public supply	49-262	spring	-
11	299	Willow Creek	(D-13-21)27ccda	39.653891	-109.55562	wildlife	-	creek	-
13	300	Sulphur Spring	(D-12-21)19bdd	39.760072	-109.61085	wildlife	-	spring	-
14	298	Willow-Domestic	(D-11-21)31bdc	39.817315	-109.61228	animal husbanda	49-188	711	1952
17	297	Big Pack	(D-11-20)10cad	39.871584	-109.66748	wildlife/BLM	43-047-31026	6900	1981
18	311	Seep Ridge	(D-10-20)35bbd	39.909306	-109.63939	wildlife/BLM	4304716530	>2510	1964
21	308	Target	(D-8-20)9ada	40.139524	-109.66448	supply for indust	43-10988	53	2003
22	309	R&N	(D-8-20)9dcd	40.137731	-109.67514	supply for indust	49-1645/49-2166	80 & 60	2003
23	310	Batty	(D-8-20)4dda	40.146973	-109.6646	supply for indust	43-3778	83	1948
24	305	Four Star	(D-7-20)28ddd	40.174596	-109.66491	public supply	43-8875	172	2001
Autumn 2009									
1	319	Windmill-Kennedy	(D-8-24)18bab	40.127418	-109.25903	see above	see above	see above	see above
2	320	White River	(D-10-24)2dbb	39.976867	- 109 .18017	multi-use	see above	river	see above
5	321	Park-USGS	(D-11-25)21cca	39.843449	-109.1287	see above	see above	see above	see above
7	322	Evacuation Creek	(D-12-25)2dad	39.801597	-109.07645	see above	see above	creek	see above
9	325	South Camp	(D-15-24)32ddd	39.4743	- 109 .2475	public h20 sup	49-1597	98	1996
11	313	Willow Creek	(D-13-21)22abc	39.6759	-109.5506	see above	see above	creek	-
13	314	Sulphur Spring	(D-12-21)19bdd	39.760072	-109.61085	see above	see above	spring	see above
14	315	Willow-Domestic	(D-11-21)31bdc	39.817315	-109.61228	see above	see above	see above	see above
17	316	Big Pack	(D-11-20)10cad	39.871584	-109.66748	see above	see above	see above	see above
18	318	Seep Ridge	(D-10-20)35bbd	39.909306	-109.63939	see above	see above	see above	see above
20	326	White/Green River	(D-9-20)caa	40.0642	-109.6731	multi-use	see above	creek	see above
22	317	R&N	(D-9-20)4dcd	40.137731	-109.67514	see above	see above	see above	see above
24	323	Four Star	(D-7-20)28ddd	40.174596	-109.66491	see above	see above	see above	see above
Spring 2010									
1	307	Windmill-Kennedy		broken, not able to sample		see above	see above	see above	see above
2	320	White River	(D-10-24)2dbb	39.976867	- 109 .18017	see above	see above	river	see above
3	337	Asphalt 1-USGS	(D-11-24)7acc	39.877389	-109.26975	monitor/wildlife?	49-329	1900/2650	1976
5	296	Park-USGS	(D-11-25)21cca	39.843449	-109.1287	see above	see above	see above	see above

all Volatile Organic Compounds are reported as μg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Field ID	Site Name	Cadastral Location	LAT	LON	water use (if known)	API # or DWRi#	Well Depth (feet)	Completion date
6	306	King's Well	(D-11-24)33dcc	39.801597	-109.07645	see above	see above	see above	see above
7	304	Evacuation Creek	(D-12-25)2dad	39.801597	-109.07645	see above	see above	-	see above
8	331	Sweet Water	(D-15-24)10bcd	39.528806	-109.22256	wildlife	49-1569	spring	see above
9	325	South Camp	(D-15-24)32ddd	39.4743	- 109 .2475	see above	see above	see above	see above
10	312	PR Spring	(D15-23)36ddd	39.46263889	-109.2838889	see above	see above	spring	see above
11	299	Willow Creek	(D-13-21)22abc	39.6759	-109.5506	see above	see above	see above	see above
13	300	Sulphur Spring	(D-12-21)19bdd	39.760072	-109.61085	see above	see above	see above	see above
14	298	Willow-Domestic	(D-11-21)31bdc	39.817315	-109.61228	see above	see above	see above	see above
15	333	Bitter Creek-USGS	(D-12-22)1bbb	39.809556	-109.41078	nitor/wildlife?/Bl	well usgs test hole	1497	1976
16	334	Buck Camp-Bitter	(D-11-22)35aaa	39.8233	-109.4136	ub sup?? Wildlif	?	eek? Or old we	see above
17	297	Big Pack	(D-11-20)10cad	39.871584	-109.66748	see above	see above	see above	see above
18	311	Seep Ridge	(D-10-20)35bbd	39.909306	-109.63939	see above	see above	see above	see above
19	335	Green River	(D-9-19)12bcd	40.047611	-109.73328	multi-use	see above	river	see above
21	308	Target	(D-8-20)9ada	40.139524	-109.66448	see above	see above	see above	see above
22	309	R&N	(D-8-20)9dcd	able to sample		see above	see above	see above	see above
23	310	Batty		no longer in use					see above
24	305	Four Star	(D-7-20)28ddd	40.174596	-109.66491	see above	see above	see above	see above
Autumn 2010									
1	307	Windmill-Kennedy	(D-8-24)18bab	40.127418	-109.25903	see above	see above	see above	see above
2	320	White River	(D-10-24)2dbb	39.976867	- 109 .18017	see above	see above	see above	see above
3	337	Asphalt 1-USGS	(D-11-24)7acc	39.877389	-109.26975	see above	see above	see above	see above
5	296	Park-USGS	(D-11-25)21cca	39.843449	-109.1287	see above	see above	see above	see above
6	306	King's Well	(D-11-24)33dcc	39.801597	-109.07645	see above	see above	see above	see above
7	304	Evacuation Creek	(D-12-25)2dad	39.801597	-109.07645	see above	see above	see above	see above
8	331	Sweet Water	(D-15-24)10bcd	39.528806	-109.22256	see above	see above	see above	see above
9	325	South Camp	(D-15-24)32ddd	39.4743	- 109 .2475	see above	see above	see above	see above
10	312	PR Spring	(D15-23)36ddd	39.46263889	-109.2838889	see above	see above	see above	see above
11	299	Willow Creek	(D-13-21)22abc	39.6759	-109.5506	see above	see above	see above	see above
13	300	Sulphur Spring	(D-12-21)19bdd	39.760072	-109.61085	see above	see above	see above	see above
14	298	Willow-Domestic	(D-11-21)31bdc	39.817315	-109.61228	see above	see above	see above	see above
15	333	Bitter Creek-USGS	(D-22-12)1bbb	39.809556	-109.41078	see above	see above	see above	see above
16	334	Buck Camp-Bitter	(D-11-22)35aaa	39.8233	-109.4136	see above	see above	see above	see above
17	297	Big Pack	(D-11-20)10cad	39.871584	-109.66748	see above	see above	see above	see above
18	311	Seep Ridge	(D-10-20)35bbd	39.909306	-109.63939	see above	see above	see above	see above
18a		Seep Ridge-pond only	e taken at NE edge of pond			see above	see above	see above	see above
19	335	Green River	(D-9-19)12bcd	40.047611	-109.73328	see above	see above	see above	see above

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***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Field ID	Site Name	Cadastral Location	LAT	LON	water use (if known)	API # or DWRi#	Well Depth (feet)	Completion date
21	308	Target	(D-8-20)9ada	40.139524	-109.66448	see above	see above	see above	see above
22	309	R&N	(D-8-20)9dcd	40.137731	-109.67514	see above	see above	see above	see above
24	305	Four Star	(D-7-20)28ddd	40.174596	-109.66491	see above	see above	see above	see above
Spring/Summer 2011									
1	307	Windmill-Kennedy	broken -			see above	see above	see above	see above
2	320	White River	(D-10-24)2dbb	39.976867	- 109 .18017	see above	see above	see above	see above
3	337	Asphalt 1-USGS	ple from pond, spig	39.877389	-109.26975	see above	see above	see above	see above
5	296	Park-USGS	(D-11-25)21cca	39.843449	-109.1287	see above	see above	see above	see above
6	306	King's Well	(D-11-24)33dcc	39.801597	-109.07645	see above	see above	see above	see above
7	304	Evacuation Creek	(D-12-25)2dad	39.801597	-109.07645	see above	see above	see above	see above
8	331	Sweet Water	(D-15-24)10bcd	39.528806	-109.22256	see above	see above	see above	see above
9	325	South Camp	(D-15-24)32ddd	39.4743	- 109 .2475	see above	see above	see above	see above
10	312	PR Spring	(D15-23)36ddd	39.46263889	-109.2838889	see above	see above	see above	see above
11	299	Willow Creek	(D-13-21)22abc	39.6759	-109.5506	see above	see above	see above	see above
12	345	Willow Spring	(D-12-21)19cdd	39.7533	-109.6094	wildlife?	na	na	na
13	300	Sulphur Spring	(D-12-21)19bdd	39.760072	-109.61085	see above	see above	see above	see above
14	298	Willow-Domestic	(D-11-21)31bdc	39.817315	-109.61228	see above	see above	see above	see above
15	333	Bitter Creek-USGS	(D-22-12)1bbb	39.809556	-109.41078	see above	see above	see above	see above
17	297	Big Pack	(D-11-20)10cad	39.871584	-109.66748	see above	see above	see above	see above
18	311	Seep Ridge	(D-10-20)35bbd	39.909306	-109.63939	see above	see above	see above	see above
19	335	Green River	D-5-3)5bac US B&M	40.0841	-109.6781	see above	see above	see above	see above
21	308	Target	(D-8-20)9ada	40.139524	-109.66448	see above	see above	see above	see above
22	309	R&N	(D-8-20)9dcd	40.137731	-109.67514	see above	see above	see above	see above
24	305	Four Star	(D-7-20)28ddd	40.174596	-109.66491	see above	see above	see above	see above

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***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	perforated zone	water level (feet)	Sample Date	Nitrogen NO2 + NO3 (mg/L)	Solids, residue @180oC, dissolved (mg/L)	Field Tempera-ture, (°C)	Field, Specific Conduct-ance (µmhos)	Lab, Specific Conduct-ance (µmhos)	pH, Field	pH, Lab	Field, Dissolv-ed Oxygen	Aluminum, dissolved (µg/L)
1	? BLM	? BLM	7/15/09	<0.1	2394	22.4	2310	2480	9.22	9.21	2.6	17900
4	700-750	350	6/15/09	<0.1	1428	15	2200	2260	9.98	9.87	1.7	<10
5	165-193	flowing	6/16/09	<0.1	796	14.3	1322	1366	9.46	9.35	1.2	<10
6	? BLM	67?	7/15/09	9.53	2114	13.7	2620	2820	7.37	7.37	2.7	<10
7	-	surface	7/14/09	<0.1	2832	29	3410	3640	8.39	8.4	2.3	18.3
10	alluvium anc	flowing	8/27/09	0.42	426	14.2	655	694	7.3	8.63	3.4	<10
11	-	surface	6/17/09	<0.1	562	14.6	861	894	7.8	8.52	3.09	-
13	-	flowing	6/17/09	<0.1	578	19.4	919	946	8.24	8.54	2.2	33.1
14	701	flowing	6/17/09	<0.1	936	17.1	1409	1470	9.18	8.79	0.9	<10
17	4828-74	flowing	6/16/09	<0.1	1298	24.7	2060	2140	8.6	8.78	0.6	10.2
18	2500-2510	flowing	8/10/09	<0.1	3056	28	4530	4760	9.52	9.57	4.25	546
21	alluvium	23	7/16/09	9.95	1442	14	2190	2350	7.77	8.36	3.3	<10
22	alluvium	49 & 23	7/16/09	7.65	1016	18	1416	-	7.9	-	2.69	-
23	alluvium	28	7/16/09	18.8	1908	19	2530	2720	7.66	8.5	-	<10
24	138	70	7/15/09	12.6	1260	14.6	1760	1885	7.66	8.26	2	<10
1	see above	flowing	10/13/09	<0.1	2236	-	-		-		-	-
2	see above	surface	10/13/09	<0.1	400	12	572	-	7.69	8.58	2.88	<10
5	see above	flowing	10/14/09	<0.1	854	12	1256	-	9.37	-	0.56	<10
7	see above	surface	10/14/09	<0.1	2724	11.5	3360	3570	8.31	8.49	4.24	<10
9	78-98	60.9	10/19/09	<0.1	1204	5.75	1431	1512	6.77	8.4	5.5	<10
11	-	surface	10/12/09	<0.1	648	11.7	935	999	7.48	8.47	16.7	83.7
13	see above	surface	10/12/09	<0.1	584	18	915	-	8.49	-	8.6	135
14	see above	flowing	10/12/09	<0.1	956	16.3	1351	-	9.07	-	5.5	<10
17	see above	flowing	10/12/09	<0.1	1308	23	2000	-	8.5	-	2.14	110
18	see above	flowing	10/13/09	<0.1	1462	10	3250	2430	9.3	8.59	6.3	347
20	see above	surface	10/20/09	<0.1	412	9	620	659	7.41	8.67	4.23	17.7
22	see above	see above	10/13/09	7.74	978	11	1405	1508	6.8	8.31	6	<10
24	see above	see above	10/14/09	13.5	1280	14.8	1760	-	6.96	-	4.8	<10
1	see above	see above	-	-	-	-	-	-	-	-	-	-
2	see above	see above	5/18/10	<0.1	300	15	470	509	7.8	7.69	7	24.1
3	see above	see above	6/23/10	<0.1	1012	23	1500	1572	9.1	8.63	1.85	<10
5	see above	see above	5/18/10	<0.1	786	12	1268	1369	9.3	8.69	0.5	<10

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***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	perforated zone	water level (feet)	Sample Date	Nitrogen NO2 + NO3 (mg/L)	Solids, residue @180oC, dissolved (mg/L)	Field Tempera-ture, (°C)	Field, Specific Conduct-ance (µmhos)	Lab, Specific Conduct-ance (µmhos)	pH, Field	pH, Lab	Field, Dissolv-ed Oxygen	Aluminum, dissolved (µg/L)
6	see above	see above	6/8/10	8.19	1988	13.01	2590	2730	7.3	8.13	6.3	<10
7	see above	see above	5/18/10	<0.1	2708	20	2650	3580	8.28	7.85	5.7	<10
8	see above	see above	5/19/10	0.604	994	9.3	1280	1321	7.36	7.29	5.1	<10
9	see above	see above	6/22/10	<0.1	1352	12.9	1540	1604	7.28	7.77	4.18	<10
10	see above	see above	5/19/10	0.561	356	6.08	567	603	7.54	7.3	8.7	<10
11	see above	see above	5/17/10	0.13	506	16	884	823	7.5	7.88	5.3	122
13	see above	see above	5/17/10	<0.1	586	20	1020	976	8.5	8.03	3.2	130
14	see above	see above	5/17/10	<0.1	924	15	1580	1482	9	8.19	1.51	<10
15		see above	6/8/10	<0.1	950	22	1415	1503	9.02	8.88	0.82	<10
16	see above	see above	6/8/10	<0.1	910	na	na	-	na	-	na	-
17	see above	see above	5/17/10	<0.1	1320	25	2300	2140	8.48	8.23	1.7	<10
18	see above	see above	5/19/10	<0.1	1486	22	2320	2440	8.29	7.7	1.1	142
19	see above	see above	6/9/10	<0.1	172	19	257	277	7.38	8	2.7	77.2
21	see above	see above	6/9/10	8.54	1496	17	2340	2460	7.35	8.17	8.5	<10
22	see above	see above	-	-	-	-	-	-	-	-	-	-
23	see above	see above	-	-	-	-	-	-	-	-	-	-
24	see above	see above	6/9/10	12.7	1332	15	1840	1938	7.64	8.18	6.24	<10
1	see above	see above	9/21/10	<0.1	2106	64 f	2030	2210	8.7	8.78	na	7810
2	see above	see above	9/21/10	<0.1	400	70 F	610		8.36		na	-
3	see above	see above	10/13/10	<0.1	958	22	1500	1590	9.4	8.59	1.46	<10
5	see above	see above	9/21/10	<0.1	782	12.4	1300	1358	9.0-9.5	9	0.4	-
6	see above	see above	9/21/10	8.26	1886	12.9	2580	2680	7.26-7.29	7.97	1.59	<10
7	see above	see above	9/21/10	<0.1	2632	19	3450	3560	8.18-8.51	8.11	1.8	<10
8	see above	see above	10/12/10	0.562	996	51f	1310	1409	7.46	7.93	na	<10
9	see above	see above	10/12/10	<0.1	1172	50f	1370	1553	7.49	7.95	na	<10
10	see above	see above	10/12/10	0.301	378	54	630	-	7.57	-	-	-
11	see above	see above	9/22/10	<0.1	592	59.5f	860	945	8.17	8.19	-	-
13	see above	see above	9/22/10	<0.1	572	68f	880	-	8.7	-	-	-
14	see above	see above	9/22/10	<0.1	888	65f	1370	-	8.9	-	-	-
15	see above	see above	10/13/10	<0.1	886	23	1411	-	9.4	-	1.09	-
16	see above	see above	10/13/10	0.622	834	16	1425	1505	8.6	8.4	1.09	-
17	see above	see above	9/22/10	<0.1	1246	75f	2050	-	8.5	-	-	15.7
18	see above	see above	9/22/10	<0.1	1516	-	-	-	-	-	-	-
18a	see above	see above	9/22/10	-	2540	63f	3350	-	8.9	-	-	-
19	see above	see above	10/13/10	<0.1	410	64f	640	-	8.3	-	na	-

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***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	perforated zone	water level (feet)	Sample Date	Nitrogen NO2 + NO3 (mg/L)	Solids, residue @180oC, dissolved (mg/L)	Field Tempera-ture, (°C)	Field, Specific Conduct-ance (µmhos)	Lab, Specific Conduct-ance (µmhos)	pH, Field	pH, Lab	Field, Dissolv-ed Oxygen	Aluminum, dissolved (µg/L)
21	see above	see above	10/13/10	9.4	1446	64f	2040	-	7.6	-	na	-
22	see above	see above	10/14/10	7.63	1058	50f	1540	1690	7.77	8.04	na	-
24	see above	see above	10/13/10	12.7	1232	60f	1800	-	7.5	-	na	-
1	see above	see above	-	-	-	-	-	-	-	-	-	-
2	see above	see above	6/7/11	0.136	220	59.7	300	356	8	8.15	-	-
3	see above	see above	6/7/11	<0.004	966	-	-	1588	-	8.79	-	-
5	see above	see above	6/7/11	<0.004	778	58.5	1240	1373	9.18	9.23	1.04	-
6	see above	see above	6/21/11	9.82	1862	58.5	2440	2710	7.2	7.74	-	-
7	see above	see above	6/7/11	<0.004	2154	75.8	2820	3000	8.24	8.32	-	-
8	see above	see above	6/22/11	0.52	1044	54	1260	1412	7.26	7.7	-	-
9	see above	see above	6/22/11	0.042	1202	58	1460	1588	7.6	7.93	-	-
10	see above	see above	6/22/11	0.503	338	50	530	617	7.7	7.95	-	-
11	see above	see above	6/8/11	0.137	412	64	630	692	8.3	8.39	-	-
12	na	na	6/8/11	<0.004	764	72	1110	1223	7.51	8.17	-	-
13	see above	see above	7/12/11	<0.004	630	71	1170	1038	7.6	8.09	-	-
14	see above	see above	6/8/11	<0.004	892	67	1360	1463	9.1	8.75	-	-
15	see above	see above	6/21/11	<0.004	892	77	1430	1498	8.86	8.67	-	-
17	see above	see above	6/6/11	<0.004	1266	82.6	2060	2130	8.5	8.78	-	-
18	see above	see above	6/8/11	-	1640	-	-	2980	-	7.9	-	-
19	see above	see above	7/12/11	0.033	242	67	320	371	7.99	7.96	-	-
21	see above	see above	7/12/11	13.3	1858	58.7	2580	2890	7.6	7.99	-	-
22	see above	see above	6/8/11	8.3	1110	58	1620	1739	7.78	8.16	-	-
24	see above	see above	8/16/11	13.7	1318	60	1850	2040	7.52	8.36	-	-

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Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Ammonia (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Boron (µg/L)	Bicarbon-ate (mg/L)	Cadmium, dissolved (µg/L)	Calcium, dissolved (mg/L)	Carbon dioxide (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Chromium, dissolved (µg/L)	Carbonate (CO3) Solids (mg/L)
1	0.083	11.1	394	3030	1084	<0.4	25.7	1	136	72.8	9.87	669
4	0.114	<1	<100	255	352	<0.1	<1	0	190	12.2	<2	363
5	0.938	<1	<100	442	620	<0.1	<1	0	138	<10	<2	443
6	<0.05	31.3	<100	5620	996	<0.1	67	11	0	63.4	6.68	490
7	<0.05	1.36	105	236	502	0.102	159	3	8	<10	<2	255
10	<0.05	<1	<100	<30	300	<0.1	76.7	1	16	<10	2.13	163
11	0.055	-	-	-	365	-	-	2	11	<10	-	191
13	0.084	2.09	<100	159	407	<0.1	4.26	2	9	<10	<2	210
14	1.1	<1	<100	321	613	<0.1	<1	2	27	12.4	<2	329
17	1.94	<1	1930	2760	1225	<0.1	1.13	3	54	55.5	<2	656
18	0.28	3.25	2160	2510	2110	<0.1	8.51	1	507	1300	11.5	154
21	0.131	3.5	<100	324	224	<0.1	106	2	2	313	2.72	112
22	-	-	-	-	-	-	-	-	-	-	-	-
23	<0.05	3.88	<100	482	262	<0.1	178	1	8	263	2.52	137
24	<0.05	6.44	<100	576	446	<0.1	72.3	4	0	102	2.34	219
1	-	-	-	-	-	-	-	-	-	-	-	-
2	<0.05	1.03	<100	99.4	192	<0.1	61.5	1	6	<10	<2	100
5	-	<1	<100	414	-	<0.1	<1	-	-	-	<2	-
7	-	1.02	<100	182	458	<0.1	122	2	12	30.9	<2	237
9	<0.05	<1	<100	31.6	349	<0.1	228	2	8	<10	3.1	180
11	0.061	6.6	<100	74	407	<0.1	85.4	2	11	<10	5.7	212
13	-	4.42	<100	135	-	<0.1	6.42	-	-	-	5.17	-
14	-	<1	<100	294	-	<0.1	1.22	-	-	-	<2	-
17	-	<1	1890	3010	-	<0.1	2.16	-	-	-	3.05	-
18	-	1.53	1980	1750	1598	<0.1	6.81	7	35	53.1	6.14	822
20	<0.05	1.12	<100	165	196	<0.1	59.6	1	11	14.3	<2	107
22	<0.05	5.09	<100	399	253	<0.1	87.2	2	0	119	<2	125
24	-	5.01	<100	672	-	<0.1	77.2	-	-	-	<2	-
1	-	-	-	-	-	-	-	-	-	-	-	-
2	<0.05	1.01	101	37.2	176	<0.1	55.6	6	0	<10	<2	87
3	0.532	<1	<100	202	478	<0.1	1.49	2	20	15.3	4.15	256
5	0.694	<1	<100	398	779	<0.1	<1	3	60	11.2	<2	444

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Ammonia (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Boron (µg/L)	Bicarbon-ate (mg/L)	Cadmium, dissolved (µg/L)	Calcium, dissolved (mg/L)	Carbon dioxide (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Chromium, dissolved (µg/L)	Carbonate (CO3) Solids (mg/L)
6	<0.05	30.3	<100	6020	1046	<0.1	67	12	0	57.2	5.96	515
7	<0.05	1.27	<100	145	464	<0.1	120	10	0	32.8	<2	228
8	<0.05	2.05	<100	33.5	322	<0.1	163	26	0	10.7	<2	158
9	<0.05	<1	<100	<30	384	<0.1	238	10	0	<10	4.45	189
10	<0.05	<1	<100	<30	312	<0.1	63.4	25	0	<10	<2	154
11	<0.05	4.06	<100	41.4	352	<0.1	80.9	7	0	<10	<2	173
13	0.232	1.78	<100	133	378	<0.1	4.48	6	0	<10	<2	186
14	1.03	<1	<100	295	618	<0.1	1.12	6	0	11.1	2.54	304
15	0.43	<1	<100	253	546	<0.1	1.16	1	34	<10	3.03	302
16	-	-	-	-	-	-	-	-	-	-	-	-
17	1.12	<1	1920	3170	1314	<0.1	1.54	12	0	56.2	4.55	646
18	0.666	<1	2490	1360	1494	<0.1	5.38	48	0	53.9	<2	735
19	<0.05	1.28	<100	88.5	105	<0.1	28.4	2	0	<10	<2	52
21	<0.05	1.35	<100	315	222	<0.1	113	2	0	348	<2	109
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	<0.05	2.21	<100	653	450	<0.1	87.1	5	0	116	2.58	221
1	-	14	197	2410	999	<0.1	8.32	3	66	77.6	<2	558
2	-	-	-	-	179	-	-	3	0	12.5	-	88
3	-	<1	<100	203	454	<0.1	<1	2	18	23.3	<2	241
5	-	-	-	-	720	-	-	1	88	<10	-	443
6	-	27.2	<100	5790	1014	<0.1	65.4	17	0	54.5	6.58	499
7	-	1.13	<100	151	480	<0.1	112	6	0	32.3	3.22	236
8	-	2.11	<100	41.4	324	<0.1	172	6	0	11.7	<2	159
9	-	<1	<100	<30	360	<0.1	227	6	0	<10	<2	177
10	-	-	-	<30	-	-	36.6	-	-	-	-	-
11	-	-	-	-	402	-	-	4	0	<10	-	198
13	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	123	-	-	<1	-	-	-	-	-
16	-	-	-	240	587	-	2	4	6	<10	-	295
17	-	<1	2070	3180	-	<0.1	1.46	-	-	-	13.2	-
18	-	-	-	-	-	-	-	-	-	-	-	-
18a	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	122	-	-	-	-	-	-	-	-

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

__Appendix D__. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.

Site ID	Ammonia (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Boron (µg/L)	Bicarbon-ate (mg/L)	Cadmium, dissolved (µg/L)	Calcium, dissolved (mg/L)	Carbon dioxide (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Chromium, dissolved (µg/L)	Carbonate (CO3) Solids (mg/L)
21	-	-	-	280	-	-	-	-	-	-	-	-
22	-	-	-	471	264	-	-	4	0	131	-	130
24	-	-	-	315	-	-	43.7	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-
2	<0.05	1.21	-	70.7	148	-	39.5	2	0	<10	-	73
3	-		-		451	-	1.35	1	26	18	-	248
5	0.54	<1	-	404	680	-	<1	1	100	<10	-	435
6	<0.05	27.4	-	5860	994	-	67.5	29	0	54.2	-	489
7	<0.05	1.36	-	135	469	-	101	4	2	25.5	-	232
8	<0.05	2.12	-	42.2	316	-	165	10	0	10.8	-	155
9	<0.05	<1	-	<30	374	-	235	7	0	<10	-	184
10	<0.05	<1	-	<30	344	-	63.1	6	0	<10	-	169
11	<0.05	2.97	-	46.2	306	-	68.8	2	5	<10	-	155
12	-		-		612	-	23	7	0	<10	-	301
13	0.236	5.28	-	130	454	-	8.2	6	0	<10	-	223
14	1.08	<1	-	295	574	-	1.97	2	26	11.3	-	309
15	0.466	<1	-	236	541	-	1.2	2	31	<10	-	297
17	0.968	<1	-	3110	1164	-	1.77	3	59	54.9	-	632
18			-		1620	-	92.2	33	0	87.4	-	797
19	<0.025	1.52	-	39	117	-	35.6	2	0	<10	-	58
21	<0.025	5.23	-	285	216	-	150	4	0	483	-	106
22	<0.05	4.59	-	460	250	-	94.8	3	0	141	-	123
24	-	6.45	-	604	426	-	88.4	3	5	131	-	215

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Copper, dissolved (µg/L)	Hydroxide (mg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Magnesium, dissolved (mg/L)	Manganese, dissolved (µg/L)	Mercury, dissolved (µg/L)	Nickel (ug/L)	Phosphate, total (mg/L)	Potassium, dissolved (mg/L)	Selenium, dissolved (µg/L)
1	38.2	0	6580	15.4	10.9	140	<0.2	<20	1.2	7.14	<4
4	1.89	0	170	0.416	1.05	10.3	<0.2	<5	<0.02	3.43	1.41
5	<1	0	<20	0.708	<1	<5	<0.2	<5	0.087	<1	<1
6	13.6	0	<20	0.931	172	<5	<0.2	6.67	0.114	2.22	50.2
7	9.17	0	27.4	2.07	203	8.21	<0.2	<5	0.047	5.52	2.76
10	5.32	0	<20	0.936	42.8	<5	<0.2	<5	0.053	<1	<1
11	-	0	-	-	-	-	-	-	0.118	-	-
13	2.09	0	70	0.867	1.26	11.7	<0.2	<5	0.126	<1	<1
14	<1	0	67.9	0.166	<1	<5	<0.2	<5	0.042	<1	<1
17	1.55	0	56.4	1.15	<1	<5	<0.2	<5	0.12	1.28	<1
18	61.3	0	467	16.9	1.89	11	<0.2	<5	0.291	3.42	2.05
21	4.14	0	75.3	0.711	45.7	<5	<0.2	<5	0.186	8.81	40
22	-	-	-	-	-	-	-	-	-	-	-
23	3.46	0	<20	0.575	70.1	<5	<0.2	<5	0.048	4.37	38.2
24	5.62	0	23.7	0.77	41.8	<5	<0.2	<5	0.052	3.51	144
1	-	-	-	-	-	-	-	-	-	-	-
2	2.24	0	<20	0.333	21.8	<5	<0.2	<5	0.051	1.25	<1
5	<1	-	28.7	0.358	<1	<5	<0.2	<5	-	<1	<1
7	2.63	0	<20	0.61	155	20.9	<0.2	<5	-	3.82	2.23
9	4.75	0	<20	0.799	77.7	53.7	<0.2	5.24	<0.02	1.45	<1
11	7.01	0	145	0.694	54	83.5	<0.2	<5	0.144	2.05	<1
13	10.3	-	250	1.22	1.98	16.8	<0.2	<5	-	1.36	<1
14	<1	-	133	0.21	<1	<5	<0.2	<5	-	<1	<1
17	1.64	-	385	2.26	<1	<5	<0.2	<5	-	1.55	1.12
18	3.54	0	227	3.12	1.21	5.59	<0.2	<5	-	2.31	2.02
20	2.81	0	<20	0.555	24	<5	<0.2	<5	0.042	1.4	<1
22	2.65	0	<20	0.893	30.2	<5	<0.2	<5	<0.02	2.98	92.7
24	5.07	0	<20	1.1	44.8	<5	<0.2	<5	-	4.04	129
1	-	-	-	-	-	-	-	-	-	-	-
2	2.44	0	22	0.494	18.3	<5	<0.2	<5	0.077	1.39	<1
3	1.89	0	<20	0.279	<1	15.4	<0.2	<5	-	<1	<1
5	<1	0	<20	0.311	<1	<5	<0.2	<5	0.086	<1	<1

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Copper, dissolved (µg/L)	Hydroxide (mg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Magnesium, dissolved (mg/L)	Manganese, dissolved (µg/L)	Mercury, dissolved (µg/L)	Nickel (ug/L)	Phosphate, total (mg/L)	Potassium, dissolved (mg/L)	Selenium, dissolved (µg/L)
6	13.9	0	<20	0.655	172	<5	<0.2	7.05	0.115	2.29	42
7	3.19	0	<20	0.637	148	<5	<0.2	<5	0.056	3.49	3.03
8	1.92	0	<20	0.438	71.7	<5	<0.2	<5	0.074	1.4	1.37
9	13.8	0	<20	0.719	79.7	<5	<0.2	5.52	<0.02	1.39	<1
10	4.64	0	<20	0.773	39.2	<5	<0.2	<5	0.054	<1	<1
11	5.26	0	177	0.301	40.1	20	<0.2	<5	0.601	2.02	<1
13	1.45	0	229	0.407	1.34	17.6	<0.2	<5	0.265	<1	<1
14	<1	0	70.4	0.1	<1	<5	<0.2	<5	0.052	<1	<1
15	1.56	0	<20	0.243	<1	<5	<0.2	<5	0.047	<1	<1
16	-	-	-	-	-	-	-	-	-	-	-
17	<1	0	97.9	0.2	<1	<5	<0.2	<5	0.056	1.34	<1
18	1.68	0	135	0.759	2.15	6.66	<0.2	<5	0.166	1.96	1.01
19	3.39	0	116	0.655	9.06	<5	<0.2	<5	0.219	1.42	<1
21	1.72	0	<20	0.428	47.8	5.23	<0.2	<5	0.051	7.01	43.6
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	3.64	0	<20	0.76	49	<5	<0.2	<5	<0.02	3.78	150
1	16.3	0	11000	16.3	7.6	53.2	<0.2	<25	-	9.44	<5
2	-	0	-	-	-	-	-	-	-	-	-
3	<1	0	<20	0.144	1.54	14	<0.2	<5	-	<1	<1
5	-	0	-	-	-	-	-	-	-	-	-
6	9.97	0	<20	2.92	172	<5	<0.2	6.24	-	2.17	31.5
7	6.44	0	<20	6.01	147	20.7	<0.2	<5	-	3.73	1.94
8	1.98	0	<20	0.349	75.8	<5	<0.2	<5	-	1.37	1.98
9	4.23	0	<20	0.312	77.2	52.8	<0.2	5.48	-	1.39	<1
10	-	-	-	-	22	-	-	-	-	<1	-
11	-	0	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	<1	-	-	-	-	-	-
16	-	0	-	-	<1	-	-	-	-	<1	-
17	<1	-	56	1.91	<1	<5	<0.2	<5	-	1.17	<1
18	-	-	-	-	-	-	-	-	-	-	-
18a	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Copper, dissolved (µg/L)	Hydroxide (mg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Magnesium, dissolved (mg/L)	Manganese, dissolved (µg/L)	Mercury, dissolved (µg/L)	Nickel (ug/L)	Phosphate, total (mg/L)	Potassium, dissolved (mg/L)	Selenium, dissolved (µg/L)
21	-	-	-	-	-	-	-	-	-	-	-
22	-	0	-	-	-	-	-	-	-	-	-
24	-	-	-	-	24.2	-	-	-	-	1.88	-
1	-	-	-	-	-	-	-	-	-	-	-
2	-	0	57.1	-	12.4	-	-	-	0.221	1.7	-
3	-	0		-	<1	-	-	-		<1	-
5	-	0	21.3	-	<1	-	-	-	0.08	<1	-
6	-	0	<20	-	175	-	-	-	0.106	2.56	-
7	-	0	36.5	-	134	-	-	-	0.156	4.06	-
8	-	0		-	71.3	-	-	-	0.051	1.32	-
9	-	0	-	-	75.8	-	-	-	<0.02	1.45	-
10	-	0	<20	-	40.4	-	-	-	0.046	<1	-
11	-	0	260	-	32.9	-	-	-	0.69	1.89	-
12	-	0		-	9.87	-	-	-	-	1.84	-
13	-	0	-	-	3.22	-	-	-	0.437	1.67	-
14	-	0	3980	-	<1	-	-	-	0.048	<1	-
15	-	0	<20	-	<1	-	-	-	0.047	<1	-
17	-	0	42.3	-	<1	-	-	-	0.051	1.35	-
18	-	0		-	23	-	-	-	-	9.36	-
19	-	0	-	-	12.5	-	-	-	0.115	1.89	-
21	-	0	<20	-	62.6	-	-	-	0.056	8.45	-
22	-	0	<20	-	35.3	-	-	-	<0.02	3.33	-
24	-	0	-	-	50	-	-	-	-	3.85	-

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Silver, dissolved (µg/L)	Sodium, dissolved (mg/L)	Sulfate (mg/L)	Total Alkalinity (mg/L)	Total Suspended Solids (mg/L)	Total Organic Carbon mg/L	Total Hardness	Turbidity, (NTU)	TKN (total Kjeldhal Nitrogen)mg/L	Zinc, dissolved (µg/L)	Alpha Gross (pCi/L)	bromoform
1	<2	658	205	1115	76	6.2	109	1099	-	80	-	u
4	<0.5	621	402	605	21.6	4.1	6.8	5.95	-	11.2	-	u
5	<0.5	344	<20	738	<4	2.7	<6.6	0.156	-	<10	-	u
6	<0.5	378	759	817	<4	28.8	874.9	1.18	-	19.6	-	u
7	<0.5	828	1640	425	150	2.2	1231.9	124	-	19.8	-	-
10	<0.5	16.6	97.8	272	<4	0.9	367.5	0.213	-	32.2	2.4	u
11	-	-	162	318	85.6	-	-	73.7	-	-	-	-
13	<0.5	189	136	349	283	3	15.8	91.5	-	12.8	6.83	u
14	<0.5	305	205	548	5.6	1.8	<6.6	1.88	-	<10	-	u
17	<0.5	447	<20	1094	55.6	4.2	6.9	1.66	-	<10	-	-
18	<0.5	1120	39.1	2575	110	31.4	29	66.8	-	33.4	3.94	-
21	<0.5	347	352	187	<4	3.5	452.5	0.874	-	17.1	-	u
22	-	-	-	-	-	-	-	-	-	-	-	-
23	<0.5	345	717	228	<4	6.2	732.5	0.788	-	15.3	-	u
24	<0.5	295	445	366	<4	3.2	352.4	0.19	-	29.9	-	u
1	-	-	-	-	-	-	-	-	-	-	-	-
2	<0.5	34.2	154	167	20.8	2.2	243.1	10.5	-	12.7	-	u
5	<0.5	349	-	-	-	2.5	-	-	-	<10	-	u
7	<0.5	590	1640	395	21	1.5	942.1	5.36	-	17.1	-	u
9	<0.5	44.2	610	300	<4	1.6	888.6	0.551	-	342	-	u
11	<0.5	72.3	209	353	112	5.9	435.3	76.9*	-	15.6	-	u
13	<0.5	231	-	-	-	-	-	-	-	16.2	-	u
14	<0.5	-	-	-	-	2.5	-	-	-	<10	-	u
17	<0.5	529	-	-	-	4.2	9.5	-	-	14.5	-	u
18	<0.5	843	31.4	1369	22	2.7	22	3.71	-	18.8	-	u
20	<0.5	57.6	163	179	30.4	1.5	247.5	20	-	22.4	-	u
22	<0.5	212	357	208	<4	2.4	341.8	0.177	-	49.1	-	u
24	<0.5	292	-	-	-	4.9	376.9	-	-	41.9	-	u
1	-	-	-	-	-	-	-	-	-	-	-	-
2	<0.5	27.9	100	144	98.4	3.2	214	99.5	-	<10	-	u
3	<0.5	377	313	426	<4	1.3	7.8	0.247	-	<10	-	-
5	<0.5	340	<20	740	<4	2.7	<6.6	0.196	-	<10	-	u

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Silver, dissolved (µg/L)	Sodium, dissolved (mg/L)	Sulfate (mg/L)	Total Alkalinity (mg/L)	Total Suspended Solids (mg/L)	Total Organic Carbon mg/L	Total Hardness	Turbidity, (NTU)	TKN (total Kjeldhal Nitrogen)mg/L	Zinc, dissolved (µg/L)	Alpha Gross (pCi/L)	bromoform
6	<0.5	361	45.4	858	<4	30.3	874.9	1.01	-	20.2	-	u
7	<0.5	569	550	380	24	1.9	908.3	14.2	-	<10	-	u
8	<0.5	62.6	484	264	32.4	1.3	701.7	3.48	-	15.8	3.31	u
9	<0.5	49.4	625	315	<4	1.3	921.7	<0.1	-	134	-	1.1
10	<0.5	15.6	62.2	256	<4	1.2	319.5	0.192	-	27.4	-	u
11	<0.5	50.3	155	289	2354	4.1	366.8	910	-	19.3	-	u
13	<0.5	218	144	310	2210	10.4	16.7	316	-	12.6	-	u
14	<0.5	345	202	507	<4	2.5	6.9	0.941	-	<10	-	u
15	<0.5	347	246	503	<4	1.3	7	0.253	-	<10	-	u
16	-	-	-	-	-	-	-	-	-	-	-	-
17	<0.5	527	<20	1077	<4	3.7	8	0.89	-	10.5	-	u
18	<0.5	602	31.4	1225	45.6	290.7	22.3	15.2	-	12.1		u
19	<0.5	15.3	50.2	86	206	5.1	108.1	225	-	<10	-	u
21	<0.5	336	443	182	<4	3.6	478.6	4.08	-	18.3	-	u
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	<0.5	285	496	369	<4	3.8	418.9	0.283	-	35.2	-	-
1	<2.5	527	220	930	180	6.6	52	6.84	-	<50	-	u
2	-	-	214	147	<4	-	-	0.852	-	-	-	u
3	<0.5	377	380	402	<4	-	<6.6	0.481	-	<10	-	u
5	-	-	<20	738	<4	-	-	0.313	-	-	-	u
6	<0.5	378	856	831	<4	-	870.9	0.725	-	<10	35.2	u
7	<0.5	592	2030	394	17.5	-	884.3	6.94	-	44.7	-	u
8	<0.5	65.7	614	266	<4	-	741	0.576	-	13.7	-	-
9	<0.5	46.8	842	295	<4	-	884	0.422	-	388	-	-
10	-	8.88	-	-	-	-	181.8	-	-	-	-	-
11	-	-	229	330	281	-	-	359	-	-	-	u
13	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	u
15	-	184	-	-	-	-	<6.6	-	-	-	-	u
16	-	358	259	492	<4	-	6.6	0.608	-	-	-	-
17	<0.5	561	-	-	-	-	7.8	-	-	<10	7.97	-
18	-	-	-	-	-	-	-	-	-	-	-	-
18a	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	Silver, dissolved (µg/L)	Sodium, dissolved (mg/L)	Sulfate (mg/L)	Total Alkalinity (mg/L)	Total Suspended Solids (mg/L)	Total Organic Carbon mg/L	Total Hardness	Turbidity, (NTU)	TKN (total Kjeldhal Nitrogen)mg/L	Zinc, dissolved (µg/L)	Alpha Gross (pCi/L)	bromoform
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	487	216	<4	3.4	-	1.02	-	-	-	u
24	-	146	-	-	-	-	208.6	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-
2	-	17.1	52.1	121	442	4.1	149.6	215	-	-	-	u
3	-	387	311	413	<4	1.3		1.14	-	-	-	u
5	-	360	<20	725	<4	2.7	<6.6	0.378	-	-	-	u
6	-	387	715	815	<4	28.3	888.5	0.755	1.99	-	-	u
7	-	520	1410	387	660	3.3	803.3	350	-	-	-	-
8	-	62.2	599	259	<4	1	705	0.364	-	-	-	u
9	-	51.7	680	307	<4	0.9	898.2	0.143	0.404	-	-	0.5
10	-	17	66	282	<4	1.2	323.7	0.12	-	-	-	u
11	-	38.6	124	259	2896	3.7	307	1125	-	-	-	u
12	-	266	152	502	56	-	-	19.9	-	-	-	-
13	-	215	164	372	4816	-	-	1805	-	-	-	u
14	-	378	199	515	260	1.7	9	207	-	-	-	u
15	-	358	340	495	<4	1.5	7.1	0.224	-	-	-	u
17	-	579	<20	1053	<4	3.3	8.5	0.76	-	-	-	-
18	-	479	39.1	1328	20140			1619	-	-	-	-
19	-	25.8	85.1	96	304	4.1	140.3	324	-	-	4.97	u
21	-	388	624	177	<4	5	631.8	2.41	-	-	36.1	u
22	-	256	491	205	<4	2.9	381.8	0.367	-	-	-	u
24	-	300	563	358	<4	5.2	426.3	0.184	-	-	-	u

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	chloroform	chloro-methane	bromo-methane	ethyl-benzene	benzene	chloro-benzene	Xylene	Toluene	1,2,4-Trimethylbenzene	napthalene	chloro di-bromomethane	bromo dichloro-methane
1	u	u	u	u	u	u	u	u	u	u	u	u
4	u	u	u	u	u	u	57.3	10	0.5	u	u	u
5	u	u	u	u	u	u	u	u	u	u	u	u
6	u	u	u	u	u	u	u	u	u	u	u	u
7	-	-	-	-	-	-	-	-	-	-	-	-
10	u	u	u	u	u	u	u	u	u	u	u	u
11	-	-	-	-	-	-	-	-	-	-	-	-
13	u	u	u	u	u	u	u	u	u	u	u	u
14	u	u	u	u	u	u	u	u	u	u	u	u
17	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-
21	u	u	u	u	u	u	u	u	u	u	u	u
22	-	-	-	-	-	-	-	-	-	-	-	-
23	u	u	u	u	u	u	u	u	u	u	u	u
24	u	u	u	u	u	u	u	u	u	u	u	u
1	-	-	-	-	-	-	-	-	-	-	-	-
2	u	u	u	u	u	u	u	u	u	u	u	u
5	u	u	u	u	u	u	u	u	u	u	u	u
7	u	0.5	u	u	u	u	u	u	u	u	u	u
9	u	0.5	u	0.5	u	u	u	u	u	u	u	u
11	u	u	u	u	u	u	u	u	u	u	u	u
13	u	u	u	u	u	u	u	u	u	u	u	u
14	u	0.5	u	u	u	u	u	u	u	u	u	u
17	u	u	u	u	u	u	u	u	u	u	u	u
18	u	u	u	0.9	6.6	u	3.8	u	u	u	u	u
20	u	u	u	u	u	u	u	u	u	u	u	u
22	u	18.5	0.8	u	u	u	u	u	u	u	u	u
24	u	u	u	u	u	u	u	u	u	u	u	u
1	-	-	-	-	-	-	-	-	-	-	-	-
2	u	u	u	u	u	1.1	u	u	u	u	u	u
3	-	-	-	-	-	-	-	-	-	-	-	-
5	u	u	u	u	u	u	u	u	u	u	u	u

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

Appendix D. *Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	chloroform	chloro-methane	bromo-methane	ethyl-benzene	benzene	chloro-benzene	Xylene	Toluene	1,2,4-Trimethylbenzene	napthalene	chloro di-bromomethane	bromo dichloro-methane
6	u	u	u	u	u	0.7	u	u	u	u	u	u
7	u	u	u	u	u	u	u	u	u	u	u	u
8	u	u	u	u	u	0.7	u	u	u	u	u	u
9	10	2.2	u	u	u	u	1.1	u	u	u	4	6.6
10	u	u	u	u	u	u	u	u	u	u	u	u
11	u	u	u	u	u	u	u	u	u	u	u	u
13	u	u	u	u	u	u	u	u	u	u	u	u
14	u	u	u	u	u	u	u	u	u	u	u	u
15	u	u	u	u	u	0.9	u	u	u	u	u	u
16	-	-	-	-	-	-	-	-	-	-	-	-
17	u	u	u	u	u	u	u	u	u	0.6	u	u
18	u	u	u	0.7	6.9	0.5	3.5	u	u	u	u	u
19	u	u	u	u	u	0.9	u	u	u	u	u	u
21	u	u	u	u	u	0.6	u	u	u	u	u	u
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-		
1	u	u	u	u	u	u	u	u	u	u	u	u
2	u	u	u	u	u	u	u	u	u	u	u	u
3	u	u	u	u	u	u	u	u	u	u	u	u
5	u	u	u	u	u	u	u	u	u	u	u	u
6	u	u	u	u	u	u	u	u	u	u	u	u
7	u	u	u	u	u	u	u	u	u	u	u	u
8	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-
11	u	u	u	u	u	u	u	u	u	u	u	u
13	-	-	-	-	-	-	-	-	-	-	-	-
14	u	u	u	u	u	u	u	u	u	u	u	u
15	u	u	u	u	u	u	u	u	u	u	u	u
16	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-
18a	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-

all Volatile Organic Compounds are reported as µg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.

***Appendix D**. Water-quality data for selected site for five different sampling intervals in the Uinta Basin.*

Site ID	chloroform	chloro-methane	bromo-methane	ethyl-benzene	benzene	chloro-benzene	Xylene	Toluene	1,2,4-Trimethylbenzene	napthalene	chloro di-bromomethane	bromo dichloro-methane
21	-	-	-	-	-	-	-	-	-	-	-	-
22	u	u	u	u	u	u	u	u	u	u	u	u
24	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-
2	u	u	u	u	u	0.6	u	u	u	u	u	u
3	u	u	u	u	u	0.7	u	u	u	u	u	u
5	u	u	u	u	u	0.5	u	u	u		u	u
6	u	u	u	u	u	0.7	u	u	u	u	u	u
7	-	-	-	-	-	-	-	-	-	-	-	-
8	u	u	u	u	u	u	u	u	u	u	u	u
9	6.5	u	u	u	u	1.1	1.2	u	u	u	2.6	3.4
10	u	u	u	u	u	0.8	u	u	u	u	u	u
11	u	u	u	u	u	0.8	u	u	u	u	u	u
12	-	-	-	-	-	-	-	-	-	-	-	-
13	u	u	u	u	u	0.8	u	0.7	u	u	u	u
14	u	u	u	u	u	0.5	u	u	u	u	u	u
15	u	u	u	u	u	u	u	u	u	u	u	u
17	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-
19	u	u	u	u	u	u	u	u	u	u	u	u
21	u	u	u	u	u	u	u	u	u	u	u	u
22	u	u	u	u	u	J	u	u	u	u	u	u
24	u	u	u	u	u	u	u	u	u	u	u	u

all Volatile Organic Compounds are reported as μg/L; highlighted values indicate concentration exceeds the U.S. EPA maximun contaminant level.