Oil & Natural Gas Technology

Water-related Issues Affecting Conventional Oil and Gas Recovery and Potential Oil-Shale Development in the Uinta Basin, Utah

Final Scientific/Technical Report

Project period: October 2008 - April 2012

Principal Investigator: Michael D. Vanden Berg
Other principal authors: Paul Anderson, Janae Wallace, Craig Morgan, Stephanie Carney

July 2012

DOE Award No.: DE-NT0005671

Submitted by:
Utah Geological Survey
P.O. Box 146100
Salt Lake City, UT 84114-6100

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

Office of Fossil Energy

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ABSTRACT

Saline water disposal is one of the most pressing issues with regard to increasing petroleum and natural gas production in the Uinta Basin of northeastern Utah. Conventional oil fields in the basin provide 69 percent of Utah's total crude oil production and 71 percent of Utah's total natural gas, the latter of which has increased 208% in the past 10 years. Along with hydrocarbons, wells in the Uinta Basin produce significant quantities of saline water – nearly 4 million barrels of saline water per month in Uintah County and nearly 2 million barrels per month in Duchesne County. As hydrocarbon production increases, so does saline water production, creating an increased need for economic and environmentally responsible disposal plans. Current water disposal wells are near capacity, and permitting for new wells is being delayed because of a lack of technical data regarding potential disposal aquifers and questions concerning contamination of freshwater sources. Many companies are reluctantly resorting to evaporation ponds as a short-term solution, but these ponds have limited capacity, are prone to leakage, and pose potential risks to birds and other wildlife. Many Uinta Basin operators claim that oil and natural gas production cannot reach its full potential until a suitable, long-term saline water disposal solution is determined.

The enclosed project was divided into three parts: 1) re-mapping the base of the moderately saline aquifer in the Uinta Basin, 2) creating a detailed geologic characterization of the Birds Nest aquifer, a potential reservoir for large-scale saline water disposal, and 3) collecting and analyzing water samples from the eastern Uinta Basin to establish baseline water quality.

Part 1: Regulators currently stipulate that produced saline water must be disposed of into aquifers that already contain moderately saline water (water that averages at least 10,000 mg/L total dissolved solids). The UGS has re-mapped the moderately saline water boundary in the subsurface of the Uinta Basin using a combination of water chemistry data collected from various sources and by analyzing geophysical well logs. By re-mapping the base of the moderately saline aquifer using more robust data and more sophisticated computer-based mapping techniques, regulators now have the information needed to more expeditiously grant water disposal permits while still protecting freshwater resources.

Part 2: Eastern Uinta Basin gas producers have identified the Birds Nest aquifer, located in the Parachute Creek Member of the Green River Formation, as the most promising reservoir suitable for large-volume saline water disposal. This aquifer formed from the dissolution of saline minerals that left behind large open cavities and fractured rock. This new and complete understanding the aquifer's areal extent, thickness, water chemistry, and relationship to Utah's vast oil shale resource will help operators and regulators determine safe saline water disposal practices, directly impacting the success of increased hydrocarbon production in the region, while protecting potential future oil shale production.

Part 3: In order to establish a baseline of water quality on lands identified by the U.S. Bureau of Land Management as having oil shale development potential in the southeastern Uinta Basin, the UGS collected biannual water samples over a three-year period from near-surface aquifers and surface sites. 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.

This multifaceted study will provide a better understanding of the aquifers in Utah's Uinta Basin, giving regulators the tools needed to protect precious freshwater resources while still allowing for increased hydrocarbon production.

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EXECUTIVE SUMMARY

The enclosed Uinta Basin water project was divided into three parts: 1) re-mapping the base of the moderately saline aquifer in the Uinta Basin, 2) creating a detailed geologic characterization of the Birds Nest aquifer, a potential reservoir for large-scale saline water disposal, and 3) collecting and analyzing water samples from the eastern Uinta Basin to establish baseline water quality.

Part 1 (Appendix I):

The base of the moderately saline water (BMSW) in Utah's Uinta Basin was first mapped in 1987 and re-mapped in this study using similar methods. Oil and gas operators in the Uinta Basin seeking underground disposal are generally required to inject waste production water below the BMSW or in waters greater than 10,000 mg/L total dissolved solids (TDS). Approximately 8000 new wells have been drilled in the basin since the 1987 study, providing significantly more data for refining the previous mapping. Water samples from primarily oil and gas activities through the basin's history were compiled into a database (2788 records) and used as an aid in mapping. In addition, interpreted oil and gas geophysical logs, in particular resistivity measurements (R_w), serve as an approximate proxy for the TDS of formation water. From the pool of new drilling, geophysical logs from 260 wells distributed throughout the basin were interpreted and used in mapping the BMSW. The Archie method, SP, and other resistivity methods were used in the interpretation of logs. Regional groundwater flow paths, saline minerals, structural shape of the basin, and faults and fractures strongly influence the distribution of TDS levels. Both older and new data points were used to create an elevation contour map of the position of the shallowest occurrence of the BMSW below the surface. Depth-correlated water analysis data were mapped and compared to the log-derived BMSW. Mapped water analysis data indicate the northern portion of the basin has numerous occurrences of water fresher than 10,000 mg/L below the BMSW, indicating a complex stratification of salinity coincident with the area of primary recharge, whereas shallow saline waters dominate the central portion of the basin. Data also demonstrate a poor correlation between TDS and the depth of the sample. Water samples from a few isolated areas show clear evidence of a change in TDS through time.

Part 2 (Appendix II):

As petroleum production increases in the Uinta Basin operators are pressed to establish suitable saline water disposal plans. Several natural gas operators have identified the Birds Nest aquifer in central Uintah County as a possible large-scale, saline water disposal zone; however, disposal into this aquifer poses unique challenges and risks.

The Birds Nest aquifer formed from the dissolution of saline minerals within a saline zone in the upper Green River Formation's Parachute Creek Member. Through the examination of core, outcrop, and geophysical logs, it was determined that the aquifer is separated into an upper zone, covering about 410 square miles with an average thickness of 79 feet, and a more extensive lower zone, covering about 719 square miles with an average thickness of 84 feet. Several maps were generated showing the aquifer's areal extent, thickness, outcrop extent, and depth.

Using water chemistry data collected from various sources, a 10,000 mg/L TDS boundary line was determined for the Birds Nest aquifer. Basically, water in the southeast portion of the aquifer averages >10,000 mg/L TDS, down to a low of 1000 mg/L TDS, whereas water in the northwest portion averages >10,000 mg/L TDS and locally exceeds 100,000 mg/L TDS. Since disposal can only take place north of the 10,000 mg/L TDS boundary line, the available areas suitable for saline water disposal within the upper and lower Birds Nest aquifer are reduced to 360 and 499 square miles, respectively.

Gilsonite, a solid hydrocarbon, occurs in veins ranging in thickness from a couple inches to tens of feet and originates from the rich oil shale beds of the upper Green River Formation, continuing up to the surface, cross-cutting the Birds Nest aquifer. Questions remain as to how these veins might affect groundwater movement through the Birds Nest aquifer – whether they act as barriers to flow or whether they create vertical and/or horizontal pathways for water transmission. The assessment provided herein

includes anecdotal evidence for both cases, barrier and conduit, depending on the type of gilsonite in the vein, vein thickness, and abundance of associated fractures. Unfortunately, very little is known about the gilsonite veins and fractures at depth in the areas suitable for saline water disposal.

The fact that the Birds Nest aquifer lies within the Uinta Basin's oil shale horizon raises questions as to how large-scale, saline water disposal into this zone might impact potential future oil shale development. Currently, all companies in Utah looking to develop an oil shale property are focused on areas near the outcrop of the Mahogany zone with plans to develop a surface/underground mine and surface retort, or employ surface modified *in-situ* technologies. Since disposal can only take place north of the 10,000 mg/L TDS boundary, active disposal will be several tens of miles northwest and down-dip of any proposed oil shale development site. Oil shale technology could potentially advance to the point where the deeper deposits, located adjacent to active Birds Nest disposal operations, might become economic. If advances in *in-situ* technologies (retorting the oil shale within the ground) allow exploitation of these deeper deposits, the oil recovery zone will be limited to the lower R-8 rich oil shale zone and below, leaving 70-90 feet of impermeable oil shale between the retort zone and the lower Birds Nest aquifer, purposely avoiding the aquifer and problems associated with retorting shale within a zone filled with water and saline minerals. Therefore, the lean oil shale within the Birds Nest has little to no economic value. In addition, if technologies advance to the point where deep underground mines prove economic (oil prices would also need to be favorably high), the mined interval would most likely be centered on the Mahogany zone, roughly 1500-3000 feet deep in the area where saline water disposal can take place, with about 300 feet of impermeable oil shale between the mining horizon and the aquifer. The most pressing question is whether water in the Birds Nest aquifer can migrate vertically through thick sequences of impermeable oil shale by way of fractures or gilsonite veins, potentially flooding operations stratigraphically below the Birds Nest zone. Any kind of water infiltration into the mining horizon could greatly affect the economics of these deeper deposits. The likelihood of such a scenario is remote but plausible, and will only increase as saline water disposal becomes more widespread.

Part 3 (Appendix III):

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. 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. BLM and having oil shale development potential.

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 TDS), nutrients (including nitrate, phosphorous, and ammonia), dissolved metals (including arsenic, lead, iron, and boron), and volatile organic compounds (VOCs). TDS 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. TDS 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. EPA'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 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

This project was completed as three independent, but related, research projects, identified as Task 2, Task 3, and Task 4 in the original research proposal. Each task's final report is included as an attached appendix (Task 2 – Appendix I, Task 3 – Appendix II, and Task 4 – Appendix III). Research for Task 5 was completed by Dr. Milind Deo, professor in the Department of Chemical Engineering at the University of Utah, and will be published independently of this final report. A summary of all technology transfer activities (Task 6) undertaken during the project is included as Appendix IV.

In addition to the release of this final report, each of the three projects will be available as UGS publications (in the fall of 2012):

Task 2 – UGS Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah
Task 3 – UGS Special Study 145
Geological Characterization of the Birds Nest Aquifer, Uinta Basin, Utah: Assessment of the Aquifer's Potential as a Saline Water Disposal Zone
Task 4 – UGS Open-File Report 595
Baseline Water Quality for Selected Sites in the Southeastern Uinta Basin, Utah

All three reports will be published on CD and include all large-scale maps and cross sections (pdf format), MS Excel™ databases, and GIS files.

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

One West Third Street, Suite 1400
Tulsa, OK 74103-3519

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
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Appendix I: Task 2 Final Report

Moderately Saline Groundwater in the Uinta Basin, Utah

by:

Paul B. Anderson[1], Michael D. Vanden Berg[2], Stephanie M. Carney[2], and Craig D. Morgan[2], and Sonja Heuscher[2]

[1]Consulting Geologist, Salt Lake City, Utah
[2]Utah Geological Survey

July 2012

(Will be published as UGS Special Study 144 in fall 2012)

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ABSTRACT

The base of the moderately saline water (BMSW) in the Uinta Basin was first mapped in 1987 and re-mapped in this study using similar methods. Oil and gas operators in the Uinta Basin seeking underground disposal are generally required to inject waste production water below the BMSW or in waters greater than 10,000 mg/L total dissolved solids (TDS). Approximately 8000 new wells have been drilled in the basin since the 1987 study, providing significantly more data for refining the previous mapping. Water samples from primarily oil and gas activities through the basin's history were compiled into a database (2788 records) and used as an aid in mapping. In addition, interpreted oil and gas geophysical logs, in particular resistivity measurements (R_w), serve as an approximate proxy for the TDS of formation water. From the pool of new drilling, geophysical logs from 260 wells distributed throughout the basin were interpreted and used in mapping the BMSW. The Archie method, SP, and other resistivity methods were used in the interpretation of logs. Regional groundwater flow paths, saline minerals, structural shape of the basin, and faults and fractures strongly influence the distribution of TDS levels. Both older and new data points were used to create an elevation contour map of the position of the shallowest occurrence of the BMSW below the surface. Depth-correlated water analysis data were mapped and compared to the log-derived BMSW. Mapped water analysis data indicate the northern portion of the basin has numerous occurrences of water fresher than 10,000 mg/L below the BMSW, indicating a complex stratification of salinity coincident with the area of primary recharge, whereas shallow saline waters dominate the central portion of the basin. Data also demonstrate a poor correlation between TDS and the depth of the sample. Water samples from a few isolated areas show clear evidence of a change in TDS through time.

INTRODUCTION

Oil and gas production in the Uinta Basin produces waste water that requires proper disposal. Annual crude oil production in Uintah and Duchesne Counties (representing the majority of the basin's production) has increased 132% in the past 10 years to 17.5 million barrels, while natural gas has increased a remarkable 227% to 317 billion cubic feet (Utah Division of Oil, Gas, and Mining, 2011). Associated produced water increased 46% over the same period and totaled 75.8 million barrels in 2010. This equates to 7328 acre-feet of waste water or over 60% of the capacity of Pelican Lake, Uintah County. Water disposed through underground injection wells in the entire Uinta Basin for 2010 was 35.6 million barrels (Brad Hill, Utah Division of Oil, Gas, and Mining, personal communication, 2011). The upper 100 feet of water-saturated material in the Uinta Basin stores 31 million acre-feet of water (USWP, 1999). By way of comparison, the volume of disposed water for 2010 is 0.011% of this volume. Today's average cost of private disposal of oil and gas waste water is about $1.50/barrel, meaning last year's disposal of waste water in Uintah and Duchesne Counties cost the industry about $114 million. Without permitted water disposal options for operators, most production in the basin would cease.

Groundwater has been classified by the U.S. Environmental Protection Agency (EPA) as fresh if the TDS concentration is less than 1000 mg/L; slightly saline with TDS values from 1000 to 3000 mg/L; moderately saline between 3000 mg/L and 10,000 mg/L; and very saline to briny when greater than 10,000 mg/L TDS. Groundwater in this report is informally classified as "non-saline" when it has a TDS concentration less than 10,000 mg/L, while saline groundwater has a TDS greater than 10,000 mg/L.

Purpose and Scope

In the early 1980s, the Utah Division of Oil, Gas, and Mining (DOGM), faced with the task of implementing new EPA regulations for underground injection, engaged the U.S. Geological Survey to jointly study and publish a map of the base of moderately saline water in the Uinta Basin. This map (Howells and others, 1987, also referred to as Technical Publication 92 or TP-92) has guided state and

federal regulatory agencies in evaluating new applications for underground disposal of oil and gas production waste water. Oil and gas operators use the map for siting new disposal wells. Since its publication, drilling in the Uinta Basin has continued, adding about 8000 new wells. These newer wells bring with them better geophysical logging techniques providing many potential additional data points to improve on the original mapping effort. With new drilling/production comes increased need for water disposal wells. The objective of this project is to examine the geophysical logs from new drilling and pick the base of the moderately saline water in a subset of these new wells. These new data points were added to the previous study's data and used in creating a new updated series of contour maps of the base of the moderately saline aquifer (BMSW). Companion cross sections were added to this study to better illustrate the third dimension and the BMSW relationship to the stratigraphy and structure of the basin. Figure 1 shows the area of study.

Through the life of the Uinta Basin's exploration and development history, water quality data have been collected by operators, governmental agencies, and academia. This study represents the first attempt to compile basin-wide water quality data and use the database in mapping subsurface groundwater TDS. Available water quality data were used in the previous mapping efforts, but not formally compiled and published.

Water-bearing rocks or sediments with the EPA water quality attributes, discussed above, are often labeled aquifers, for example the "moderately saline aquifer." Howells and others (1987) carefully avoided attaching the term "aquifer" to their map. By definition (Bates and Jackson, 1987), an aquifer must "...yield economically significant quantities of water to wells..." Without testing, it is difficult to know what the yield would be from permeable beds encountered in the basin. Add to this the evaluation of current economics, determining what is an aquifer and what is not becomes a difficult task and beyond the scope of this project. However, state and federal regulations require saline waste waters be re-injected into saline "aquifers." State regulations allow for disposal of production waste water in other "non-saline" zones, but only with a special "aquifer exemption." BMSW (base of the moderately saline water) is the abbreviation used throughout the report and is specifically defined on subsequent pages. Mapping the BMSW will help all stakeholders in the basin achieve the goals of continued economic development of hydrocarbon resources while protecting future potential use of the basin's groundwater resources.

Previous Studies

In 1987, the U.S. Geological Survey and Utah Department of Natural Resources jointly published *Base of moderately saline ground water in the Uinta Basin, Utah* (Howells and others, 1987). The publication provides a complete explanation of the various geophysical log interpretation techniques used to estimate groundwater TDS, along with a description of the geology of the Uinta Basin. Key recent papers related to Uinta Basin deep bedrock water quality include Gwynn (1992, 1995) and Zhang and others (2009). Steiger (2007) investigated water quality impacts related to underground injection in the Altamont-Bluebell field.

METHODS

Mapping groundwater TDS utilized two principle methods which produce results with a large range of accuracy. The primary method used geophysical log interpretation techniques. The second method used direct measurement of TDS from water samples taken primarily in oil and gas wells. Mixing of groundwater or connate water with anthropogenic sources from drilling and completing wells renders some of these samples questionable to unusable, but many samples were obtained from a production stream and are considered representative of in-situ conditions. Water quality data were not directly used to map the BMSW, but consulted during each log interpretation, when available. Additional details about the contouring methods for both the water quality and log-based estimates of the BMSW are discussed in the Results section.

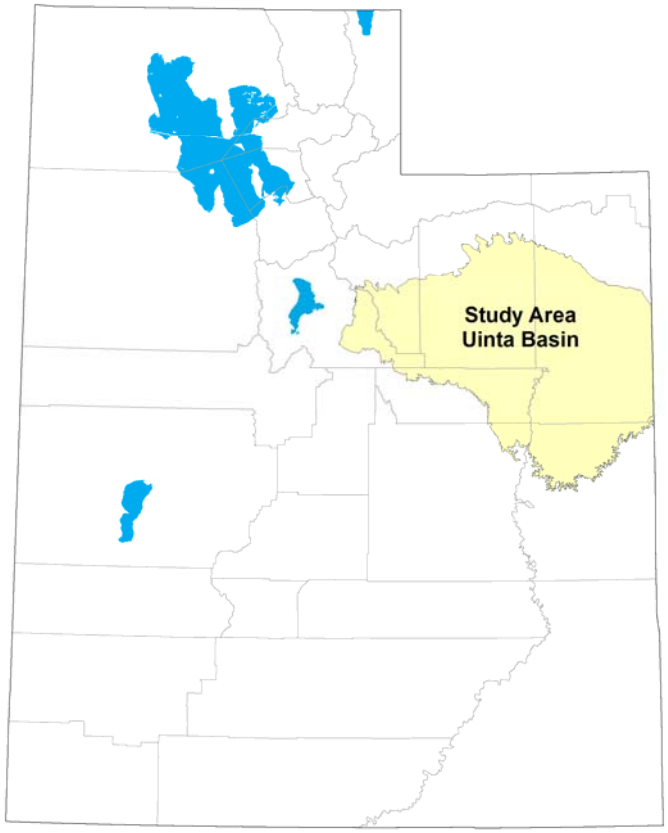

Figure 1. *Location of study area.*

Groundwater Samples

Groundwater samples from deep in the basin are an important contributor to a better understanding of the position of the "non-saline" water within the Uinta Basin. Representative samples of water from a particular horizon in a well create a firm point of reference for mapping and a calibration point for log interpretation methods. The addition of a groundwater database for use during log interpretation and final mapping of the BMSW improves the accuracy of the results. Figure 2 shows the locations of the 2788 water samples from 1520 different wells compiled for this study and the database can be found in appendix A.

Groundwater samples were compiled from a variety of sources. Sampling protocol is rarely available from these sources and likely ranges from poor to excellent. The user of these data should be aware of this important limitation. In addition, the thickness of the sampled interval is often several hundred to over 1000 feet, limiting the sample's usefulness.

Data Sources

The groundwater data source is identified in the database, with data gathered from prior publications, U.S. Geological Survey, contributions from operators in the basin, service companies, and a search of well files housed at DOGM. Many of the groundwater samples found in DOGM's files originate from permitted (present and past) disposal or injection wells. DOGM rules require operators to provide an analysis of injected water, which leads to analysis from surrounding producing oil and gas wells waste water stream, but filed under the disposal well's API number. This adds a great deal of information to the database, but makes it difficult to trace the source of the analysis back to an individual DOGM well file.

Table 1 provides a break-down of the sources of data for the water database. Due to this wide variety of sources, many of the fields of the database are incomplete and some fields are estimated. The "comment" field in the database describes various assumptions.

Quality Control

The database contains many water analyses found in Gwynn (1995) that were collected from drill stem tests (DST). Contamination of these samples from drilling fluids or water cushions often occurs. Where possible, the recovery of each reported DST-sourced analysis was reviewed. If mud or water cushion was noted in the recovered fluids, the sample was rejected and not used in the mapping effort. When no information was available about the type of water sample, the date of the sample was used to check the well history files (DOGM website) in an attempt to understand the likely source. These endeavors were not always successful in producing a clear picture of the sample's validity and a qualitative judgment was required to accept or reject the sample.

Operator and DOGM file-sourced data presented other challenges. Often the depth interval of a sample was omitted. Other times, the sample date was not listed but an analysis date was available. In some cases, a complete anion-cation analysis was reported, but no TDS value was included. In these situations, the TDS was calculated and noted in the "comment" field of the database.

When a water sample was from an initial production test (IP), additional judgment was required. The amount of fluids recovered was reviewed and pre-testing stimulation considered as a source of formation water contamination. Water of condensation in very low water producing wells can dominate or contaminate water samples. Well 4304736731, SRU#8 in section 23, T. 13 S., R. 22 E., Salt Lake Base Line and Meridian (SLBLM), is an example. The well has a total depth (TD) of 10,134 feet and a production water sample from the separator recorded a TDS of 1799 mg/L. Production for the month was dominantly gas with 43 barrels of water. The following month only two barrels of water were produced. The well is perforated in the Dakota-Cedar Mountain Formations. The TDS value seemed anomalously low for this formation and depth, but few wells are sampled from this interval in the area. The logs on the well were examined and indicated saline water. The operator was contacted (Carl Kendall, Summit Resources, personal communication, 2010) and confirmed produced water from the well was typically

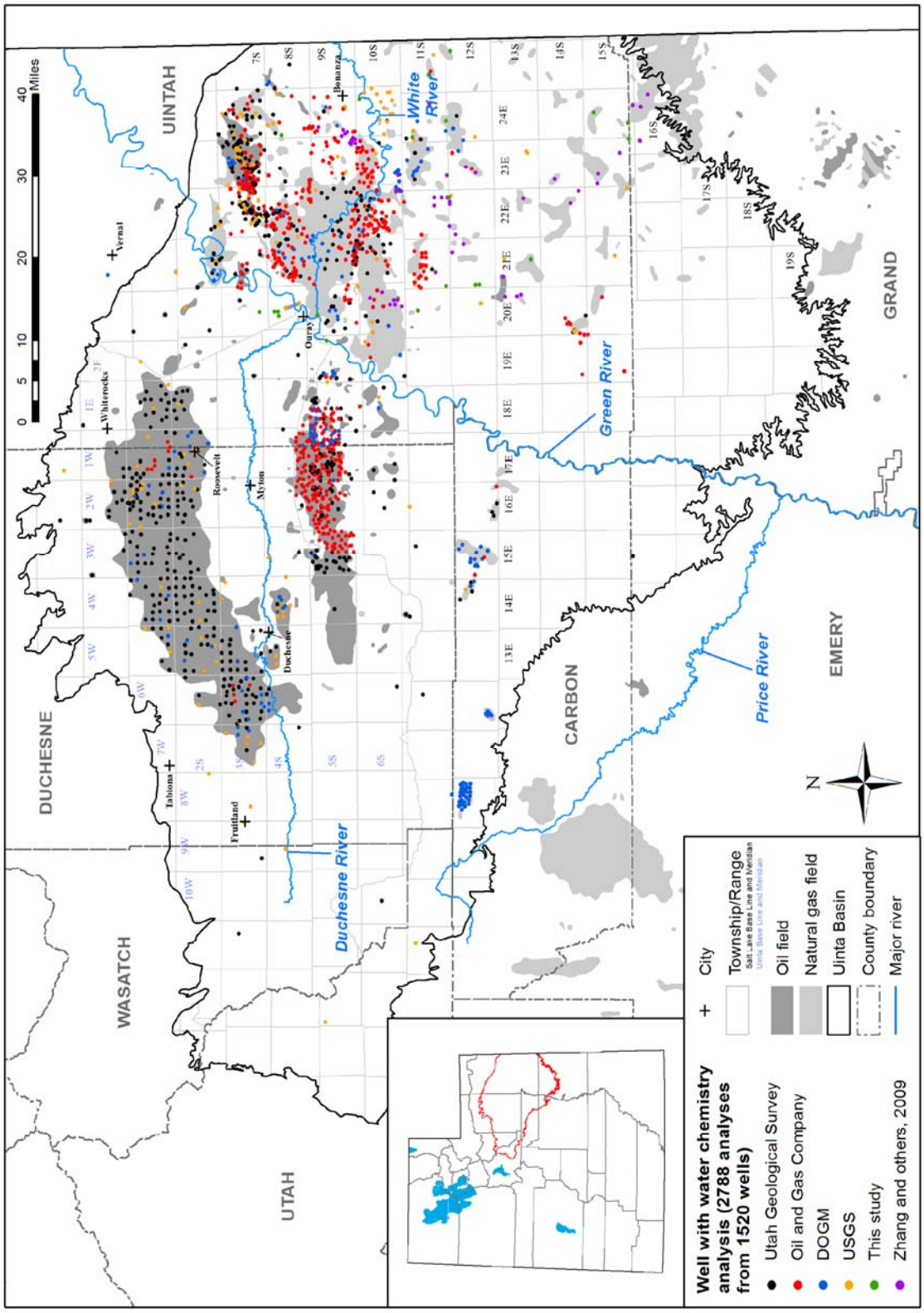

Figure 2. *Locations of water analyses compiled and found in appendix A.*

Source	Number of analyses
Utah Geological Survey (published)	1187
Oil and Gas company	833
Questar	*367*
Newfield	*194*
Anadarko	*185*
EOG	*22*
Bill Barrett	*20*
Halliburton	*16*
El Paso	*13*
XTO	*10*
Enduring Resources	*5*
Wind River Resources	*1*
DOGM well files	440
U.S. Geological Survey (published)	102
U.S. Geological Survey (unpublished)	87
This study	82
Zhang and others (2009)	57
Total	2788

Table 1. *Sources of water analyses in the project database.*

"salty" but did not have a representative analysis. Mr. Kendall indicated that similarly low TDS waters have been found in other oil and gas wells with low water production and is believed to be mainly water of condensation formed during production.

Potassium was used as an indicator of contamination from drilling and completion activities. Potassium-chloride water is commonly introduced by various downhole operations. Producing a well should "clean up" any introduced fluids from drilling and completion activities. Water analyses from production-type samples were queried from the database and should indicate the natural range of potassium found in the formation water. The query yielded 904 samples in the database sourced from "production" and sampled for potassium. Of these, 69 had a potassium concentration greater than 250 mg/L, with 47 sampled within one year of the completion date of the well. These data indicate that after one year of production about 97% of the produced water had a potassium concentration of less than 250 mg/L. Potassium concentration greater than 250 mg/L is a reasonably accurate indication of drilling and completion contamination of native reservoir fluids.

An example of mixed saline and "non-saline" waters within a 1500-foot zone in the Monument Butte field (southeastern Duchesne County) can be demonstrated using the Castle Peak 43-5 well (4301330858, section 5, T. 9 S., R. 16 E., SLBLM). The well was originally perforated from 4350 to 5756 feet in three zones and produced for three months with a cumulative water production of about 1600 barrels and then sampled with a TDS of 9260 mg/L. The well continued to produce. In April 1985, two new zones were added (net four additional feet) to the original gross interval, hydraulically fractured, and immediately sampled, resulting in a TDS of 28,877 mg/L and potassium ion concentration of 2600 mg/L. Two years later and after about an additional 200 barrels of produced water, the TDS was 19,931 mg/L. Assuming the first and last samples are representative of formation water, just four feet of new perforations in the middle of the original zone moved the entire section from above the BMSW to below it.

Since the water quality checks are a combination of quantitative and qualitative methods, some contaminated samples have been inappropriately included or rejected as the list of analyses was developed for water quality mapping. Where possible, the well files were checked to attempt to understand the context of operations at or around the time of the sample date.

Database

The water database for the project is found in appendix A. Table 2 provides a list of the fields in the database and a short explanation of the type of data in each field. Note the dual key fields in the table which use both the API number and TDS of the sample. This method allowed for multiple analyses per well. In just a couple of cases, the TDS was altered by 1 mg/L to avoid a key violation. Where this occurred it is noted in the comment field. The field "Used in Mapping BMSW" contains an entry of "yes" or "no," answering the question of whether the sample should be used in mapping the BMSW. Of all the records in the database, 68% received a "yes" for use in the mapping. Rationale for a "yes" or "no" is based on the following: 1) Data are assumed valid without cause to doubt it. 2) If the potassium (K) is high, and an equal milli-equivalent amount of chloride could move the water's TDS over or under the 10,000 mg/L line when added or subtracted, then a sample gets a "no." 3) The anion-cation balance should be within about plus or minus 2% of 1.0 for dilute concentrations <1000 mg/L TDS (Hem, 1985), but for higher concentrations, like most in this study, tolerances are greater. A few of the laboratories did not analyze for TDS but noted the value was calculated from the sum of the anions and cations. In these few cases, the anion-cation balance must be considered in reaching a "yes" or "no" for the field. If the imbalance is sufficient to move the analysis over or under the 10,000 mg/L boundary (this is considered along with the high potassium values) then the sample received a "no." 4) Other reasons relating to inconsistencies in historic data or type of fluid recovered on DSTs could result in a "no." As mentioned above, most analyses of TDS use an evaporation method and the TDS concentration is not calculated from the anion-cation analysis. Most of the most recent samples for TDS fall into the analyzed group, and an anion-cation imbalance may be related to omission of reporting a major ion, whereas the TDS value is reliable within normal ranges.

Field name	Description
Number	Arbitrary identification number
API	(KEY FIELD) API number of well from which sample taken - no number indicates non-oil & gas type well
Sample Date	Date sample taken, sometimes is the analysis date. When format 1-Jan-year, only the year is know.
Well Name	Well name assigned by operator
Field Name	Oil and gas field name, blank if undesignated
County	
UTM E	Easting coordinate of well location, UTM using the NAD 83 projection
UTM N	Northing coordinate of well location, UTM using the NAD 83 projection
Elevation	Elevation in feet of the reference point in the field, Elevation Datum
Elevation Datum	GR = ground; DF = derrick floor; KB = Kelly bushing
Township	
Range	
Section	
Meridian	S = Salt Lake Base and Meridian; U = Uinta Base and Meridian
Data Source	Source of the entry, generally a publication, agency, or operator name
Sample Depth Top	Depth in feet to the top of the sampled interval
Sample Depth Base	Depth in feet to the bottom of the sampled interval
Formation	Formation of depth interval
Sampled by	Who took the sample, usually a company or agency
Type of Sample	Method, means, or location where sample taken
Analysis Method	Lab or field
Lab Name	Name of lab where analysis was performed
Raw R_w	Resistivity of the water in ohms-meters
Temp Raw R_w	Temperature of the water when Raw R_w was measured
TDS	(KEY FIELD) Total dissolved solids in mg/L - either measured or calculated
pH	pH of the sampled solution
Specific Gravity	Specific gravity of water sample
Ca	Calicum ionic concentration measured in mg/L
Na	Sodium ionic concentration measured in mg/L
K	Potassium ionic concentration measured in mg/L
Mg	Magnesium ionic concentration measured in mg/L
CO_3	Carbonate ionic concentration measured in mg/L
Cl	Chloride ionic concentration measured in mg/L
SO_4	Sulfate ionic concentration measured in mg/L
Bicarbonate	Bicarbonate ionic concentration measured in mg/L
Anion-Cation ratio	Anion-cation balance in percent difference
Used in Mapping BMSW	Yes or no - Quality of water analysis, was it used in BMSW mapping
Comments	

Table 2. *Water analysis database fields and explanation.*

Appendix A was constantly referenced during the log analysis part of the project. These data often aided in making better interpretations, but, unfortunately, only rarely did the sample interval fall within the same portion of the hole where the BMSW was believed to occur. This is because most of the water samples are associated with deeper producing intervals and the BMSW does not commonly fall within this depth interval in most of the Uinta Basin.

Total Dissolved Solids Estimated Using Borehole Geophysics

Most oil and gas wells run a suite of open-hole geophysical logs upon reaching total drilling depth. This has been the practice in the Uinta Basin with very few exceptions, and generally these unlogged holes were drilled in the earliest years of the basin's development history. This study, like its predecessor, used interpretation of the suite of geophysical logs run in selected wells as the primary means of mapping the BMSW. Several methods have been developed over the past 100 years of downhole geophysics, which provide an estimate of the TDS (salinity) of waters encountered in permeable strata and are discussed below.

Procedural Methods

Logs and software: Unfortunately, no project files from the original BMSW mapping effort from Howells and others (1987) could be located. DOGM did have some information in Mr. Gil Hunt's personal files relating chiefly to log interpretation methods. Howells and others (1987) elevation contour map of the BMSW is on two plates at a scale of 1:250,000 with all the data points plotted on these maps. The points represent Howells and others' estimated base of the moderately saline water picked using geophysical logs run in oil and gas wells. Using ArcGIS georeferencing techniques on a scanned version of Howells and others' original map, and plotting it along with well locations in DOGM's oil and gas well database, provides the means of linking each data point to an oil and gas well log or API number. Where the well spacing density near a data point was low, these picks are made with confidence. Where the well spacing density was high, possible error in tying the older data to a specific well may have occurred. Table 3 lists Howells and others' (1987) points with ambiguous or problematic well locations and appendix B lists all of the best ties of Howells' mapped points to specific wells, identified by API number.

LAS geophysical logs are digital, depth to logging parameter-type files that have been generated by service company logging equipment beginning in the late 1980s or have been digitized from older image log prints. All interpretation of geophysical logs for this study is LAS-based, enabling use of log interpretation software or direct calculation and presentation of derived curves on a digital suite of logs. Oil and gas operators generously donated hundreds of LAS logs for use in this project, while the Utah Geological Survey scanned or purchased the remaining needed LAS files.

Howells and others' (1987) evaluation did not include wells drilled after about 1985. For this study, all wells drilled after 1985 were plotted on a base map, along with Howells and others' data points and the elevation contours from their BMSW map. New wells were selected for evaluation based on locations that would "fill in" holes in Howells and others' (1987) data or help to better evaluate areas with steep BMSW elevation contours. Candidate wells with available LAS logs were selected. Many of these wells had to be subsequently rejected because the top of the logged depth was below the suspected (or previously mapped) BMSW boundary. This is a common problem in much of the Greater Natural Buttes area where operators regularly set the first string of casing between 3000 and 4000 feet in depth and rarely run open-hole logs before the casing is set. Well log suites needed to include a combination of both resistivity and porosity to be considered for picking the BMSW.

Wells meeting the criteria for selection for log analysis were then loaded into an LAS-capable viewer and saved. The software allowed for mathematical manipulations and display of any of the LAS parameters. *PfefferPro* software was used to analyze logs, as well as spreadsheet applications found in Asquith and Krygowski (2004).

API	Location Problem	BMSW Elevation	BMSW Depth	UTM E	UTM N	Elevation[1]	Twn	Rng	Sec	Mer.	Total Depth	Completion Date	Modifier[2]
		ft	ft	NAD 83	NAD 83	ft					ft		
4300711160	No nearby well	3456	2800	557135	4405405	6256 KB	12S	14E	3	S	4500	16-Jul-60	1
4301310496	No nearby well	3438	2317	583312	4473964	5755 GR	1S	1W	8	U	11482	22-Dec-63	1
4301330005	ambiguous	4002	1911	577913	4474860	5913 GR	1S	2W	2	U	10545	24-Aug-68	1
4301330039	ambiguous	3391	2686	577838	4476639	6077 GR	1N	2W	35	U	12030	11-Aug-70	4
4301330156	ambiguous	3048	2504	578344	4467432	5552 GR	1S	2W	35	U	13800	8-Feb-74	5
4301330346	ambiguous	3473	2245	575495	4468772	5718 GR	1S	2W	28	U	3500	11-Dec-74	1
4301330362	ambiguous	2619	4177	549974	4467467	6796 GR	1S	5W	35	U	4650	10-Apr-75	4
4301330371	ambiguous	3362	2772	554805	4457485	6134 GR	2S	4W	32	U	4000	17-Apr-75	1
4301330387	ambiguous	1707	4653	535307	4453498	6360 GR	3S	6W	8	U	11400	19-Jan-76	4
4301330388	ambiguous	3729	2046	545169	4452698	5775 GR	3S	5W	17	U	3710	2-Sep-75	1
4301330506	ambiguous	5142	288	582123	4431038	5430 GR	9S	17E	17	S	6200	27-Jan-83	1
4301330589	ambiguous	3711	2151	566157	4460634	5862 GR	2S	3W	21	U	12679	15-Jan-82	1
4301330630	ambiguous	3051	2645	576907	4432533	5696 GR	9S	16E	10	S	6085	15-May-82	1
4301330634	ambiguous	2885	2837	576139	4431715	5722 GR	9S	16E	15	S	5699	8-Apr-82	1
4301330704	ambiguous	3249	2966	565234	4466797	6215 GR	1S	3W	33	U	13845	25-Mar-83	1
4301330719	ambiguous	1083	5984	545977	4463249	7067 GR	2S	5W	9	U	14397	12-Jul-83	2
4301330762	ambiguous	5705	240	566241	4437033	5932 GR	5S	3W	4	U	6698	8-Aug-83	2
4301330842	ambiguous	5834	544	557600	4432579	6378 GR	5S	4W	15	U	6250	9-Jun-84	1
4301530022	No nearby well	-1743	8378	565649	4368651	6635 GR	16S	15E	3	S	8752	6-Oct-75	1
4301930240	ambiguous	4846	3597	652240	4367480	8443 GR	16S	24E	2	S	7600	13-Aug-75	1
4304710032	ambiguous	822	4776	663730	4438072	5598 GR	8S	25E	34	S	6610	5-Sep-65	1
4304710114	ambiguous	-439	5809	638961	4453478	5370 KB	7S	23E	7	S	3196	29-Oct-57	3
4304710870	ambiguous	1689	3428	633901	4456837	5117 GR	6S	22E	34	S	6600	10-Mar-64	1
4304715134	ambiguous	3183	1860	623012	4457281	5043 GR	6S	21E	33	S	7750	23-Jun-65	1
4304715300	ambiguous	-42	5542	641802	4448133	5500 KB	7S	23E	33	S	5592	22-Jul-64	1
4304720202	ambiguous	728	4552	607194	4463822	5280 GR	6S	19E	12	S	5894	1-Mar-68	1
4304720408	ambiguous	-1918	7118	627948	4474397	5200 GR	5S	22E	6	S	2349		3
4304720438	ambiguous	1085	3774	629050	4458950	4859 GR	6S	22E	30	S	8944	29-May-52	4
4304730066	ambiguous	982	4585	662509	4438875	5567 GR	8S	25E	34	S	14125	21-Jan-71	4
4304730103	ambiguous	2082	3330	633794	4449804	5412 GR	7S	22E	27	S	5888	18-Jun-71	1
4304730153	ambiguous	1261	3700	616316	4426432	4961 GR	10S	20E	2	S	11100	25-Jun-73	1
4304730156	No nearby well	2730	2471	646632	4431437	5201 GR	9S	23E	24	S	8500	20-Dec-73	1
4304730163	ambiguous	773	4748	660313	4446854	5521 GR	8S	25E	5	S	4561	10-Dec-73	3
4304730190	ambiguous	1468	3705	596262	4466115	5173 GR	2S	1E	3	U	12387	31-Mar-75	4
4304730298	ambiguous	4448	626	644473	4432500	5074 GR	9S	23E	15	S	9170	2-Dec-78	1
4304730341	ambiguous	309	5288	646222	4448618	5597 GR	7S	23E	25	S	5700	18-Oct-78	1
4304730369	ambiguous	1535	3800	640587	4423927	5335 GR	10S	23E	17	S	7085	13-May-78	1
4304730412	ambiguous	1922	3074	613399	4422688	4996 GR	10S	20E	16	S	8350	14-Nov-79	1
4304730458	ambiguous	1208	4167	634148	4450275	5375 GR	7S	22E	22	S	6801	16-Apr-81	1
4304730522	ambiguous	627	4907	644616	4449047	5534 GR	7S	23E	26	S	5700	20-Jun-79	1
4304730549	ambiguous	4531	226	626103	4432953	4757 GR	9S	21E	14	S	7000	23-May-79	2
4304730603	ambiguous	1627	3253	620413	4429787	4880 GR	9S	21E	30	S	6920	18-Mar-80	1
4304730647	ambiguous	4591	208	614277	4432304	4799 GR	9S	20E	15	S	5060	12-Nov-80	1
4304730732	ambiguous	203	4710	634269	4443586	4913 GR	8S	22E	10	S	6061	15-Jun-81	1
4304730826	ambiguous	2586	2381	597326	4424409	4967 GR	10S	18E	11	S	4818	24-Nov-82	1
4304730894	ambiguous	-205	5663	646122	4454597	5458 GR	7S	23E	12	S	5675	9-Jul-81	3
4304730959	ambiguous	4353	514	607752	4454941	4867 GR	7S	19E	1	S	4401	10-Aug-81	2
4304731018	ambiguous	4765	194	614912	4452286	4959 GR	7S	20E	15	S	7514	25-Jun-81	2
4304731128	ambiguous	4365	340	603067	4431718	4705 GR	9S	19E	16	S	7475	4-Feb-82	2
4304731200	ambiguous	4471	306	600566	4431637	4777 GR	9S	19E	18	S	5860	14-Jan-83	1
4304731300	No nearby well	-473	5747	634890	4453828	5274 GR	7S	22E	11	S	6186	26-May-83	1
4304731380	ambiguous	4758	295	587324	4436714	5053 GR	8S	17E	35	S	6200	27-Jan-84	2
4304731410	ambiguous	4544	295	596079	4436406	4839 GR	8S	18E	34	S	6237	7-Feb-84	2

[1]GR = ground; KB = kelly bushing.

[2]1= picked point in well; 2= BMSW above this point in well; 3= BMSW is below this point in well; 4= picked point in well with "non-saline" water >500 ft below; 5= same as 2, but "non-saline" water at least 500 ft below

Table 3. *TP-92 problematic locations.*

Spatial distribution of data: Plate 1 posts all but one of Howells and others' (1987) estimated BMSW points, also referred to here as TP-92 data consisting of 400 points. One of the TP-92 points was not included because no oil or gas wells were found in the township where this point was plotted (T. 16 S., R. 19 E., SLBLM). New points from this study's estimated BMSW are also plotted on plate 1, but with a slightly different color, totaling 260 points. Examination of plate 1 shows the uneven distribution of points in the study, as wells are clustered within active oil and gas fields. The exception to this is in the Greater Natural Buttes area where the deep shallow-casing depth reduces the number of usable wells.

Geophysical Log Analysis

The resistivity of a solution can be precisely calculated using the composition of dissolved ions, their concentrations, and the temperature. TDS of formation water is the concentration of all dissolved ions in solution, regardless of composition, and is not dependent on temperature. Since the resistivity of a solution is composition dependent, and TDS is not, converting resistivity to TDS without knowing the concentration of ions requires some assumptions about the solutions composition. The simplifying assumption is: the bulk of the ions affecting resistivity are sodium and chloride. This is true for most, but not all, produced waters from the Uinta Basin.

Resistivity of rocks is measured by a variety of geophysical methods. The resistivity of a rock is dependent on two main properties: 1) the resistivity of the non-porous mineral matter, and 2) the resistivity of the fluids within the pores of the rock. The non-porous mineral matter resistivity is high and very close to a constant for a given lithology, whereas the pore-filling fluid resistivity can vary greatly. Therefore, changes in the measured resistivity of similar lithologies in the subsurface are due primarily to changes in the pore-filling fluids. Using the known relationships between resistivity of solutions and TDS, we can use measured resistivity from oil and gas well geophysical logs as a proxy or estimate for the TDS of the formation water.

Geophysical log analysis is the method used for picking the BMSW in wells in both this study and the prior study (Howells and other, 1987). Howells and others provide an excellent detailed discussion of all the geophysical log interpretation methods so only a brief review follows. Others have published on similar techniques (Peterson, 1991; Jorgensen, 1989, 1996). Log analysis methods provide an approximation of a variety of parameters needed in calculating an estimate of the TDS of a permeable bed's formation water. If all the variables involved in calculating an estimated TDS were know with certainty, the result would be quite accurate, but generally most of the variables are not precisely known. Table 4 provides an overview of the accuracy of various petrophysical properties and the sensitivity of an Archie-based estimate of TDS (see discussion of Archie method below) on those parameters. Porosity and water/hydrocarbon saturation stand out as the most sensitive parameters related to the estimated TDS.

One of the difficulties with log analysis in the Uinta Basin is the common presence of hydrocarbons in the system. Resistivity measurements in a well are sensitive not only to the pore-filling fluid chemistry, but also to the amount of gas and more so of oil. Lipinski (2008) provides an excellent analysis of this effect in the Green River Formation, Monument Butte field, and how it can impact water saturation calculations and derived apparent water resistivity (R_{wa}). Montgomery and Morgan (1998) comment on the challenges stratified formation waters offer in the Bluebell field: "...apparent variability in formation water resistivities makes calculations of water saturation potentially suspect or unreliable."

Well logs were evaluated by combining two primary mechanisms, 1) using the *PfefferPro* software to evaluate a discrete bed or unit and, 2) using the mathematical manipulation capabilities of the LAS viewing software (*Strater*) to develop and display new derived curves. Initially an F-log (1/porosity squared) was created using the average density-neutron porosity, density porosity, or sonic porosity, usually in that order based on availability of the curves. Combined with the SP log, these curves help to grossly bracket the BMSW interval in the well. Using the *PfefferPro* approach, zones both above and below the bracketed BMSW were selected, based first on permeability and second on lithology (sandstone being preferred). Individual "units" were picked on the log and entered into the *PfefferPro* worksheet. With the units for evaluation selected, the LAS values were imported and each

Accuracy	± 2 %	± 1 φ unit (0.01)	variable	variable	±5%	±2°	up to 25%	TDS mg/L	
Parameter	resistivity ohm-m	Density φ (2.68)	Sw %	Rwa	FT	MAST	non-saline ions	estimate	% change
True values	28	0.1	100	0.28	95°F	50°F	100% NaCl	18,000	na
S_w 50% (R_w .28@FT)	111	0.1	50	1.12	95°F	50°F	100% NaCl	4,000	-78%
S_w 75% (R_w .28@FT)	49.6	0.1	75	0.50	95°F	50°F	100% NaCl	9,500	-47%
Max + porosity error	28	0.11	100	0.34	95°F	50°F	100% NaCl	14,200	-21%
Max - porosity error	28	0.09	100	0.23	95°F	50°F	100% NaCl	23,000	28%
Max + log variables	28.6	0.11	100	0.35	95°F	50°F	100% NaCl	14,000	-22%
Max - log variables	27.4	0.09	100	0.22	95°F	50°F	100% NaCl	24,000	33%
Matrix density 2.65 g/cc	28	0.084*	100	0.20	95°F	50°F	100% NaCl	26,000	44%
89.5% NaCl (HCO3+SO4)	28	0.1	100	0.28	95°F	50°F	89.5% NaCl	18,940	5%
80% NaCl (HCO3+SO4)	28	0.1	100	0.28	95°F	50°F	80% NaCl	20,130	12%
Max both temperatures	28	0.1	100	0.28	99.5°F	52°F	100% NaCl	17,500	-3%
Min both temperatures	28	0.1	100	0.28	90.4°F	48°F	100% NaCl	18,500	3%

Based on hypothetical BHT of 138° F, TD of 6500 ft, depth of zone 3320 ft.

Assume a =1, m =2, n =2 (a=tortousity, m=cementation exponent, n=saturation exponent)

FT = formation temperature

MAST = mean annual surface temperature

R_{wa} = apparent water resistivity

φ = porosity

*hold raw density the same

Table 4. *Sensitivity of Archie method and other parameters in estimating TDS of formation water.*

unit run through a series of evaluation techniques. A Pickett Plot was constructed for each unit and generally a cross-plot lithologic analysis was run, when the correct curves were available. The software provided a range of different techniques and the ability to experiment with differing parameters. With the best estimate for the apparent resistivity of the formation water (R_{wa}) for all units, the BMSW boundary could be further limited to a discrete footage range.

The second method used in log interpretation was the preparation of a hypothetical 10,000 mg/L pure Na-Cl water R_w curve adjusted for borehole temperature and plotted on the depth scale of each log. A second curve, representing a calculated R_{wa}, was plotted on the same depth scale. An added fill pattern allowed for a quick visual check on when the calculated estimate was over or under the 10,000 mg/L curve. This method allowed for a check on the first method and a quick view of the deeper portion of the borehole, below the picked BMSW.

Archie method: This method is based on the equation:

$$R_o = F(R_w) \quad (1)$$

where: R_o = the resistivity of water-filled formation.
F = the formation factor = a/ϕ^m, a = tortuosity factor, ϕ = porosity, and m = cementation factor.
R_w = the resistivity of the water in the pore space (Archie, 1942).

The Archie equation is rearranged to solve for R_w. Howells and others (1987), Asquith and Krygowski (2004), and Ellis and Singer (2008) provide a more detailed discussion of use of the Archie method. Without core petrophysics and water analyses from a particular zone, all of the parameters in the Archie equation are assumed or estimated from field studies, geophysical logging techniques, or operator trial and error. The results are as good as the combination of assumptions and estimates of Archie parameters. The beginning approach was to assume a =1 and m = 2.0, which is supported by work from Cluff and others (2008) and from unpublished company reports (Jim Kinser, Bill Barrett, personal communication, 2010). Based on work in the Uinta Basin by Cluff and others (2008), m was determined using their constructed curve relating the best choice of m for a given porosity. Their work showed that the m factor was reduced when porosity dropped below 10%. Cluff and others (2008) also demonstrated that the m value was affected by the salinity of the formation waters. Their experiment looked at varying the salinity from 20,000 mg/L to 200,000 mg/L. Within this range, m decreased with decreasing salinity. Inappropriate use of a value of 2.0 for m causes an overestimation of the salinity, which could occur when the porosity is below 10% or in zones with moderately saline formation waters. In table 4, when the porosity dropped below 10%, and no such adjustment was made, the resulting estimated TDS error increased.

SP method: The SP (self-potential) method is based on the electrical potential developed between the borehole and the permeable beds or zones encountered. Howells and others (1987) and Ellis and Singer (2008) provide more detailed explanations of the method. An advantage of this method is that it does not require knowing the porosity of the zone of interest. Like many other log analysis methods, there are many things that can cause incorrect results. Thin beds, shale, and hydrocarbon content suppress the SP and negatively affect the accuracy of the calculated R_w. Since shale and hydrocarbons are both commonly associated with a large part of the stratigraphic section of the Uinta Basin, these limitations must always be considered when applying the method.

Resistivity method: This method is used when no porosity log is available. In the current study, a well was eliminated from the selection list if it did not have a porosity log and so the method was not used. Additional information about the method is found in Howells and others (1987), Jorgensen (1996), and Asquith and Krygowski (2004).

Input Factors

Log calculations involve various input factors which profoundly affect the resultant estimate of the TDS concentration. Table 4 helps to illustrate the effects of the parameters discussed below.

Temperature: The resistivity of a solution is dependent on the temperature. Determining the temperature of the borehole and/or near borehole temperature involves several assumptions. The first of these is estimating the mean annual surface temperature (MAST) of the location of the well. With very few temperature measurement sites in the Uinta Basin, constructed maps are created using known temperature averages and topography. The map used (Thornton and others, 1996) bracketed the temperature in five degree Fahrenheit increments and used a small scale. The map was overlain on the project base map. An estimate of the temperature within this five degrees was then based on the elevation of the well.

The bottom hole temperature (BHT) was determined using a combination of the reported BHT from the log header information and an adjustment based on the Horner technique, as modified by Chapman and Keho (1982) and Chapman and others (1984), which uses the difference between the recorded BHT with elapsed time. The objective of the analysis is projecting the temperatures to an equilibrium bottom hole temperature (EBHT). Data points were gathered from wells where two temperature measurements were taken over some known period of time (Chapman and Keho, 1982). Chapman and others (1984) used 97 such data points from the Uinta Basin to develop a curve relating elapsed time since drilling stopped and recorded BHT to EBHT, shown in figure 3. The greater the elapsed time, the lower the percent adjustment to BHT. All R_{wa} calculations were made at formation temperature and then converted to a temperature of 68ºF using the equation:

$$R_{w2} = R_{w1}(T_1 + 6.77/T_2 + 6.77) \quad (2)$$

where:
- R_{w2} = resistivity at 68ºF.
- R_{w1} = resistivity at formation temperature.
- T_1 = formation temperature.
- T_2 = 68ºF.

Water chemistry: The composition of dissolved solids in the water will change its resistivity. All industry chart books are based on a pure sodium-chloride solution. The resistivity of a 10,000 mg/L solution of pure sodium-chloride at 68ºF is 0.65 ohm-m (Schlumberger, 1984; Baker-Hughes, 1995). As other constituents are substituted for sodium and chloride, the resistivity of the resultant solution, of similar concentration, increases. Most industry chart books provide a page devoted to estimating the resistivity of a complex solution containing more than sodium and chloride ions. Within the Uinta Basin, a strongly calcium-bicarbonate or sulfate-dominated 10,000 mg/L solution can yield an R_w of up to 0.82 ohm-m. Sodium-chloride dominated waters are most common within the deeper portions of the basin (Zhang and others, 2009). Unfortunately it was uncommon to find a water analysis from the depth interval near the BMSW in wells. Most water samples are from deeper producing zones, so calibrations of the expected R_w from water samples in units near the BMSW in a well were rarely performed. Typically, a pure sodium-chloride solution was used in construction of the expected R_w curve unless available water data indicated otherwise.

Hydrocarbons: Hydrocarbons are abundant within the stratigraphic section of the Uinta Basin, causing one, if not the most, difficult factor in log interpretation. Hydrocarbons increase the resistivity of a permeable zone and resistivity is a proxy for TDS. Unrecognized hydrocarbon saturation in permeable beds drives the interpreter towards concluding the R_w of the formation water is fresher than reality. Lipinski (2008) provides an excellent discussion of this problem in the Monument Butte field. From sidewall core analysis in the well 4304733662 (DOGM web files, accessed 11/30/11), the middle Green River Formation contains oil saturations from 5 to 58%.

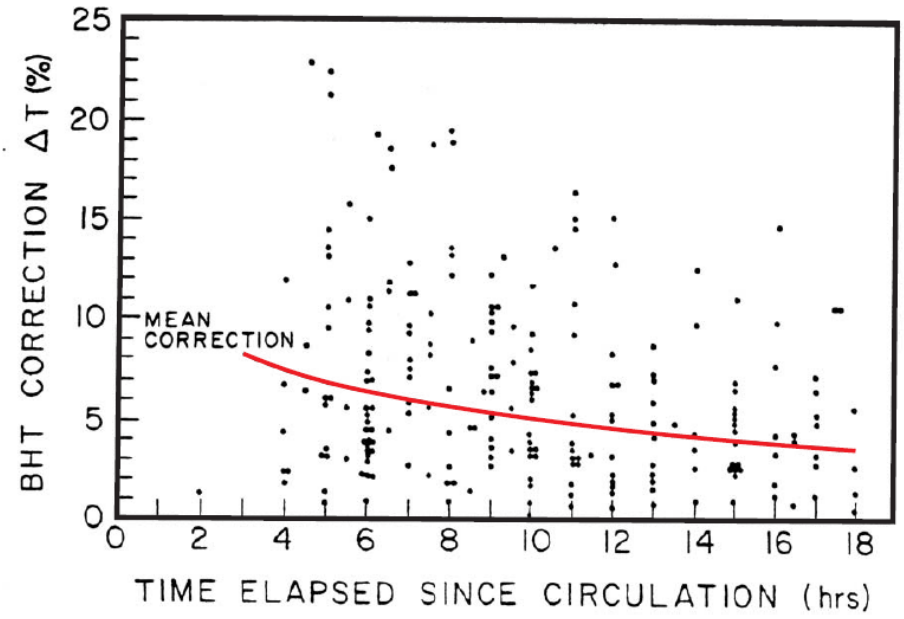

Figure 3. *Magnitude of bottom-hole correction, expressed as a percentage of the observed value in °C as a function of elapsed time after circulation, for 97 wells with BHT values recorded (after Chapman and Keho, 1982).*

Typical methods for gas detection were used including density-neutron crossover, lithology cross plotting, and SP deflection in contrast to the polarity of the resistivity curve separation. Access to a mud log during salinity interpretation is very helpful in attempting to adjust the R_{wa} for the effects of hydrocarbon saturation. Unfortunately, mud logs are not available for most wells in the basin. Pickett plots with water saturation (S_w) curves of 100 and 60 percent were helpful in adjusting R_{wa} for some assumed hydrocarbon saturation. Interpretive license was applied to this problem and when such license impacted the interpreted R_{wa} for a zone, it was so noted. Correction for hydrocarbons was probably on the conservative side (R_{wa}'s too high). This approach errs on the side of aquifer protection, but points to the need for collection of good formation water samples in the regulatory process for future disposal wells.

Lithology: Lithologic interpretation makes a considerable difference in the assumed porosity for a unit. Most logs in the basin are run using a density of 2.68 g/cc and a sand matrix for the neutron log. Sandstone is the dominant reservoir in the basin, but occasionally a lime-dominated zone was evaluated and the porosity values appropriately changed. Data from core indicate 2.65 g/cc may be the best representation of Mesaverde Group sandstone reservoirs (Brynes and others, 2007; Jim Kinser, Bill Barrett Corporation, personal communication, 2009). A change in density from 2.68 g/cc to 2.65 g/cc will change the porosity of the unit downward about 1.5%. Table 4 shows how this change in porosity affects the R_{wa} and estimated TDS. As with hydrocarbons, available mud logs would aid in lithologic determination, but are not commonly available.

Time: This fourth dimension was not directly studied but is worthy of a few comments. From Howells and others' (1987) mapping, no profound changes are implied by the new data that can be related to time. In reviewing the more recent drilling, caution was used in areas where water injection is, or has been, part of the operating history. Several water analyses were rejected for use in mapping the BMSW based on nearby injection history and anomalous water quality. Future changes in basin water quality are inevitable, but the small amount of injected water relative to basin capacity would require more detailed study to document these changes.

HYDROGEOLOGY

The Uinta Basin's hydrogeology is very complex. About 80% of the basin's recharge occurs in the north from the Uinta Mountains, with elevations in excess of 13,000 feet (Hood and Fields, 1978; Zhang and others, 2009). The southern edge of the basin (as defined in this study, Plate 1) includes part of the Book Cliffs, a relatively high (8000 to 9000 ft) escarpment that contributes minor recharge from the south. To date, no basin-wide computer-based groundwater-flow model with a water budget has been developed for the Uinta Basin. A water budget was developed prior to the use of computer models and summarized by Holmes (1985) to be 630,000 acre feet. Waste production water disposed by injection for 2010 represents 0.5% of this volume. Bredehoeft and others (1994) modeled the basin, but with an objective of explaining high pressure encountered at depth in the Altamont-Bluebell field. The reader is referred to Howells and others (1987) for a more detailed summary of the basin's hydrogeology. Smaller portions of the basin have been studied since 1987 and are briefly reviewed below, based on where they occur in the stratigraphic section.

Stratigraphy

Figure 4 is a diagrammatic stratigraphic column of Uinta and Piceance Basin stratigraphy. The applicable stratigraphy for the Uinta Basin is on the left side of the diagram. Howells and others (1987) provide a brief hydrogeologic description of each of the formations in the Uinta Basin, while several other

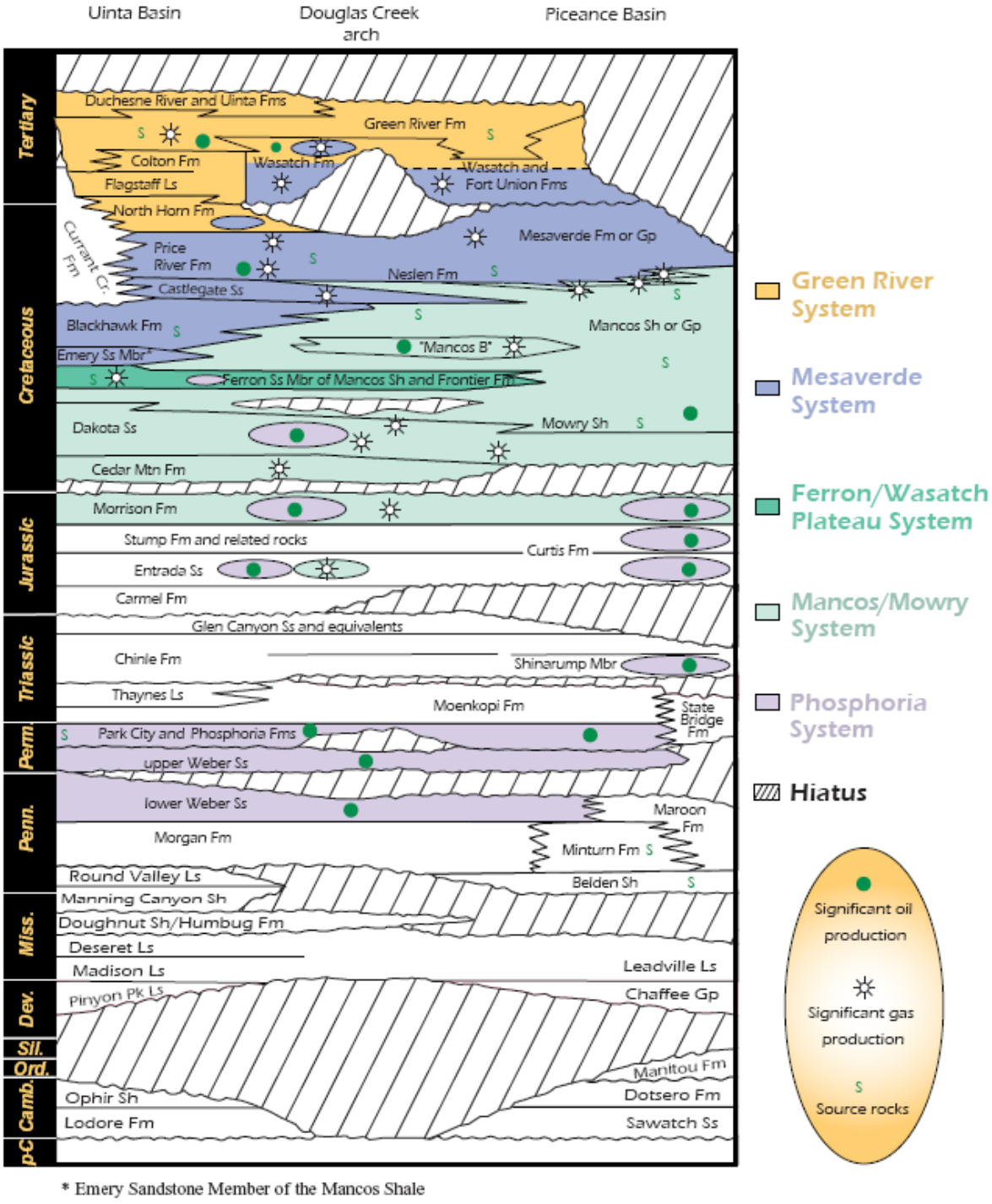

Figure 4. *Stratigraphic column of the Uinta and Piceance Basins, Utah and Colorado (from U.S. Geological Survey, 2003).*

authors have addressed the natural gas (Morgan, 1993; Chidsey, 1993a, 1993b) and crude oil (Morgan, 2009a, 2009b) resources of the basin. Relevant new hydrogeologic studies or discussion follow below.

Duchesne River - Uinta Formations

The Duchesne River and Uinta Formations are the youngest sedimentary rocks in the basin and only crop out in the north. Underground injection and disposal wells are sited in these formations. Glover (1996) combines these two formations into one aquifer, with most of its recharge from the Uinta Mountains and discharge to local streams. The thickness of this combined unit is about 8000 feet and Glover models a confining unit below the aquifer consisting of the Parachute Creek Member of the Green River Formation, which separates it from the underlying Douglas Creek aquifer. The Duchesne River-Uinta aquifer coarsens towards the Uinta Mountains, with the Uinta Formation being the finer-grained of the two units. Glover reports an area of confined conditions in the center of the model area.

Freethey (1992) studied an area in the Altamont-Bluebell field, mainly in eastern Duchesne County, looking for evidence of upward leakage from existing water disposal wells into shallow domestic groundwater wells. Most of the shallow disposal wells were completed in the lowermost section of the Duchesne River Formation, from 2000 to 3500 feet deep, where the BMSW is relatively shallow. Groundwater flow in this part of the basin appears to be from
northwest to southeast. Freethey (1992) found no direct evidence of upward leakage, but suggests several approaches to a more detailed study of the issue. Naftz (1996) describes rock-water interactions from recharge to discharge areas in this aquifer. The lower Uinta Formation and upper Green River Formation in the Cedar Rim field contain trona and likely other evaporites, affecting the salinity of the formation fluids (Jim Kinser, Bill Barrett Corporation, written communication, 2012).

Green River Formation

The Green River Formation is found throughout most of the subsurface of the basin except for a band about 3 to 10 miles wide along the southern limit of the study area. The formation is an important source and reservoir for oil and gas. The upper portion of the formation in the eastern part of the basin contains the Birds Nest aquifer, a potential large-scale saline water disposal zone (Vanden Berg and others, 2011). Holmes and Kimball (1987) studied the Green River Formation in the eastern portion of the basin, near the potential oil shale development areas. Stratigraphically, the study looked at the formation from the Birds Nest aquifer (upper Green River Formation) to the intertonguing Renegade Member of the Wasatch Formation. The section studied had a strong east-west anisotropy based on flow modeling, believed to be tied to a similarly oriented fracture pattern, which parallels the region's gilsonite veins. The authors provide a detailed analysis of the geochemical evolution of waters as they move through these aquifers. Wanty and others (1991) discuss groundwater geochemistry of the Green River and Wasatch Formations along flow paths in the basin.

Kelso and Ehrenzeller (2008) provide a good summary of oil and gas activity in the western Greater Monument Butte area, which includes core data from several holes and lithologic descriptions from the middle portion of the Green River Formation. Lipinski (2008) discusses the log responses from the Green River Formation in the central Uinta Basin noting: 1) the complexities of varying R_w, lithologic variations, and the almost ubiquitous partial saturation of solid hydrocarbons, 2) the value of applying shale models in log interpretation are not particularly helpful given the inability to accurately predict shale volume, 3) calculating R_w from Archie's equation almost always yields a value too high (too fresh) because the residual oil found in the rocks causes anomalously high resistivity, and 4) porosity of greater than 20% is an indication of relatively fresh water because these higher porosity rocks are the result of dissolution of carbonate cement by non-saline water.

Wasatch Formation

The Wasatch Formation lies below, but interfingers with the lower portion of the Green River Formation. Many of the recent studies mentioned above for the Green River Formation also address the Wasatch Formation. Zhang and others (2009) cover this formation in their basin-wide paper on

hydrogeochemistry. Pitman and others (1986) offer updated studies on the geology and hydrocarbon potential of the formation.

Estes-Jackson and others (2008) share their experience in the Hanging Rock field (T. 12 S., R. 23 E., SLBLM) with Wasatch production. Four sidewall core samples yielded an average grain density of 2.64 g/cc, water samples from the reservoir indicate an $R_w = 0.058$ at 68° F, and the sandstone reservoir rocks are chert arenites with a shale content of about 10% and gamma-ray cutoff of 75 API units.

Stancel and others (2008) studied the Love field (T. 11 S., R. 21 E., SLBLM) and give a range of TDS values for waters from the Wasatch and Mesaverde of the Greater Natural Buttes field, which range from 20,000 to 30,000 mg/L and 45,000 to 50,000 mg/L respectively. Co-mingled waters have a TDS range of 31,000 to 44,000 mg/L. The authors provided water analyses from 17 wells within the Love field for this study (see appendix A). From 409 core samples, the average grain density was 2.68 g/cc. Stancel and others (2008) noted the following relating to vertical movement of water in the basin.

> "Faults with 50 to 150 ft of throw are recognized in the western part of the GNB [Greater Natural Buttes] Fairway where they cut the top of the Uteland Butte Limestone . . . Limited 2-D seismic coverage coupled with interpretation from aeromagnetic data indicate that these faults overlie and may be in continuity with the major west-northwest-trending fault system that defines the southern extent of the GNB Fairway. Some "plumbing" associated with deeper seated faults is supported by the observation that several wells drilled in proximity to the Uteland Butte faults have recovered anomalously high water cuts that may be coming from a deeper source."

Mesaverde Group

The Mesaverde Group has been an expanding frontier for new drilling in the Uinta Basin in the past 20+ years. Where most of this drilling has occurred, the formation has produced mostly saline water. Water freshens with shallower depths and toward its outcrop on the south side of the basin (Zhang and others, 2009). Stancel and others (2008) characterized the produced water TDS from the Mesaverde in the Greater Natural Buttes field as ranging from 45,000 to 50,000 mg/L; from 564 core samples in the Love field the average density was 2.67 g/cc. However, the Mesaverde section drilled in the West Tavaputs area had a matrix density of 2.65 g/cc (Jim Kinser, Bill Barrett Corporation, personal communication, 2009).

Sub-Mesaverde Group

In the past, most drilling below the Mesaverde Group was limited to the southern part of the basin (mainly to the Dakota Formation) where drilling depths were shallower. Improved drilling and completion techniques along with higher petroleum prices have increased interest in reservoirs such as the Mancos Shale, along with plays in Jurassic and older rocks. These factors have driven drilling ever deeper and farther north into the basin for these objectives. In the deeper part of the basin, water in these formations is generally saline.

Structure

Plate 1 shows the structural axis of the basin. South of this line, rocks dip to the north, and north of this line, beds dip steeply south or are overturned. For additional structural information on the Uinta Basin see references such as: Johnson, 1986; Stone, 1993; U.S. Geological Survey Assessment Team, 2003; Anderson, 2005; Sprinkel, 2007, 2009; and Morgan, 2009a. Plate 1 also shows faults taken from the digital geologic map of Utah (Hintze and others, 2000). The basin has two dominant fracture patterns which follow the faulting, east-west (Duchesne fault zone) and northwest-southeast (gilsonite dike trend). Local areas may have fractures that vary from these regional trends.

RESULTS

The results of the mapping the BMSW are presented on plate 1, which shows the elevation of the BMSW surface. Both the old (TP-92) data and new points added in this study are used in the contouring (Table 5). Some of the old TP-92 points were re-evaluated and changed (15 points). These altered points are shown on Plate 1 with a red dot in the center of the map symbol. TP-92 and new data points are divided by symbol color (TP-92 = dark blue, new points = light blue) with five different conditions of data points for both old and new. The data conditions are: 1) BMSW is picked within the logged interval; 2) the BMSW was not found in the logged interval and the water appears to be saline in the shallowest part of the well log, and generally the top of the logged interval is also the depth/elevation assigned to the point, thus the BMSW is "less than" the depth posted (greater than when converted to elevation); 3) the well logs indicate "non-saline" water to the total logged depth, and the total depth of the logged interval is the depth of the point, thus this is "deeper than" the point depth posted (less than when converted to elevation); 4) BMSW picked within the logged interval, but the logs also indicate "non-saline" water more than 500 feet below the mapped BMSW; 5) same as condition 2 above, but "non-saline" water is observed at depth in the well at least 500 feet below the picked BMSW.

Water analyses from wells help constrain the BMSW picks from geophysical logs. Figure 5 summarizes all of the water analyses from the database (appendix A) that received a "yes" for mapping the BMSW. From the figure, TDS and depth show some increase in the bottom end of the data cloud, but the highest TDS values are associated with depths less than 6000 feet. This is likely related to the saline zones in the shallow Green River Formation (Birds Nest aquifer). Clearly depth and TDS are poorly correlated when all of the basin's aquifers are lumped together; however, as mentioned earlier, some individual aquifers may show increasing salinity with depth (e.g., Mesaverde). The BMSW should be expected at a large range of depths.

Rules for Mapping the BMSW Boundary

The BMSW boundary is identified in a well log by the shallowest natural occurrence of the first 500-foot gross interval or "window" containing a net thickness of saline permeable beds greater than 50%. Other "non-saline" permeable beds may be present in the 500-foot "window" but must represent less than 50% of the total net permeable beds. The BMSW boundary is placed at the base of the first "non-saline" permeable bed above the gross 500-foot saline "window." Figure 6 shows several hypothetical wells, "windows," and the BMSW to help illustrate the mapping rule.

The mapping rule is slightly different than the one used by Howells and others (1987) in TP-92. In the prior study, the 500-foot window was used but could contain no "non-saline" permeable bed greater than 30-feet thick. The new mapping rule has its greatest effect where the basal Mesaverde Group and Mancos Shale/Dakota Formations are penetrated in a well and the Mesaverde is "non-saline" and Dakota saline. In these cases, TP-92 authors placed the BMSW at the top of the first saline permeable bed, typically at or near the Dakota. This put the entire Mancos Shale above the BMSW. The Mancos Shale is known for its high salt content (Tuttle and others, 2005, 2007) and low permeability (Schamel, 2006). Therefore, it is more reasonable to place the BMSW boundary at the base of the Mesaverde; the last "non-saline" permeable zone. In the eastern Uinta Basin, the clastic tongues of the Mancos (Emery and Ferron Members) rarely exhibit much permeability or are unrecognizable. However, if the Emery and Ferron were present and saline, the BMSW would still fall at the base of the Mesaverde, assuming it is "non-saline." TP-92 data points in the southern portion of the study area were reviewed and modified using the new mapping rules.

API	Well Name	BMSW Elevation	BMSW Depth	Mapped[1]	Twn	Rng	Sec	Mer.	Well Type[2]	Total Depth	Completion Date
		ft	ft							ft	
4304737831	UTE 2-17A1E	3371	2190		1S	1E	17	U	OW	11226	13-Sep-08
4304730830	UTE TRIBAL 1-25A1E	327	5000	NO	1S	1E	25	U	D	14054	14-Nov-83
4304731112	BOLTON 2-29A1E	41	5394	NO	1S	1E	29	U	OW	13100	10-Feb-82
4304739467	FLYING J FEE 2-12A1	3317	2400		1S	1W	12	U	OW	10854	28-May-08
4301330011	VICTOR C BROWN 1-4A2	5095	863		1S	2W	4	U	OW	11434	9-Apr-69
4301332202	BOWMAN 5-5A2	2655	3485	NO	1S	2W	5	U	OW	16015	25-Jun-01
4301330737	FISHER 1-16A4	2111	5420		1S	4W	16	U	OW	17593	10-Sep-83
4301330196	STEVENSON HEIRS 1-36A5	2734	3966		1S	5W	36	U	OW	15700	14-Oct-86
4304730931	1-2B1E	1486	3710		2S	1E	2	U	OW	12600	5-Nov-83
4304732409	HORROCKS 2-5B1E	2923	2448		2S	1E	5	U	OW	12672	27-May-93
4304734080	THOMAS 4-10B1	2410	2706		2S	1W	10	U	OW	12900	8-Mar-02
4304732744	RICH 2-13B1	2112	3000		2S	1W	13	U	OW	12500	1-Oct-96
4304731981	COOK 1-26B1	2494	2530		2S	1W	26	U	OW	15500	5-Nov-91
4301331056	EVANS-UTE 2-17B3	3511	2530		2S	3W	17	U	OW	13200	27-May-85
4301331298	WEIKART 2-29B4	-293	6500	NO	2S	4W	29	U	OW	12900	18-Mar-92
4301330316	S. BROADHEAD 1-9C5	4718	1300		3S	5W	9	U	OW	11516	9-Nov-74
4301332112	OWL 3-17C5	1618	4214		3S	5W	17	U	OW	9897	12-Jan-99
4301331612	UTE 2-5C6	2576	4389		3S	6W	5	U	OW	12600	6-Sep-98
4301334276	9-11-36 BTR	3305	2990		3S	6W	11	U	OW	11280	12-Apr-10
4301330243	CEDAR RIM 6	2889	3202		3S	6W	21	U	OW	10005	29-Mar-74
4301330298	UTE TRIBAL G-1 (1-24C6)	5355	500		3S	6W	24	U	OW	10230	8-Nov-74
4301333638	12-36-36 BTR	5003	990		3S	6W	36	U	GW	10146	20-Oct-07
4301331038	SMITH 1-20C7	-1205	7902		3S	7W	20	U	OW	10800	28-Feb-85
4301331634	SMITH 2X-23C7	2333	4318		3S	7W	23	U	D	5250	25-Jun-96
4305130010	MA SMITH OIL INVEST. 1	1980	5317		3S	9W	16	U	D	13260	28-Jul-81
4304751046	UTE TRIBAL 11-2-4-1E	4601	630		4S	1E	2	U	OW	7900	20-Sep-10
4304733541	UTE TRIBAL 4-25	4292	789		4S	1E	25	U	OW	6720	1-Mar-01
4301333944	UTE TRIBAL 12-22-4-1	3686	1452		4S	1W	22	U	OW	6975	14-Oct-08
4304734527	UTE TRIBAL 31-31	4682	338		4S	2E	31	U	D	14614	30-Sep-02
4304734158	LELAND BENCH 35-22	4605	100		4S	2E	35	U	D	14400	21-Aug-02
4301333634	UTE TRIBAL 8-30-4-2	5100	430		4S	2W	30	U	D	285	20-Oct-07
4304733017	UTE TRIBAL 29-13 D3E	4171	540	NO	4S	3E	29	U	GW	8062	21-Jan-98
4301331938	UTE TRIBAL 33-16-D3	4128	1750	NO	4S	3W	33	U	WI	6529	24-Dec-97
4301331012	COYOTE UTE TR 4-9D4	4862	888		4S	4W	9	U	OW	8500	19-Oct-85
4301331212	UTE TRIBAL 2-18D	4460	1490		4S	4W	18	U	OW	7990	28-Sep-88
4301331818	FEE 28-02D4W (WSW)	4408	1552		4S	4W	28	U	WS	3027	13-Nov-98
4301333565	7-7-46BTR	5022	912		4S	6W	7	U	GW	8731	1-Nov-07
4301333657	7-20-46 DLB	5111	1017		4S	6W	20	U	OW	7406	21-Mar-08
4301333576	LC TRIBAL 8-28-46	5671	1618		4S	6W	28	U	OW	6250	28-Feb-08
4304738400	HUBER FED 26-24	2746	2600		5S	19E	26	S	OW	14529	24-Sep-07
4301331858	UTE TRIBAL 07-15	4994	1080		5S	3W	7	U	WI	6208	30-May-97
4301331475	UTE TRIBAL 29-10	5079	1463		5S	3W	29	U	WI	5962	16-Dec-95
4301332568	UTE TRIBAL 11-13-54	5590	685		5S	4W	13	U	OW	6475	12-Oct-04
4301333300	UTE TRIBAL 10-18-54	4808	1777		5S	4W	18	U	OW	6190	5-Feb-07
4301332891	UTE TRIBAL 13-26-54	4903	1868		5S	4W	26	U	OW	6180	15-Apr-06
4301332896	UTE TRIBAL 4-32-54	5170	1740		5S	4W	32	U	OW	5981	6-Sep-06
4301332720	UTE TRIBAL 11-8-55	3120	4050		5S	5W	8	U	D	6226	23-Oct-05
4301332841	UTE TRIBAL 13-20-55	6244	1308		5S	5W	20	U	OW	6108	30-Dec-05
4301332759	UTE TRIBAL 16-25-55	6237	845		5S	5W	25	U	OW	6075	29-Jul-05
4301333363	UTE TRIBAL 3-32D-55	4765	1652		5S	5W	32	U	OW	6120	20-Apr-07
4301333577	LC TRIBAL 7-3-56	5841	1540		5S	6W	3	U	OW	6150	3-Nov-07
4301333541	LC TRIBAL 3-17-56	5972	1893		5S	6W	17	U	OW	6040	1-Dec-07
4301332993	UTE TRIBAL 3-25-56	5899	1908		5S	6W	25	U	OW	6292	15-Dec-06
4304737558	FEDERAL 6-11-6-20	3001	1916		6S	20E	11	S	OW	8270	30-Mar-07
4304739078	FEDERAL 14-24-6-20	2383	2388		6S	20E	24	S	OW	7700	24-Nov-08
4304737559	FEDERAL 5-19-6-21	2384	2366		6S	21E	19	S	OW	7671	27-Jan-07
4304733871	HORSESHOE BEND 26-2	2266	2700		6S	21E	26	S	GW	3750	19-Jul-01
4304734682	HSB 4-28	3035	1787		6S	21E	28	S	GW	3869	17-Dec-02
4304731698	ANNA BELLE 31-2-J	2704	2000	NO	6S	21E	31	S	OW	7150	28-Mar-86
4304731672	CROQUET FEDERAL 2	3250	1540		6S	21E	35	S	GW	3530	4-Nov-85
4304730878	W WALKER ST 2-32	3295	1667		6S	22E	32	S	D	3565	22-Jul-85
4304737399	N WALK HOLL 2-32-6-23	392	4542		6S	23E	32	S	GW	10732	29-Sep-07
4304732444	WILLOW CREEK 1-8	2544	2581		6S	24E	8	S	D	7500	30-Oct-93
4301333449	FEDERAL 8-1-64	5751	685		6S	4W	1	U	OW	5620	9-Nov-07

4301333448	FEDERAL 5-3-64	5910	1128		6S	4W	3	U	OW	5985	29-Jun-07
4301332699	FEDERAL 6-1-65	6383	977		6S	5W	1	U	OW	5920	15-Nov-06
4301333491	FEDERAL 6-11-65	4575	3106		6S	5W	11	U	OW	5985	19-Oct-07
4301330538	INDIAN CANYON U 2	3172	4084		6S	7W	14	U	GW	18003	30-Sep-81
4304930014	HALLS FED 1-13-3C	6298	1452		7S	05E	13	S	D	12061	24-Mar-85
4304736668	WALL 13-17	3941	890		7S	20E	17	S	GW	14761	21-Dec-06
4304731381	PELICAN FED 3-35	2044	2803		7S	20E	35	S	D	6857	24-Nov-83
4304735408	BBE 15G-16-7-21	2776	2018		7S	21E	16	S	OW	7111	10-Feb-06
4304736516	BBW 11G-20-7-21	1239	3710		7S	21E	20	S	OW	7330	30-Mar-06
4304734837	SU BW 6M-7-7-22	3494	1574		7S	22E	7	S	GW	14250	6-Jul-04
4304733765	RW 22-13A	3881	1540		7S	22E	13	S	OW	6175	18-Oct-01
4304734403	SU BRENNAN 15W-18-7-22	4202	944		7S	22E	18	S	GW	9200	19-Jun-02
4304735670	RWU 32-27AG	2647	2796		7S	22E	27	S	OW	6030	15-Feb-05
4304735608	WHU 84	28	5380		7S	23E	1	S	OW	5504	30-Sep-04
4304733497	RW 13-19B	508	4908		7S	23E	19	S	WI	8594	24-Jul-00
4304737946	RW 12-32BG	803	4545		7S	23E	32	S	GW	7588	3-Apr-07
4304735238	RW 32G-16C	112	5700		7S	24E	16	S	GW	5765	19-Mar-04
4304735239	RW 12G-20C	111	5540		7S	24E	20	S	GW	5613	30-Mar-04
4304735098	RW 34-22C	47	5700		7S	24E	22	S	GW	9990	11-Dec-03
4301332374	SAND WASH 11-19-8-17	4962	400		8S	17E	19	S	WI	6590	5-Dec-05
4304734475	IGNACIO 33-221	4195	470		8S	20E	33	S	GW	7855	28-Apr-02
4304733648	WV 9W-2-8-21	2045	3000		8S	21E	2	S	GW	8225	8-Jan-01
4304735412	SU 11MU-9-8-21	3811	1000	NO	8S	21E	9	S	GW	10130	24-Jun-04
4304735372	WVX 8MU-19-8-21	3808	902		8S	21E	19	S	GW	10100	8-Sep-04
4304732458	GH 12	1206	3500	NO	8S	21E	19	S	WI	5420	6-Apr-95
4304734340	WV 8W-24-8-21	3194	1605		8S	21E	24	S	GW	7585	18-Mar-03
4304734105	NDC 109-27	1469	3314		8S	21E	27	S	D	6867	4-Sep-03
4304734507	TRIBAL 36-148	3645	1065		8S	21E	36	S	GW	12104	8-Feb-04
4304735457	GB 3MU-3-8-22	448	4795		8S	22E	3	S	GW	9992	21-Apr-05
4304734762	OU GB 12W-4-8-22	1911	3295		8S	22E	4	S	GW	8300	8-Mar-03
4304735381	SG 2MU-11-8-22	638	4500		8S	22E	11	S	GW	9600	27-May-05
4304734646	OU WIH 13W-21-8-22	2739	2195		8S	22E	21	S	GW	7475	4-Apr-03
4304735388	WRU EIH 4MU-25-8-22	908	3998		8S	22E	25	S	GW	8520	10-Jan-05
4304735331	EIHX 11MU-25-8-22	675	4270		8S	22E	25	S	GW	8335	14-Mar-05
4304733583	N CHAPITA 111-32	3330	1400	NO	8S	22E	32	S	D	6737	7-Aug-00
4304736061	WKRP 823-34A	2794	2300		8S	23E	34	S	GW	9150	19-May-06
4304732538	RW 41-4F	1683	3920		8S	24E	4	S	GW	10055	1-Feb-95
4304737671	BZ 10D-16-8-24	2200	3018		8S	24E	16	S	GW	13694	30-Aug-07
4304738498	SAND RIDGE 1-28	1863	3316		8S	24E	28	S	GW	8300	10-Nov-08
4304737276	CWD 12ML-32-8-24	2900	2210		8S	24E	32	S	D	8000	21-Jun-06
4304737884	E COYOTE 10-2-8-25	-281	5962		8S	25E	2	S	D	7200	25-Jan-07
4304732253	COYOTE FEDERAL 12-5	1978	3636		8S	25E	5	S	OW	4674	25-Aug-92
4304732255	COYOTE FEDERAL 13-7	2331	3198		8S	25E	7	S	OW	4500	10-Oct-92
4304737114	HK 12ML-30-8-25	2909	2374		8S	25E	30	S	D	7376	2-Oct-06
4304731129	FEDERAL 7-14R-9-17	3981	1180		9S	17E	14	S	OW	6011	18-Jun-82
4301332274	BELUGA U 4-18-9-17	4197	1260		9S	17E	18	S	WI	5875	25-Aug-04
4304735594	FEDERAL 10-4-9-18	4622	350		9S	18E	4	S	OW	6020	20-Jun-06
4304731199	DRIETTE BENCH 34-5	4507	270		9S	19E	5	S	OW	5700	29-Sep-82
4304737755	NBU 920-20I	1987	2800	NO	9S	20E	20	S	GW	10700	9-Aug-08
4304737011	FEDERAL 920-26M	2143	2720		9S	20E	26	S	GW	7600	18-Apr-07
4304733869	JENKS 5-153	4215	470		9S	21E	5	S	GW	7315	24-Aug-01
4304733009	NBU 260	3233	1721		9S	21E	28	S	GW	8418	2-Mar-00
4304730234	CWU 33-16	3179	1600		9S	22E	16	S	GW	6620	30-Mar-77
4304739371	NBU 922-18G	2139	2677	NO	9S	22E	18	S	GW	9530	1-May-08
4304735547	CWU 651-6	3467	1442		9S	23E	6	S	GW	8063	8-Nov-04
4304738875	NBE 12SWD-10-9-23	3324	1650		9S	23E	10	S	WD	2070	29-Nov-07
4304736353	NBE 5ML-10-9-23	2891	2080	NO	9S	23E	10	S	GW	9100	1-Jun-06
4304736098	NBE 4ML-10-9-23	2714	2272	NO	9S	23E	10	S	GW	9175	22-Nov-06
4304733806	BONANZA 4B-12	2644	2404		9S	23E	12	S	D	8529	18-Mar-05
4304735278	CWU 859-29	3200	2045		9S	23E	29	S	GW	8948	3-Jan-06
4304737667	CWU 868-33X(RIGSKID)	2064	3272		9S	23E	33	S	GW	8575	14-Aug-06
4304735362	SOUTHMAN 9-23-22-36	2222	3160		9S	23E	36	S	WD	8552	15-Apr-04
4304735695	WK 9ML-2-9-24	2494	2747	NO	9S	24E	2	S	GW	7050	10-Oct-05
4304735966	BONANZA 9-24-21-8	2735	2200		9S	24E	8	S	GW	7855	17-Nov-06
4304735694	BONANZA 2B-16	2384	2855		9S	24E	16	S	D	7823	16-Jun-04
4304735693	BONANZA 9-24-31-27	2667	2892		9S	24E	27	S	GW	6882	17-Aug-04
4304735861	BONANZA 9-24-11-36	3102	2398		9S	24E	36	S	GW	6566	11-Feb-06

4304734814	LITTLE JOE 9-25-41-7	3378	2102		9S	25E	7	S	GW	6450	3-Jun-04
4304734756	HOSS 9-25-34-20	1899	3908		9S	25E	20	S	GW	6300	31-Dec-02
4304736422	SOUTHAM CYN 9-25-22-32	3307	2218		9S	25E	32	S	D	5447	5-Nov-05
4305130002	GREMO HILL FEE 1	1433	6200		10S	08E	16	S	D	6200	13-Jan-70
4301332242	FUZZY CLOUD 1-12	3449	2940		10S	15E	12	S	D	12935	24-May-02
4301333168	BIG SPRING 3-36 GR	3508	3265		10S	15E	36	S	OW	4980	9-Oct-07
4301333485	BIG WASH 61-16GR	3329	3170		10S	16E	16	S	OW	5650	7-Aug-07
4301333202	PETES WASH U 14-24 GR	3363	2956		10S	16E	24	S	OW	5440	31-Oct-07
4304732155	DESERT SPRINGS 24-C-11	2509	3054		10S	17E	24	S	D	7500	9-Jan-92
4304735932	RB DS FED 1G-7-10-18	1940	3393		10S	18E	7	S	OW	5346	1-Apr-05
4304735798	MANATEE FED 1	1922	3172		10S	18E	9	S	OW	5027	1-Jan-06
4304733244	FEDERAL 7-19-10-18	2315	3110		10S	18E	19	S	WS	4933	8-Sep-03
4304731882	WH FED 2-26	1942	3426		10S	19E	26	S	GW	6500	23-Feb-90
4304736666	KINGS CANYON 1-32E	2293	2994		10S	19E	32	S	GW	9668	27-Jan-06
4304731704	ISLAND UNIT 28	1423	3460		10S	20E	6	S	GW	6750	30-Jul-86
4304735549	RBU 1-14F	1623	3532		10S	20E	14	S	GW	8597	1-Jan-07
4304734986	RBU 2-20F	1880	3280		10S	20E	20	S	GW	8517	30-Sep-04
4304732988	NBU 391-5E	2452	3476	NO	10S	21E	5	S	GW	6600	29-Jul-98
4304738109	NBU 1021-10P	1895	3250		10S	21E	10	S	GW	9410	3-Nov-07
4304739098	STATE 1021-28M	2361	2956		10S	21E	28	S	GW	9155	25-Feb-08
4304738849	STATE 1021-36K	2316	3142		10S	21E	36	S	GW	8714	6-Jul-07
4304739482	NBU 1022-13M1S	1618	3688		10S	22E	13	S	GW	8100	9-May-08
4304737546	NBU 1022-17J	1961	3296		10S	22E	17	S	GW	8705	23-Jan-08
4304736407	ROCK HOUSE 10-22-21-36	2566	3052		10S	22E	36	S	GW	8212	5-Mar-06
4304737214	BONANZA 1023-6F	1999	3140		10S	23E	6	S	GW	8380	20-Oct-06
4304738299	BONANZA 1023-14C	2595	2970		10S	23E	14	S	GW	7800	19-Mar-08
4304736306	ROCK HOUSE 7-32-10-23	2839	2402		10S	23E	32	S	GW	7500	19-Aug-05
4304732560	FEDERAL 21-27	347	5058		10S	24E	27	S	GW	6490	28-Mar-95
4304736238	SOUTHMAN 10-24-13-30	2554	2512		10S	24E	30	S	GW	6575	23-Apr-08
4304736933	SOUTHAM CYN 10-25-11-6	3306	2060		10S	25E	6	S	GW	5630	3-Nov-06
4304739595	WEAVER CYN 26-2	2995	2782		10S	25E	26	S	GW	4520	27-Oct-08
4304736421	SOUTHAM 10-25-21-32	1452	4356		10S	25E	32	S	GW	4900	11-Dec-05
4304930003	SKYLINE GOVT 1	3196	5002		11S	07E	10	S	D	11750	16-Jan-70
4301332308	CASTLEGATE 1-35-12-10	2560	4705		11S	10E	35	S	WD	6400	13-Jun-02
4301333005	BADLANDS 1-01	3528	4224		11S	14E	1	S	D	12900	28-Dec-06
4301332475	GATE CYN 41-20-11-15	3653	2934		11S	15E	20	S	GW	9565	2-May-05
4301332611	GATE CYN 41-19-11-16	3330	3068		11S	16E	19	S	GW	11925	5-Apr-05
4301331949	SEGO RESOURCES 4	3551	2978		11S	16E	31	S	D	6992	15-Jan-98
4301331996	TWIN KNOLLS 5-9 J	4296	2276		11S	17E	9	S	D	7998	1-Feb-98
4304731824	ALGER DSS 1	1450	4000	NO	11S	19E	2	S	GW	9375	19-Oct-88
4304736907	ALGER DSS 8-17	2192	3538		11S	19E	17	S	GW	10860	1-Nov-06
4304736165	LCU 2-1H	2181	3212		11S	20E	1	S	GW	9116	6-Nov-05
4304731818	WILLOW CREEK UNIT 2	2237	3260		11S	20E	5	S	GW	9105	19-Jun-88
4304736939	BIG DCK U 3-27H	3330	2280		11S	20E	27	S	GW	9503	17-Oct-08
4304736674	LOVE 1121-15H	2714	3042		11S	21E	15	S	GW	8650	12-Sep-06
4304736728	BIG DCK 11-21-11-28	2867	3030		11S	21E	28	S	GW	8624	2-Aug-06
4304736996	BITTER CREEK 1122-2B	2648	3048		11S	22E	2	S	GW	8080	9-Jun-07
4304734774	BITTER CREEK 4-2	2520	3088		11S	22E	4	S	GW	8110	9-Jun-03
4304736045	LIZZARD 1122-21O	2563	3430		11S	22E	21	S	GW	8144	8-Mar-05
4304737836	BUCK CAMP 11-22-14-36	2816	2595		11S	22E	36	S	WD	6690	11-Aug-06
4304736152	ROCK HOUSE 11-23-44-2	2670	3360		11S	23E	2	S	GW	7510	26-Nov-06
4304733026	ATCHEE 1	2982	2930		11S	23E	15	S	WD	5160	28-Apr-98
4304736314	STUMPJUMP 11-23-23-33	2921	3518		11S	23E	33	S	GW	7700	15-Oct-06
4304738281	HANG ROCK 11-23-41-36	2739	3240		11S	23E	36	S	D	4550	3-Sep-07
4304736184	RAINBOW 11-24-31-16	3130	2366		11S	24E	16	S	GW	6330	15-Dec-06
4304737460	RAINBOW 11-24-23-20	3217	2695		11S	24E	20	S	D	6400	17-Mar-07
4304734118	QUEST 11-25-24-10	1933	4113		11S	25E	10	S	D	4538	8-Jul-09
4304731803	HELLS HOLE 9110	3357	3500	NO	11S	25E	12	S	GW	7460	11-Dec-87
4304731896	EVACUATION CR UNIT 1	1587	4292		11S	25E	25	S	D	8543	11-Sep-90
4300730141	MATTS SUMMIT ST A-1	4163	3836		12S	09E	14	S	GW	5202	22-Aug-92
4300730140	HUBER-FED 6-8	3321	4072		12S	10E	8	S	GW	6030	28-Oct-93
4300731450	P5	6467	2102		12S	11E	31	S	GW	2654	17-Nov-08
4300730158	SLEMAKER A-1	2702	4780		12S	12E	5	S	GW	7000	13-Feb-93
4300730209	BRYNER A-1X (RIG SKID)	3199	3895		12S	12E	11	S	GW	6415	16-Dec-93
4300730851	SOLDIER CREEK 4-28	3342	4000		12S	12E	28	S	GW	3990	9-Nov-02
4300731008	PRIC. PEAR 5-13-12-14	4987	2612		12S	14E	13	S	GW	7485	29-Jun-06
4300731193	PRIC. PEAR 15-18-12-15	4739	2798		12S	15E	18	S	GW	7280	19-Oct-06

4300730954	PRICKLY PEAR U FED 7-25	4386	2668		12S	15E	25	S	GW	7400	27-Jan-06
4300731196	PRIC. PEAR 10-27-12-15	4555	2746		12S	15E	27	S	GW	7375	19-Jan-07
4300731318	PPU FED 16-27-12-16	4191	3021		12S	16E	27	S	GW	7571	9-Oct-07
4300730460	JACK CANYON UNIT 8-32	4279	2674		12S	16E	32	S	GW	9406	7-Feb-04
4304735970	UTE TRIBAL 3-9-1219	2599	2966		12S	19E	9	S	D	6505	3-Feb-06
4304736555	BIG DCK U 41-3	2792	3197		12S	20E	3	S	GW	8553	7-Oct-08
4304733243	FEDERAL Q 33-4	2879	3100		12S	21E	4	S	D	6500	8-May-99
4304736133	COTTONWD 12-21-14-10	2836	3256		12S	21E	10	S	D	7945	16-May-06
4304736424	AGENCY DR 12-21-31-36	3021	3052		12S	21E	36	S	GW	7050	10-May-06
4304732839	ROSEWOOD FED 4-6	3024	3230		12S	22E	4	S	D	6201	15-Aug-98
4304738055	HR 10MU-2-12-23	2873	3092		12S	23E	2	S	GW	4862	4-Jan-07
4304733484	DWR 12-23-31-21	3382	2610		12S	23E	21	S	GW	4500	22-Dec-08
4304732674	E BITTER CREEK 23-24	2995	3298		12S	23E	24	S	D	5800	6-Aug-95
4304733343	DWR 12-23-12-28	3804	1822		12S	23E	28	S	GW	5989	21-Oct-99
4304735084	HANGING ROCK FED 7-2	1933	4225		12S	24E	7	S	GW	4364	5-Jan-04
4304735927	ATCHEE RIDGE 16-19 #1	3346	3428		12S	25E	19	S	GW	4510	19-Oct-07
4304732587	DRAGON CYN 27-12-25 1	2456	3870		12S	25E	27	S	D	5421	24-Jun-96
4300730804	TD-3	6387	2000	NO	13S	13E	19	S	GW	2002	26-Oct-01
4300730982	PETERS PT 11-6-13-17	4177	2565		13S	17E	6	S	GW	9125	13-Sep-05
4304736931	UTE TRIBAL 1-20-1319	3265	3234		13S	19E	20	S	GW	13250	2-Apr-07
4304736598	UTE TRIBAL 1-33-1319	3455	3316		13S	19E	33	S	GW	5356	24-Jun-05
4304737291	MUSTANG 1320-10I	2773	3494		13S	20E	10	S	GW	8658	22-Jun-06
4304737289	MUSTANG 1320-13D	2791	3296		13S	20E	13	S	GW	8300	3-Aug-06
4304736383	MUSTANG 1321-6C	2785	3028		13S	21E	6	S	GW	7600	2-Jan-06
4304736374	UTAH OIL SHALE 1321-8A	3053	2914		13S	21E	8	S	GW	7444	9-Mar-06
4304733448	CHIMNEY ROCK 32-14	3532	3068		13S	21E	32	S	GW	11644	5-Oct-00
4304736731	SRU #8	3955	2730		13S	22E	23	S	GW	10465	23-Mar-06
4304738771	ATCHEE FED 32-4-13-25	3950	3250		13S	25E	4	S	GW	3851	23-Oct-07
4304732659	ATCHEE RIDGE 15-13-25 1	4462	3000		13S	25E	15	S	D	6860	26-Jul-96
4304732602	ATCHEE RIDGE 24-13-25 1	5188	2647		13S	25E	24	S	D	5805	26-Jul-96
4304736910	NHC 1-25-14-19	3946	3304		14S	20E	30	S	GW	4717	3-Nov-06
4304731096	PINE SPRINGS 9-12-14-21	3202	2755		14S	21E	12	S	GW	6225	21-Feb-82
4304736911	NHC 15-31-14-21	4082	2998		14S	21E	31	S	GW	10121	14-May-07
4304736962	PINE SPRINGS 15-36-14-22	3863	3310		14S	22E	36	S	GW	6050	12-Jul-06
4304730325	RAT HOLE CYN 1 7-8-14-25	4859	1864		14S	25E	8	S	D	4950	17-Nov-77
4304732705	RAT HOLE CYN 23-14-25 1	5131	2125		14S	25E	23	S	D	4600	6-Jun-96
4301931388	DIVIDE 2	4747	3500		15.5S	24E	32	S	GW	3600	10-Oct-01
4304737541	WF 14C-29-15-19	2845	5290		15S	19E	29	S	GW	13910	30-Aug-06
4304734955	N HILL CREEK 2-14-15-20	2678	4473		15S	20E	14	S	GW	11700	21-Jan-05
4304739499	NHC 12-33-15-20	3900	3640		15S	20E	33	S	GW	12149	15-Feb-08
4304738968	V CYN 20-1	4024	3242		15S	21E	20	S	GW	11309	20-Nov-07
4304737705	MAIN CYN FED 23-7-15-23	4980	2050		15S	23E	7	S	GW	10370	20-Feb-07
4304735685	HORSE POINT ST 43-32	4550	3106		15S	23E	32	S	GW	8425	10-Sep-04
4304732592	BLACK HORSE 9-15-24 1	3875	3725		15S	24E	9	S	GW	6192	6-Jun-96
4304731012	TP SPRINGS 14-18-15-25	4774	3097		15S	25E	18	S	D	8492	29-Oct-82
4301530022	NELSON UNIT 1	2347	4300		16S	15E	3	S	GW	8752	6-Oct-75
4301931405	MOON CYN # 2	2787	4610		16S	21E	9	S	GW	10300	2-Jun-05
4301931398	MOON CANYON 1	3456	4748		16S	21E	32	S	GW	10220	10-Dec-03
4301931458	KELLY CYN 10-8-16-22	2947	4392		16S	22E	8	S	GW	10962	21-Feb-06
4301931448	CEDAR CAMP 3-5-16-23	3895	3748		16S	23E	5	S	D	10369	27-Apr-05
4301930788	THREE PINES ST 32-10	4384	2092		16S	23E	32	S	D	7153	9-Aug-81
4301931454	WESTWATER ST 22-32	4539	2802		16S	24E	32	S	GW	7555	17-Jul-06
4301930646	FED 13-3-16-25	5213	3266		16S	25E	3	S	GW	7475	3-Jan-81
4301930460	FEDERAL 1-20	4370	2926		16S	25E	20	S	D	6479	9-Jul-79
4301911165	DIAMOND RIDGE UNIT 3	3837	2580		17S	22E	25	S	D	7633	24-May-60
4301930398	STATE 411 2	132	5270		18S	20E	23	S	D	10786	24-Jan-79
4301930727	BOGART CANYON 35-4	5351	3817	NO	18S	20E	35	S	D	8932	29-Aug-81
4301930770	DIAMOND CYN II U 15-15	3403	2674		18S	22E	15	S	GW	6334	7-Sep-81
4301930809	RATTLESNAKE CYN 2-12	4075	3498		19S	19E	2	S	GW	8174	10-Dec-81
4301930804	RATTLESNAKE CYN 16-4	4084	2565		19S	19E	16	S	D	7670	26-Aug-81
4301930734	STATE 14-4	4819	3820		19S	20E	14	S	D	8175	21-Dec-81
4301930086	FEDERAL 418-1	947	6028		19S	21E	23	S	D	6713	31-May-72

[1]If the column is blank the BMSW value was mapped, if "NO," the well was not used for mapping.

[2]GW = gas well; OW = oil well; WI = injection well; WD = water disposal; WS = water source well; D = dry hole

Table 5. *Well logs interpreted and BMSW picked for this study.*

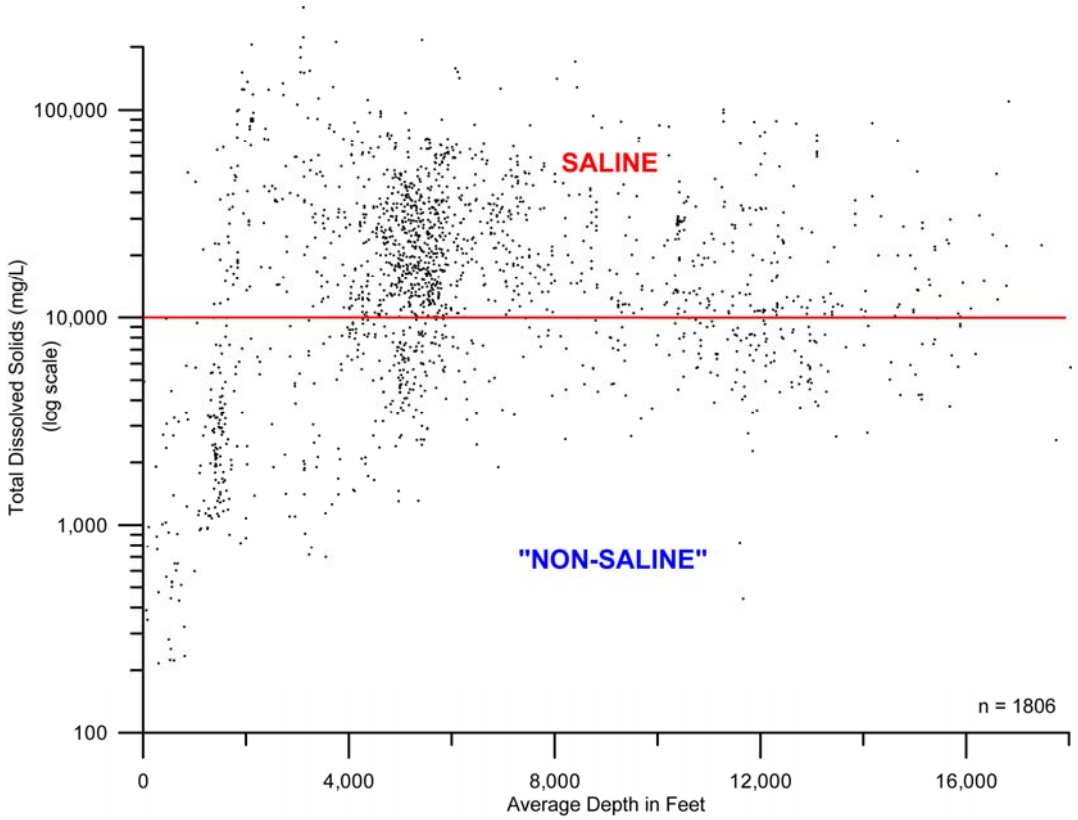

Figure 5. *Plot of TDS verses average depth of sample for all water analyses used in mapping.*

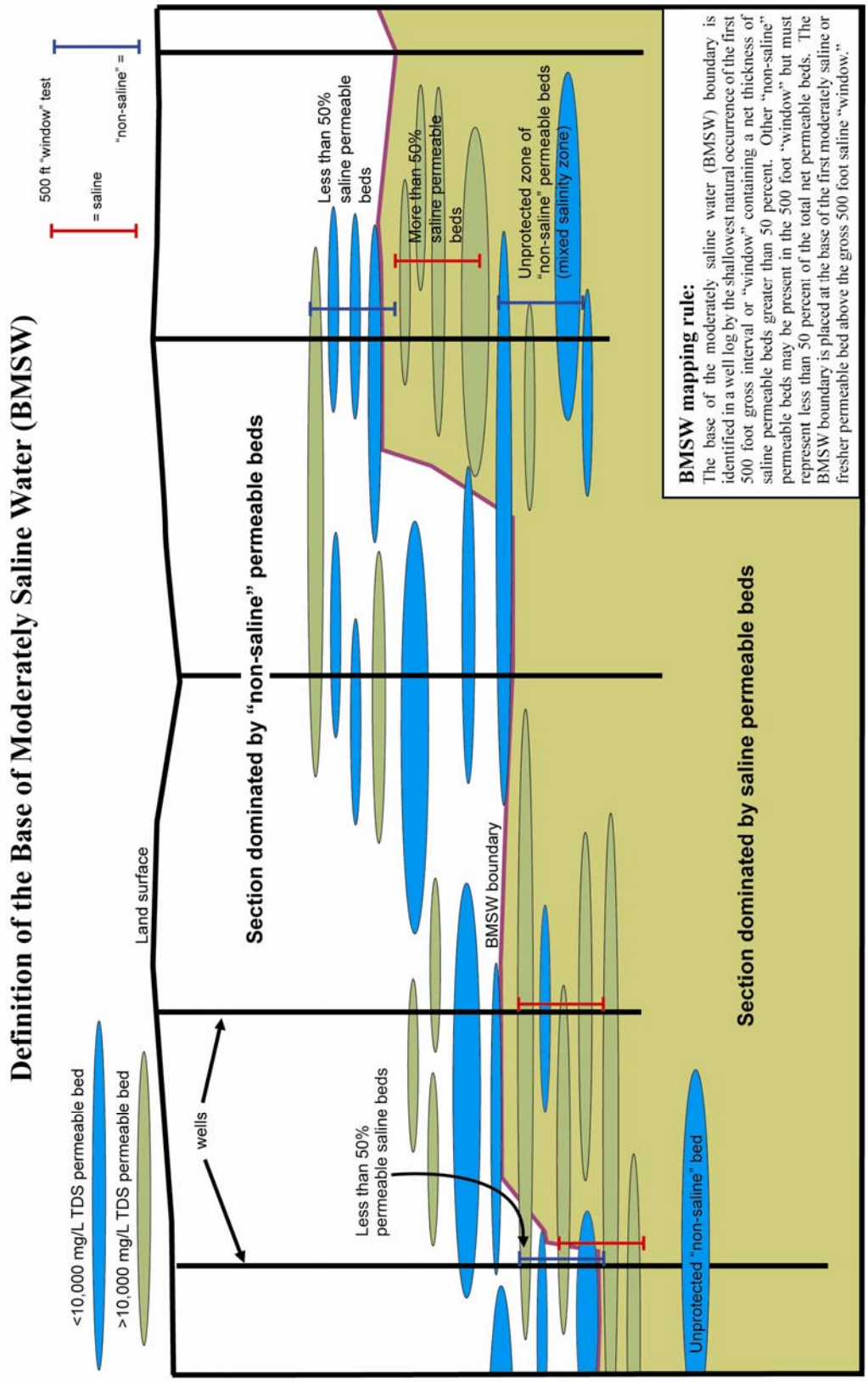

Figure 6. *Diagrammatic section illustrating the rule used in mapping the BMSW. The red bars are hypothetical "windows" or vertical intervals used when applying the BMSW mapping rule.*

Base of the Moderately Saline Water

Plate 1 is a contour map of the elevation of the BMSW. The contours were developed using algorithms to organize the "scattered" data points into regular gridded data. The output grid was generated for square grids of 100 meters. Information about the gridding parameters is provided in appendix C. The TP-92 data and new points generated by this study were combined for gridding/mapping, but all points from both data sets were not used in the contouring of the BMSW surface. Points of the type described above as 2, 3, or 5 were reviewed when plotted spatially to eliminate points that would inappropriately limit the contours. For example, if two nearby points were both type-2 points (or type 2 and 5), where the BMSW was shallower than the depth listed for each point, and one had an elevation of 3000 feet and the other an elevation of 4000 feet, the first point was dropped from the scattered data input file. The same procedure was used to drop inappropriately shallow type-3 wells. The points on plate 1 with posted elevation values were used in making the contoured surface of the BMSW. A point without an elevation label was dropped from the gridded scattered data file for the above reasons. Three additional wells were dropped from the TP-92 data set based on new well log analysis and water analyses in the area (see Area Specific Anomalies section, T. 3 S., R. 6 W., Uinta Base Line and Meridian [UBLM])

Plates 2 and 3 compare the surface generated in plate 1 with two additional surfaces generated from the water quality database. Plate 2 is the result of mapping the elevation of the top interval of saline water (>10,000 mg/L TDS) based on water analyses in appendix A. The method involves a similar procedure of gridding the saline water quality sample's top interval in the well, converted to elevation on a 100 meter grid. The saline water elevation grid could then be subtracted from the BMSW grid to find areas where the top of the saline water surface is above the BMSW surface. The gridded surfaces of the saline and "non-saline" waters were generated using a Kriging algorithm.

The color-filled contours on plates 2 and 3 are based on the amount of difference in the elevation between the top elevation of the water chemistry-sourced grids and the BMSW elevation grid (the greater the difference in elevation the cooler the colors). The red-filled contour represents a difference of 1000 feet or less, which, considering the accuracy of the log-based calculations, may be insignificant. The cause of these anomalies in plate 2 is either the log calculation-based mapping is inaccurate or thin isolated beds of saline water are present above the BMSW, which are tolerated based on the mapping rule. The water samples are from a discreet depth interval (sometimes rather large) and generally do not afford application of the mapping rules; therefore, the BMSW shown in plate 1 has not been altered based on the saline areas shown in plate 2. Red-filled areas on plate 2 represent areas where the BMSW may be more ambiguous or reflect an inaccuracy with the log interpretation methods, lack geophysical log coverage in the shallow section of wells, and these are areas where more care and study are required to define safe disposal zones. Overall, plate 2 demonstrates that the methods used to map the BMSW are generally consistent with water chemistry above the BMSW.

Plate 3 is generated using similar methods to those described above for plate 2, but displays those areas where gridded values of "non-saline" water elevation, based on water analysis, lie below the BMSW shown in plate 1. The grid generated for the "non-saline" water elevation is based on a kriging algorithm. The contoured area on plate 3 represents the area that lies within a search radius of 6400 meters (about 4 miles). This limited the influence of a water sample to the search radius. The difference in the elevation of the two gridded surfaces is contoured with color fill. Warm colors (red-yellow) represent the smallest difference and cooler colors (blue-purple) represent the largest differences. The warm-colors represent minor differences that may be related to methods, similar to areas on plate 2, but with opposite deviation from the BMSW. Areas of significant differences (>1000 feet, cool colors) are areas where a shallow moderately saline zone is underlain by one or more moderately deep to very deep "non-saline" zone(s), implying that more than one "BMSW" occur in these areas.

The colored-filled areas of plate 3 represent one method of identifying areas where the "non-saline"/saline waters are complexly stratified. Howells and others (1987) identified this same complex vertical stratification of varying TDS levels when they called out wells in which "... one or more intervals

of fresh to moderately saline water is known (from chemical analysis) or believed (from analysis of logs) to occur more than 500 feet below the base of moderately saline water shown." These types of points are identified as conditions 2 and 5. The colored areas identified on plate 3 are based solely on data from water analyses. Note that many type-2 or type-5 log-based interpretation points lie outside any color-filled contours on plate 3, indicating these deeper "non-saline" water areas are larger than the water analysis mapped areas of plate 3.

A section of "non-saline" water underlying a shallower saline section is illustrated by well 4304730174 located in section 1, T. 2 S., R. 1 W., UBLM. The well was first completed in 1976 from 11,035 to 12,752 feet in the Wasatch Formation and produced for about a year at a few hundred barrels of water a day with a TDS of 7750 mg/L. In late 1977, the well was plugged back and perforated in the lower Green River Formation from 8770 to 8906 feet. A water analysis taken in October of 1978 contained a TDS of 20,900 mg/L. Clearly "non-saline" water is present in the deeper Wasatch. Plate 1 shows the BMSW deepening in the area and wells to the west one mile and south two miles indicate deeper "non-saline" water. The southern of these wells, 4304732744, is completed from 9518 to 10,936 feet and a water sample from this interval had a TDS of 6604 mg/L. Other evidence for complex stratification of TDS comes from operator experience. Jack Watson (Enduring Resources, personal communication, 2009) identified an area southeast of the Oil Springs field (T. 12 S., R. 24 E., SLBLM) and shown on plate 3, where "non-saline" water is encountered in the top of the Mesaverde Group, well below the mapped BMSW. Similarly, Smouse (1992) lists R_w values for Altamont-Bluebell field ranging from 1.0 to 1.2 for the Green River Formation and from 0.97 to 4.12 for the deeper Wasatch Formation.

Plate 4 is a contour map of the depth to the BMSW surface mapped in plate 1. This map was constructed using the U.S. Geological Survey 30-meter digital elevation model (DEM) grid and subtracting the same grid used to contour the BMSW. The map should aid in planning future disposal well locations. Cross section lines A through E are labeled on plates 1 through 4 and numbered in subsequent order, plates 5 through 9. The BMSW and formation boundaries are shown on these structural sections.

Old versus New Mapping

Figure 7 compares BMSW mapping from TP-92 with mapping done for this study. The TP-92 data, minus some select wells (TP-92 edited data), as previously described, were used in this figure, but to better preserve the character of the earlier work, the TP-92 points that were altered (red dot on symbol, plate 1) were changed back to their original value. Using these TP-92 points, a grid on 100-meter centers was prepared. BMSW points generated by this study, and appropriate "less than" and "greater than" points edited out, were used for creating the second grid of similar size. The "new" grid was subtracted from the TP-92 grid to produce a difference grid, which was then contoured. The grid was cropped in the north portion of the basin because no new points were available in this area. Positive depths values represent areas where the newly mapped BMSW is shallower than that on the TP-92 map, whereas negative value areas are where the newly mapped BMSW is deeper than TP-92 data.

In the northwestern portion of the basin, in Wasatch County, two shallower anomalies are caused by two new points surrounded by numerous deeper TP-92 points. Few post-TP-92 wells were available in the area, giving the new shallower points greater influence than perhaps deserved. Additionally, the deeper anomaly (blue) along the Wasatch-Duchesne County boundary is an area with no new points but is an old shallow anomaly from TP-92 mapping that persists (section B-B', plate 6). The TP-92 point at well 4305110747 (see plates 1-3) at the center of the anomaly was reviewed. "Non-saline" beds likely occur at depth, so the anomaly is related to a shallow perched zone of saline water. This anomaly appears to be large on figure 7, but is the result of no new data points near the shallow TP-92 point at the center of the anomaly, and many deeper new points surrounding the TP-92 point. This anomaly may prove to be much smaller or disappear with additional drilling and analysis.

The anomaly south of the town of Tabiona, on the northern edge of the mapped area, is related to data density. At the center of the anomaly is the relatively shallow TP-92 data point. The anomaly lies along

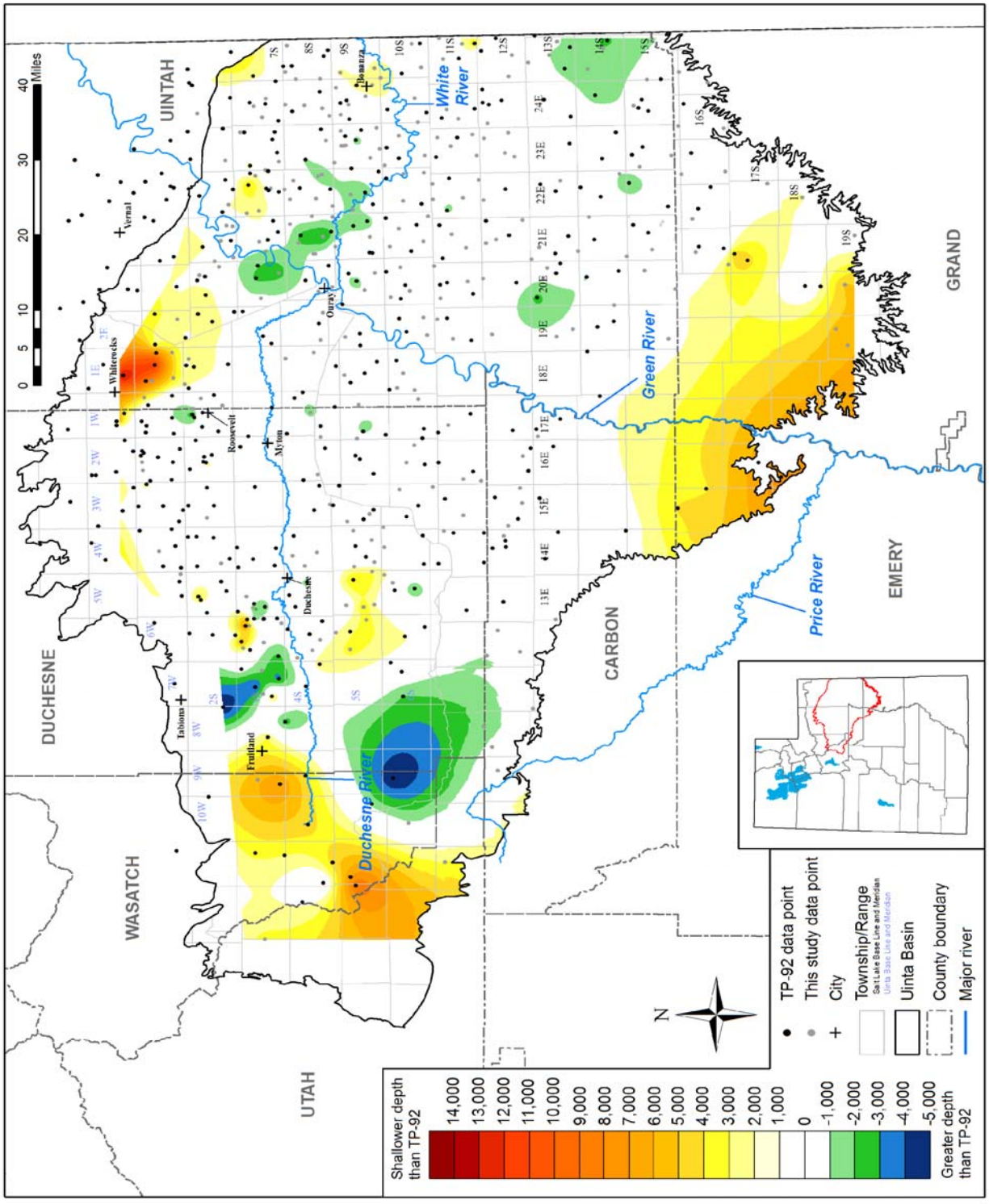

Figure 7. *Contour map of the depth difference in feet of the BMSW between new values from this study and select TP-92 values.*

the edge of the available new data, all with deeper picks. Southeast of Whiterocks is a shallow anomaly involving two wells and trending grossly north-south. Recall the map for TP-92 points is using the original values. These two points were reviewed and changed to much shallower depths, reflected on plate 1. This is an area with a shallow saline zone (perhaps perched) over a deeper "non-saline" section.

Between Ouray and Bonanza (T. 8 S., R. 21 E., SLBLM) is a deeper anomaly with new points running 1000 to greater than 2000 feet deeper than the TP-92 data. Old and new points number the same within the colored contours, but two of the new points were not used in mapping (because they tend to pull down the contours) while all of the TP-92 points were used (plate 1). The TP-92 points had six wells that were "less than the top of the logged interval," condition 2 points and two actual picked depths, while the new data had only one "less than" point and all the others were picked points (plate 1). The southern third of the anomaly lies within the Greater Natural Buttes field where it is difficult to find new drilling with logs run over the upper 3000 feet of the hole. The newer data found deeper "non-saline" water. Since the newer data is in an area where the start of the logged interval is deeper, it is possible the new points are mapping a second BMSW and the TP-92 data is principally mapping in a shallow saline zone.

The southeasternmost deeper anomaly (T. 14 S., R. 25 E., SLBLM) has its center near the Utah border at TP-92 well 4304730597 (plate 1), which indicates a very shallow BMSW. Nearby wells indicate gas saturation in the shallow section, making a pick difficult and suspect. This well has no logs posted on the DOGM website (accessed 11/30/10) so no check of the pick is possible. As a substitute, logs for 4304731894 to the south were examined from 800 to 7800 feet. The BMSW appears to be near the base of the Mesaverde Group or the top of the Mancos Shale. This corroborates the new data point and 4304732705 is partly responsible for the anomaly. Perhaps there is a very shallow thin zone of saline water, but the logs in the area start too deep to confirm this.

Figure 7 indicates a broad area of shallower BMSW at the very southern end of the project area. This is caused by the change in the mapping rules between the two studies. The BMSW is now mapped at the base of the moderately saline Mesaverde, much shallower than the saline Dakota-Morrison Formations mapped by original TP-92 data.

Regional Trends

A prominent deep trend in the BMSW wraps around the northern end of the entire basin (plates 1, 5, and 8). Howells and others (1987) suggest this is related to recharge from the Uinta Mountains immediately to the north. Other authors concur with Howells and others (1987) and suggest this same regional flow path to account for the thick section of "non-saline" groundwater (Freethey, 1992; Glover, 1996; Zhang and others, 2009). Howells and others (1987) suggest a possible deep regional discharge to the southwest, but offer no particular evidence to support the idea. Deep upward flow in the center of the basin and discharge to surface streams is referenced by Zhang and others (2009) as a regional sink for groundwater flow. Desolation Canyon of the Green River at Three Fords Rapid is the deepest incision in the project area's topography, with an elevation of 4260 feet. The BMSW's deepest elevation is just under -5000 feet (plate 1), or 9260 vertical feet below this potential discharge point.

Lucas and Drexler (1975), Bredehoeft and others (1994), and McPherson and Bredehoeft (2001) mapped an area of over-pressured rocks in the Uinta Basin which approximately matches the area of deep "non-saline" water shown in plate 1. Bredehoeft and others (1994) show evidence for hydrocarbon generation and believe it is the cause of the over-pressured zone. Bartberger and Pasternack (2009) called on expulsion of water from clays in the over-pressured deep eastern Greater Green River Basin, Wyoming, to explain a freshening of formation water at depth. This may contribute to "non-saline" water found in the deep Green River Formation along the northern edge of the Uinta Basin. It is hard to envision a present day groundwater flow path from the Uinta Mountains into this "over-pressured vessel." However, "non-saline" water is found both in the deep over-pressured area and above it, indicating that perhaps both earlier freshwater recharge from the Uinta Mountains and later water expulsion from clays at depth may explain the TDS pattern.

A long east-west trend of shallow BMSW parallels the Duchesne fault zone north of T. 5 S. (UBLM) or T. 10 S. (SLBLM) (plate 1). This trend also corresponds with the center of the basin during Green

River Formation deposition. The upper Green River Formation was deposited by a retreating and sometimes saline lake whose center migrated through time to the west (Franczyk and others, 1992). Dyni and others (1985) mapped an area of bedded salts in the upper Green River Formation (saline facies) centered on T. 3 S., R. 5 W., UBLM. The combination of available salts in the upper Green River Formation, an east-west fault and fracture system, which may enable vertical mobility of fluids in the rock column, and the topographic low (see plate 8, D-D') of the Uinta Basin all likely contribute to shallow saline groundwater along this trend. Disruption and widening of the trend to the east is likely related to a fracture orientation change to northwest-southeast (similar to the gilsonite veins) and groundwater in-flow from the Douglas Creek arch along the Utah-Colorado state line (Zhang and others, 2009).

A similar, but less prominent trend of shallow saline water is found in the south-central portion of the basin and parallels the structural trend of faults shown on plate 1. This trend begins on the West Tavaputs Plateau (T. 13-14 S., R. 15 E., SLBLM) and continues southeast toward T. 15 S., R. 22-23 E, SLBLM. The trend is sub-parallel to the Garmesa fault zone (Stone, 1977) and the northeastern edge of the Uncompahgre uplift. The saline facies of the Green River Formation thins to the south and is a less important factor than in the northern trend, perhaps a reason the trend is less prominent than its northern neighbor. The southwest side of this trend is defined by a subtle "low," which is based on very few data points.

Area Specific Anomalies in the BMSW

T. 1 N., R. 1 W., UBLM: The BMSW elevation difference between the two TP-92 BMSW points 4301330707 and 4301330942 is 8095 feet in less than one mile. The well with the deeper BMSW (11,037 feet deep), 4301330707, has resistivity/SP log (R_{mf} 3.0 at 83°F) from 2353 feet to TD (17,419 feet) and density-neutron log coverage from 8500 feet to TD. The SP character confirms the BMSW pick, but deeper in the well, the SP indicates a return to less saline conditions. Additional review found Howells and others' (1987) original pick reasonable. Well 4301330942 has a resistivity/SP (R_{mf} 1.03 at 50°F) log from 24 feet to TD (17,264 feet), and density-neutron log coverage from 5000 feet to TD. Based on the SP log, Howells and others' (1987) pick is on the top saline bed with 140 feet of impermeable beds above. Mapping rules used in this study would move the BMSW up to the base of the overlying permeable bed at 2720 feet, increasing the BMSW's difference between the two studies. This abrupt change of the BMSW is likely the edge of a perched layer of saline groundwater (to the south and east) overlying deeper "non-saline" groundwater. Plate 1 data points to the south and east indicate this tongue of shallower saline water has "non-saline" water below.

T. 3 S., R. 6 W., UBLM: In the northeast portion of this township is a minor "hole" in an otherwise fairly consistent shallow BMSW. On first pass the feature had considerable relief defined mainly by three TP-92 points, which have subsequently been dropped from inclusion in the scattered data set. These three dropped points all have red dots on the TP-92 well symbology (plate 1). The TP-92 wells were dropped based on three factors.

First, new water analyses from well 4301334276 (section 11, T. 3 S., R. 6 W., UBLM) have a TDS of 11,609 mg/L from a large interval from 8565 to 10,705 feet in the hole. A second well, 4301334277 (section 10, T. 3 S., R. 6 W., UBLM), sampled from 8102 to 10,740 feet yielded a TDS of 10,970 mg/L, and both wells indicated the water at depth is very near the 10,000 mg/L boundary, but above it. In section 9, T. 3 S., R. 6 W., UBLM, the well 4301350646 sampled formation water from 7676 to 7812 feet in the well and reported a TDS of 14,073 mg/L. Finally, well 4301330056 (section 14, T. 3 S., R. 6 W., UBLM), a disposal well, took two samples from the interval 2857 to 3373 feet, reporting a TDS of over 200,000 mg/L for both. The water analysis data indicate formation water is going from shallow very saline to deeper and freshening water. Most of the sampled water has high sulfate and bicarbonate, which will increase the resistivity of the water for 10,000 mg/L water. It is best to use a resistivity near 0.74 at 68°F for the 10,000 mg/L boundary.

Second, all of the dropped TP-92 logs were examined along with several newly drilled wells in the area and all logs give ambiguous indications of water salinity. One new well in section 11 was added to the newly interpreted well collection with the BMSW likely above the shallow casing. The water analyses from the area provided a bias for the well interpretation. Difficulty in log interpretation has been noted by others for the Altamont-Bluebell area (Morgan, 2009a).

Third, recent drilling and analysis by Bill Barrett Corporation has indicated saline minerals in the lower Uinta Formation and upper Green River Formation in this area (Jim Kinser, Bill Barrett Corporation, written communication, 2012). These saline minerals are likely related to the shallow-depth, high salinities in the area. The anomaly, defined by the 2000 foot elevation contour on plate 1, is surrounded by a BMSW encountered at higher elevations (shallower depths). As drilling and water sampling continues with step out and in-fill drilling, evidence may support a much shallower BMSW in the area of the present anomaly.

T. 3 S., R. 7 W., UBLM: From east to west across the township is a steep drop in the BMSW. Westward the BMSW stays deep (plate 5), but the well density drops in this area. In well 4301310754, at the apex of the low, a water sample was obtained via production from 10,055-11,670 feet with a TDS of 10,800 mg/L. The top of the sample depth is just a few hundred feet higher in the hole than the log-estimated BMSW (10,687 ft), indicating reasonable agreement between water quality and log analysis. However, like the anomaly described in the township to the east, more water samples may prove the BMSW lies at shallower depths.

T. 5 S., R. 5 W., UBLM: The logs were examined for the anomalous TP-92 well 4301330541 and the BMSW pick of 493 feet in elevation was confirmed. However, the top of the logs are at a depth of 1250 feet (5156 feet elevation) and many surrounding wells have higher elevations for their BMSW picks. It is probable that the first BMSW is shallower but was not detected because of no log coverage in the shallow part of the well. Assuming an undetected shallower BMSW, this would be a good example of multiple intervals of moderately saline water separated by saline waters.

Birds Nest aquifer: The area of the Birds Nest aquifer, which contains large nodules of nahcolite ($NaHCO_3$), is shown on plate 1 and centers around T. 9 S., R. 21 E., SLBLM (Vanden Berg and others, 2011). A dashed line within this area on plate 1 delineates the approximate change in the Birds Nest aquifer from saline to the north to "non-saline" in the south. As shown on plate 1, this boundary corresponds with a northward shallowing of the BMSW related to high-salt content in the Birds Nest likely, related to active dissolution of nahcolite.

T. 7 S., R. 25 E., SLBLM, and Red Wash field: TP-92 well 4304710078 creates a closed low near the Utah-Colorado border. Logs for this well are not publicly available (DOGM website, accessed 2011). The well lies outside the Uinta Basin bounding fault and on the east side of Raven Ridge (Sprinkel, 2007). This low is connected to a trough extending to the west into the Red Wash field (T. 7 S., R. 23 E., SLBLM) where complexly stratified TDS water is common (see plate 3). The Red Wash low, or trough, can be also seen in cross section on plate 5. The drop in elevation of the BMSW on the section line is near the mapped edge of the Birds Nest aquifer shown on plate 1. The low may be related to recharge from the Douglas Creek arch along the Utah-Colorado state line and the eastern edge of the saline facies in the upper Green River Formation. However, if the reduction of saline water in the shallow portion of the Red Wash field is related to the reduction of salines in the upper Green River Formation, the tongue of shallow saline water to the north of the Red Wash low must have another source. This saline tongue crosses the basin axis (Roberts, 2003) and bounding fault into a structurally complex area north of the Section Ridge anticline (Sprinkel, 2007).

T. 14 S., R. 25 E., SLBLM: This high on the southeast flank of the basin is partly related to a topographic high in the same area. The high extends southwest toward T. 15 S., R. 22 E., SLBLM. From

cross section C-C' (plate 7), on the south part of the high, the BMSW rises along with the land surface. On the cross section, the BMSW approximately parallels the top of the Mesaverde Group. At the center of the anomaly in T. 14 S., R. 25 E., SLBLM, the BMSW lies in the Green River Formation to Mesaverde Group, with depths ranging from 433 to 3250 feet (see plate 4). This edge of the basin is different from the most southern part (plate 1), where the BMSW becomes deeper near the basin edge (plate 9, E-E'), but in cross section E-E', the surface drainage divide is crossed near well 4304731448 and both the topography and the BMSW generally descend southward from this well.

The Fourth Dimension - Time

The groundwater flow system in the Uinta Basin is dynamic and changes with time. Numerous examples of a well's changing produced water chemistry are found in the data (for example, 430130130, 4301330149, 4301330202, 4301330105, 4301330143, 4301330106, appendix A). Some of these examples may be related to "cleaning up" after the well begins to produce, but many of the examples span significant periods of time and produce large volumes of water, clearly indicating real changes over time in the chemistry of the formation water.

Another element effecting changes in produced water quality with time is injection into the subsurface either by disposal wells or injection wells. To evaluate a possible change in water quality due to injection, TDS data from the water quality database in the Monument Butte field were queried for all analyses from wells in the field completed before and after January 1, 1996 (the approximate date when injection began), and with a "yes" in the "used in mapping the BMSW" column (appendix A). Injection water used in the field is "non-saline," generally taken from shallow water wells, so water injection in the field should freshen produced natural formation waters. Table 6 summarizes the findings. A very minor drop in the TDS has occurred in water samples from the field which post-date the on-set of injection. Red Wash field has been using water injection to enhance production since about 1950. A query of analyses for Red Wash field yielded no water samples taken before water injection began, so a similar comparison was not possible.

CONCLUSIONS

The BMSW in the Uinta Basin is complex and influenced by the interaction of recharging fresh groundwater, saline stratigraphy, and groundwater flow paths. In many parts of the basin, multiple stratified intervals of saline and "non-saline" groundwater are present in the vertical section to depths over 15,000 feet, implying more than a single moderately saline zone. Compiled and depth-correlated water analyses from various sources provide a calibration for geophysical-log interpretation of the elevation of the BMSW, although most of the water samples are recovered from producing intervals, which are rarely coincident with the BMSW. The TDS concentration of depth-correlated water quality samples clearly shows a poor correlation to depth taken as a whole, but individual formations may show some correlation of quality and depth. Spatial distribution of geophysical log-derived estimates of TDS and formation water sample analyses are not equally distributed, both spatially and vertically in the basin, impacting the local accuracy of the mapping. Prior mapping and new mapping are similar, with some exceptions, and new mapping has better defined the BMSW surface. Injection and disposal effects on the groundwater quality in the basin from the mid-1980s to the present can be demonstrated, but only in a few specific wells and fields. The volume of disposed water is relatively small compared to the storage space available within the basin, and therefore is not expected to affect large areas. The BMSW surface is influenced by the stratigraphy and structure of the basin, with the surface commonly crossing formation boundaries. In the northern portion of the basin, water analyses and log-picked salinity both indicate a broad zone of deep "non-saline" water, often complexly stratified with saline water. Because log-based calculations used to estimate TDS in a well are sometimes uncertain, a need for a definitive characterization of formation water of a specific bed or zone for regulatory purposes should always rely on a laboratory analysis of a valid water sample.

Condition	Number of Analyses	Average	Maximum	Minimum	Std. Dev.
Pre-injection	64	24,459 mg/L	73,000 mg/L	3800 mg/L	14,004 mg/L
Post-injection	114	21,245 mg/L	73,497 mg/L	5139 mg/L	12,043 mg/L

Table 6. *Changes in produced water TDS before and after water injection in the Monument Butte field, Utah.*

ACKNOWLEDGEMENTS

This project was generously funded by the U.S. Department of Energy, National Energy Technology Laboratory under project code NT0005671. Additional funding was provided by the Utah Geological Survey. Special thanks to our DOE project officers Traci Rodosta, Virginia Weyland, and Skip Pratt.

Howells and others (1987) prior work laid an excellent foundation and is appreciated. Special thanks to Gil Hunt (DOGM) for tracking down files left from the previous study. Baker-Atlas generously provided a current well log interpretation handbook and charts. Thanks to the following operators in the basin for sharing LAS digital geophysical logs or in-house water analyses: Alta-Blue; Anadarko Petroleum Corporation; Anschutz; Berry Petroleum Company; Bill Barrett Corporation; Blue Tip Castlegate, Inc.; David Allin; Devon Energy Production Co., LP; El Paso E&P Company, LP; Elk Resources, LLC; Enduring Resources, LLC; EOG Resources, Inc.; FMIL Natural Resources; Flying J; Forest Oil Corporation; GASCO, Inc.; Halliburton; JW Operating; Kansas Geological Survey; McElvin Oil & Gas Properties, Inc.; Mustang Fuel Corporation; Newfield Production Company; Pendragon Energy Partners, Inc.; Questar Energy Company; Robert L. Bayless Production, LLC; Rosewood Resources, Inc.; Royale Energy, Inc.; Summit Operating, LLC; TCC Royalty Corporation; Whiting Oil & Gas Corporation; Wind River Resources Corporation; and XTO Energy, Inc. Dr. Ye Zhang of the University of Wyoming also provided her complete database of water analyses. Thanks to the U.S. Geological Survey (Salt Lake and North Dakota offices) for looking for old project files and Briant Kimball for sharing water analyses.

Discussions regarding log analysis and R_w were particularly helpful, with special thanks in this regard to Dr. Rich Jarrard, University of Utah; Paul Lipinski, Berry Petroleum; Jim Kinser and Jason Anderson, Bill Barrett Corporation; Sean Kelly, Anadarko Petroleum Corporation; Russell Griffin, Questar Energy Company; Marc Eckels, Wind River Resources; Carl Kendall, Summit Operating; and Jack Watson, Enduring Resources, LLC. Thanks to Brad Hill, Dan Jarvis, John Rogers, and Clint Dworshak of DOGM for input on mapping rules and review of the new mapping. Acknowledgment also goes to Utah Geological Survey employees Ammon McDonald, Danielle Lehle, Jay Hill, and Rebekah Wood for their support and to David Tabet, Robert Ressetar, Kimm Harty, and Rick Allis for their detailed review.

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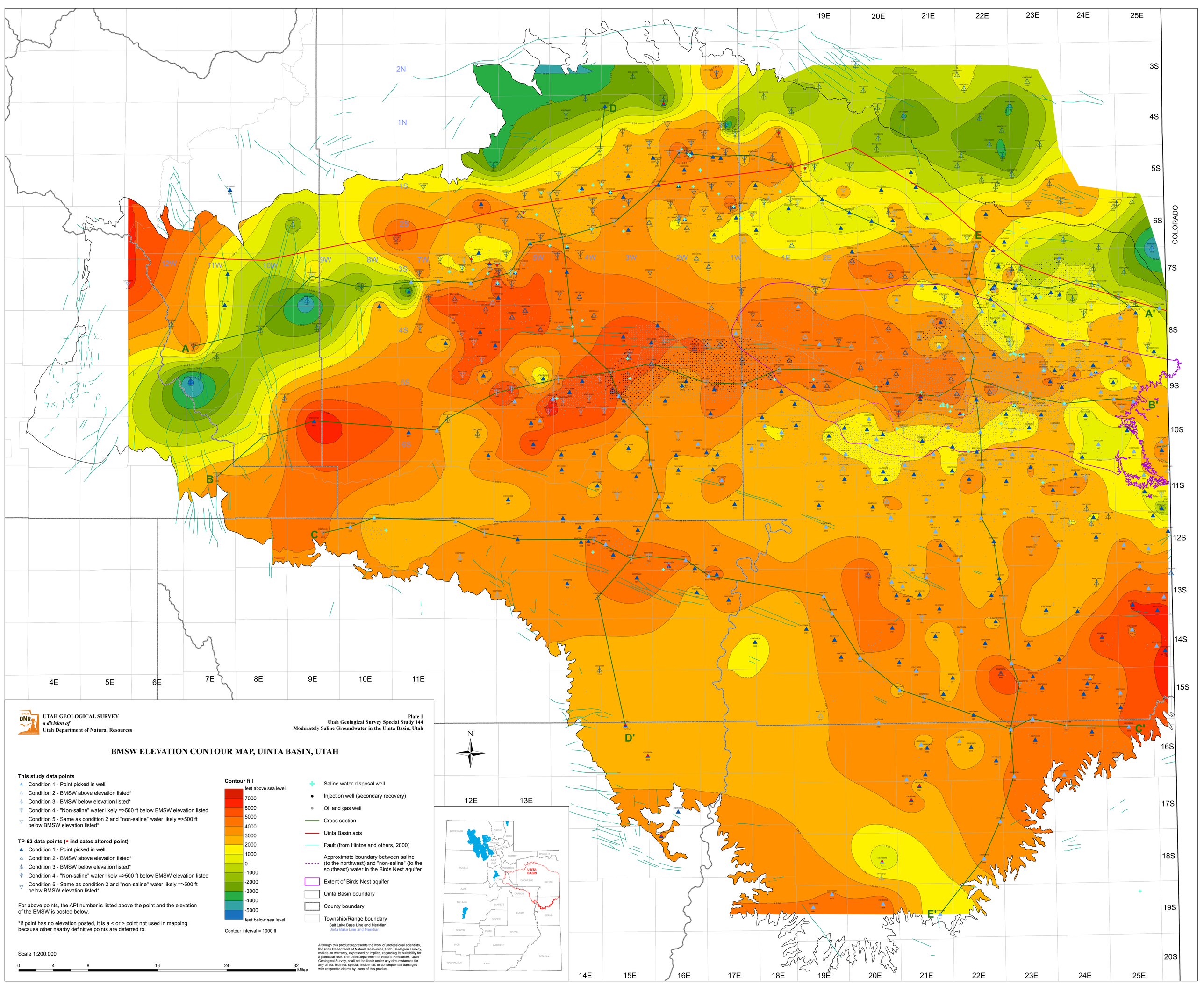

UTAH GEOLOGICAL SURVEY
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Plate 1
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah
BMSW ELEVATION CONTOUR MAP, UINTA BASIN, UTAH
This study data points
Condition 1 - Point picked in well
Condition 2 - BMSW above elevation listed*
Condition 3 - BMSW below elevation listed*
Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*
TP-92 data points (• indicates altered point)
Condition 1 - Point picked in well
Condition 2 - BMSW above elevation listed*
Condition 3 - BMSW below elevation listed*
Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*
For above points, the API number is listed above the point and the elevation of the BMSW is posted below.
*If point has no elevation posted, it is a < or > point not used in mapping because other nearby definitive points are deferred to.
Contour fill
feet above sea level
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
feet below sea level
Contour interval = 1000 ft
Saline water disposal well
Injection well (secondary recovery)
Oil and gas well
Cross section
Uinta Basin axis
Fault (from Hintze and others, 2000)
Approximate boundary between saline (to the northwest) and "non-saline" (to the southeast) water in the Birds Nest aquifer
Extent of Birds Nest aquifer
Uinta Basin boundary
County boundary
Township/Range boundary
Salt Lake Base Line and Meridian
Uinta Base Line and Meridian
Scale 1:200,000
0 4 8 16 24 32 Miles
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N
COLORADO
A
A'
B
B'
C
C'
D
D'
E
E'
UINTA BASIN

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Plate 2
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

CONTOUR MAP OF ELEVATION DIFFERENCE OF SALINE WATER ANALYSIS SAMPLE POINTS THAT LIE ABOVE THE BMSW, UINTA BASIN, UTAH

This study data points

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

TP-92 data points (• indicates altered point)

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

For above points, the API number is listed above the point and the elevation of the BMSW is posted below.

*If point has no elevation posted, it is a < or > point not used in mapping because other nearby definitive points are deferred to.

Water sample >10,000 mg/L TDS. Label below point is elevation of the top of the sample interval. Color contoured where gridded elevation value of samples is above the BMSW.

Scale 1:200,000

0 4 8 16 24 32 Miles

Contour fill
feet above BMSW grid

3000
2000
1000
0

Contour interval = 1000 ft

Contour values drawn on the positive difference in elevation between the gridded value of the elevation of the deepest top interval of water analyses from a well in which the TDS is >10,000 mg/L and the gridded value of the BMSW (plate 1). Contour algorithm for water sample grid is inverse distance (2), search radius 6400 m (~4 miles).

- Saline water disposal well
- Injection well (secondary recovery)
- Oil and gas well
- Cross section
- Approximate boundary between saline (to the northwest) and "non-saline" (to the southeast) water in the Birds Nest aquifer
- Extent of Birds Nest aquifer
- Uinta Basin boundary
- County boundary
- Township/Range bounday
  Salt Lake Base Line and Meridian
  Uinta Base Line and Meridian
- Section boundary

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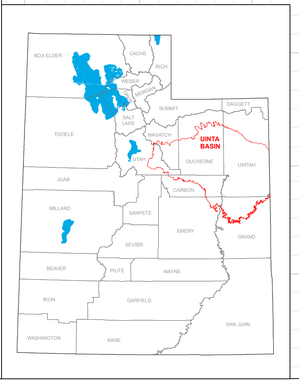

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Plate 3
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

CONTOUR MAP OF ELEVATION DIFFERENCE OF "NON-SALINE" WATER ANALYSIS SAMPLE POINTS THAT LIE BELOW THE BMSW, UINTA BASIN, UTAH

This study data points

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

TP-92 data points (• indicates altered point)

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

For above points, the API number is listed above the point and the elevation of the BMSW is posted below.

*If point has no elevation posted, it is a < or > point not used in mapping because other nearby definitive points are deferred to.

Water sample <10,000 mg/L TDS. Label below point is elevation of the top of the sample interval. Color contoured where gridded elevation value of samples is below the BMSW.

Scale 1:200,000

0 4 8 16 24 32 Miles

Contour fill
feet below BMSW grid

0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-11000
-12000
-13000

Contour interval = 1000 ft

Contour values drawn on the negative difference in elevation between the gridded value of the BMSW (plate 1) and the gridded value of the elevation of the shallowest top interval of water analyses from a well in which the TDS is <10,000 mg/L. Contours are blanked beyond 4 miles from data points in TDS file.

- Saline water disposal well
- Injection well (secondary recovery)
- Oil and gas well
- Cross section
- Approximate boundary between saline (to the northwest) and "non-saline" (to the southeast) water in the Birds Nest aquifer
- Extent of Birds Nest aquifer
- Area of "non-saline" water at top of Mesaverde (source: Enduring Resources)
- Uinta Basin boundary
- County boundary
- Township/Range boundary
  Salt Lake Base Line and Meridian
  Uinta Base Line and Meridian

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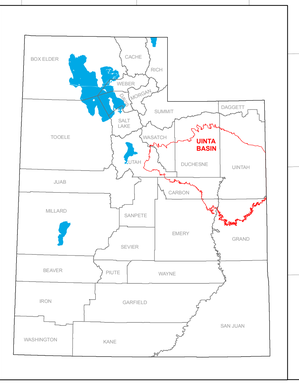

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Plate 4
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

DEPTH TO THE BMSW, UINTA BASIN, UTAH

This study data points

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

TP-92 data points (• indicates altered point)

- Condition 1 - Point picked in well
- Condition 2 - BMSW above elevation listed*
- Condition 3 - BMSW below elevation listed*
- Condition 4 - "Non-saline" water likely =>500 ft below BMSW elevation listed
- Condition 5 - Same as condition 2 and "non-saline" water likely =>500 ft below BMSW elevation listed*

For above points, the API number is listed above the point and the depth of the BMSW is posted below.

*If point has no depth posted, it is a < or > point not used in mapping because other nearby definitive points are deferred to.

Contour fill
Depth in ft to BMSW

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000

Contour interval = 1000 ft

- Saline water disposal well
- Depth contour^
  1000 ft contour interval, + or - 100 ft
  (grey line = 500 ft contour interval)
- Cross section
- Uinta Basin boundary
- County boundary
- Township/Range boundary
  Salt Lake Base Line and Meridian
  Uinta Base Line and Meridian

^This map was constructed using the gridded surface of the BMSW displayed on plate 1, which was subtracted from a more detailed grid of the surface topography of the area.

Contours are an approximation of the depth to the BMSW. Mapping methods result in an accuracy of about + or - 100 ft in mild terrain.

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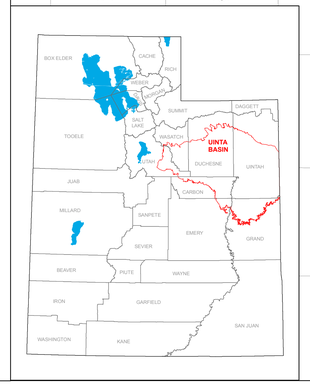
Scale 1:200,000

0 4 8 16 24 32 Miles



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A-A' WEST TO EAST CROSS SECTION (NORTHERN)

Plate 5
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

A West — A' East

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
4305130008 EXXON CO USA STRAWBERRY RES 1 T4S R11W S30	4305130001 GULF OIL CORP TRIBAL-WILLOW CREEK 1 T4S R10W S16	4305130010 AMOCO PROD CO SMITH M A OIL 1 T3S R9W S16	4301311126 CONTINENTAL OIL CO CORE HOLE 4 T3S R8W S20	4301331038 LINMAR ENERGY CORP SMITH 1-20CT T3S R7W S20	4301331634 BENNETT E&P&PROD BENNETT E & P ZK-23C7 T3S R7W S23	4301330243 KOCH EXPL CO CEDAR RIM 6 T3S R6W S21	4301332112 BARRETT RES CORP OWL 3-17-CS T3S R5W S17	4301330340 SHELL OIL CO LDS CHURCH 2-27-8S T2S R5W S27	4301331298 ANR PRODUCTION CO WEIKERT 2-29B4 T2S R5W S29	4301331056 PENNZOIL CO INC EVANS-UTE 2-17B3 T2S R5W S17	4301330169 CHEVRON U S A INC UTE TRIBAL 5-30A2 T1S R5W S30	4301330011 CHEVRON U S A INC VICTOR BROWN UNIT 1 T1S R5W S4	4301330026 CHEVRON U S A INC CURTIS-BASTIAN UNIT 1 T1S R4W S7	4304739467 FLYING J O&G INC FLYING J FEE 2-12A1 T1S R4W S12	4304739920 BOW VALLEY PETR INC UTE TRIBAL 1-15A1E T1S R1E S15	4304739830 BOW VALLEY PETR INC UTE TRIBAL 1-25A1E T1S R1E S25	4304730300 ALBERTA GAS COMPANY FEDERAL 1 T5S R1E S33	4304720202 BARRETT RES CORP TRIUMPH FEDERAL 2 T6S R3E S12	4304739078 NEWFIELD EXPL CO FEDERAL 14-24-8-20 T6S R2E S24	4304731698 ALTA ENERGY CORP ANNA BELLE 31-2-3 T6S R1E S31	4304735408 QUESTAR EXPLORE&PROD BRENNAN BOTTOM E 15G-16-7-2 T7S R1E S16	4304734403 SHENANDOAH ENERGY SU BRENNAN W 15W-18-7-22 T7S R2E S18	4304733497 SHENANDOAH ENERGY FEDERAL 13-19B T7S R1E S19	4304731076 CHEVRON U S A INC RED WASH 27I811-26B T7S R2E S26	4304735239 QEP UINTA BASIN INC RED WASH RW12G-20C T7S R2E S20	4304735098 QEP UINTA BASIN INC RED WASH UNIT 34-22C T7S R1E S22	4304732253 EQUITABLE RES ENERGY BALCRON COYOTE 12-5 T8S R2E S5	4304737894 HOUSTON EXP CO THE EAST COYOTE 10-3-8-25 T8S R1E S2
GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150	GR 0–150

Subsea Depth (ft) 8500 … −9000 (left) — Subsea Depth (ft) 8500 … −9000 (right) — Measured Depth(ft) 6500 … 5500

Ground Level

4176 · 1980 · 1747 · 2445 · 1205 · 2333 · 2889 · 1618 · 3841 · >293 · 3511 · 3141 · 6095 · 3584 · >3317 · >3392 · >327 · 977 · 728 · 2383 · 2704 · >2776 · 4202 · 508 · >627 · <111 · <47 · 1978 · 281

Sea level

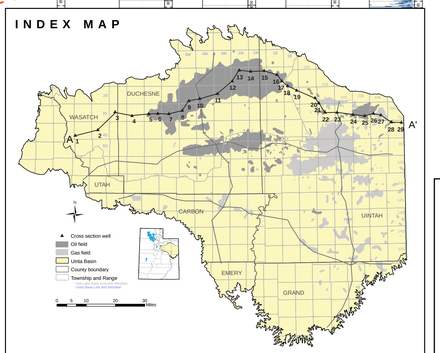
GREEN RIVER

WASATCH

Tie to D-D'

Tie to E-E'

INDEX MAP



EXPLANATION

- 4148 — Base of moderately saline water (elevation in feet) (dash line = uncertain pick)
- Top of Tertiary Green River Formation
- Top of Tertiary Wasatch Formation
- Saline water above (see plate 2)
- "Non-saline" water below (see plate 3)

Note: < or > in front of elevation indicates uncertain absolute BMSW pick due to incomplete log (i.e., BMSW is somewhere above/below this value). The cross section elevation was picked from the BMSW elevation map (plate 1).

Note: Only the gamma ray log is shown, salinity calculations were made using multiple other log traces which could include depths not covered by the gamma ray log.

UTAH GEOLOGICAL SURVEY
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B-B' WEST TO EAST CROSS SECTION (MIDDLE)

Plate 6
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

B West — B' East

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4304930003 MOUNTAIN FUEL SUPLY SKYLINE-FEDERAL 1	4305130002 MOUNTAIN FUEL SUPLY GREMO HILL 1	4305110747 MONSANTO CHEMICAL CO FRED 1	4301330538 ENERGY RESV GRP INC INDIAN CANYON UNIT 2	4301310418 GULF OIL CORP FEDERAL 1	4301332993 FIML NATURAL RES LLC UTE TRIBAL 3-25-56	4301333900 BERRY PETROLEUM CO UTE TRIBAL 10-18-54	4301331858 PETROGLYPH OPERATING UTE TRIBAL 07-15	4301330451 PACIFIC TRNSMSN SPLY STATE 64-36	4301332274 NEWFIELD EXPL BELUGA UNIT 4-18-9-17	4304731129 NATURAL GAS NGC-FEDERAL 32-14	4304735594 NEWFIELD EXPL FEDERAL 10-4-9-18	4304731199 DIAMOND SHMROCK CORP PARIETTE BENCH 34-5	4304737755 KERR-MCGEE O&G ON LP NATURAL BUTTES UNIT 920-20I	4304733009 COASTAL O&G CORP NATURAL BUTTES UNIT 260	4304739371 KERR-MCGEE O&G ON LP NATURAL BUTTES UNIT 922-18G	4304735278 EOG RESOURCES INC CHAPITA WELLS UNIT 859-29	4304735362 HOUSTON EXP CO THE SOUTHMAN CANYON 6D-36	4304735863 ENDURING RES LLC BONANZA 9-24-11-36	4304736432 ENDURING RES LLC SOUTHAM CANYON 9-25-22-32
T11S R7E S10	T10S R9E S16	T6S R9W S9	T6S R7W S14	T6S R7W S12	T5S R5W S25	T5S R4W S18	T5S R3W S7	T8S R3E S36	T9S R17E S18	T9S R17E S14	T9S R18E S4	T9S R19E S5	T9S R20E S20	T9S R21E S28	T9S R22E S18	T9S R23E S29	T9S R24E S36	T9S R24E S36	T9S R25E S32
GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR	GR
0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150	0 150

Subsea Depth (ft) — Measured Depth(ft)

Ground Level

Sea level

3196 | 1433 | 6971 | 3172 | <2499 | 5899 | 4808 | 4994 | >5330 | 4197 | 3981 | >4622 | >4507 | >1987 | >3233 | >2139 | 3200 | 2222 | 3102 | 3307

GREEN RIVER

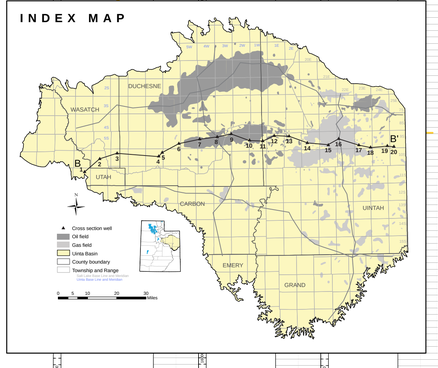
WASATCH

MESAVERDE

Tie to D-D'

Tie to E-E'

INDEX MAP



EXPLANATION

- 4148 — Base of moderately saline water (elevation in feet) (dash line = uncertain pick)
- Top of Tertiary Green River Formation
- Top of Tertiary Wasatch Formation
- Top of Cretaceous Mesaverde Group
- "Non-saline" water below (see plate 3)

Note: < or > in front of elevation indicates uncertain absolute BMSW pick due to incomplete log (i.e., BMSW is somewhere above/below this value). The cross section elevation was picked from the BMSW elevation map (plate 1).

Note: Only the gamma ray log is shown, salinity calculations were made using multiple other log traces which could include depths not covered by the gamma ray log.

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C-C' WEST TO EAST CROSS SECTION (SOUTHERN)

Plate 7
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

C West — C' East

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
4300730141 ANADARKO PET CORP MATTS SUMMIT STATE A-1 T12S R9E S14	4300730140 PG&E RESOURCES CO 1210-0806 1 T12S R10E S8	4301332308 HUBER J M CORP HUBER-ST 1-35 WDW T11S R10E S35	4300730158 ANADARKO PET CORP SLEMAKER A A-1 T12S R12E S5	4300730209 ANADARKO PET CORP BRYNER A-1X T12S R12E S11	4300730753 MOUNTAIN FUEL SUPLY KEEL RANCH 1 T12S R13E S16	4300731008 BARRETT BILL CORP PRICKLY PEAR 5-13-12-14 T12S R14E S13	4300731196 BARRETT BILL CORP PRICKLY PEAR 10-27-12-15 T12S R15E S27	4300730954 BARRETT BILL CORP PRICKLY PEAR 7-25 T12S R15E S25	4300731318 BARRETT BILL CORP PETERS POINT 16-27D-12-1 T12S R16E S27	4300730982 BARRETT BILL CORP PETERS POINT 11-6-13-17 T13S R17E S6	4304736931 FIML NATURAL RES LLC UTE TRIBAL 1-20-1319 T13S R19E S20	4304736598 FIML NATURAL RES LLC UTE TRIBAL 1-33-1319 T13S R19E S33	4304736910 WIND RIVER RES CORP NORTH HILL CREEK 1-25-14-19 T14S R20E S30	4304734955 WIND RIVER RES CORP HILL CREEK NORTH 2-14-15-20 T15S R20E S14	4304738968 ROYALE ENERGY V CANYON 20-1 T15S R21E S20	4304730644 PACIFIC TRNSMSN SPLY WINTER RIDGE UNIT 11-32 T15S R22E S32	4301931448 BARRETT BILL CORP CEDAR CAMP 3-5-16-23 T16S R23E S5	4304735685 NATIONAL FUEL CORP HORSE POINT STATE 43-32 T15S R23E S32	4301931388 COCHRANE RESOURCES, INC DIVIDE 24-16-32 T15S R24E S32	4301930645 COSEKA RES FED 13-3-16-25 T16S R25E S3

Subsea Depth (ft) 8500 … -9000 (Subsea Depth (ft))

Ground Level

GREEN RIVER

WASATCH

MESAVERDE

MANCOS

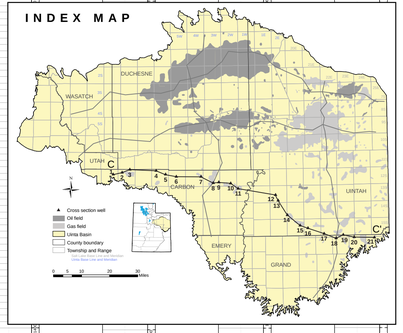
Sea level

4163 3321 2560 2702 3195 3880 4987 4555 4386 4191 4177 3265 3455 3946 2678 4024 3420 3895 4550 <4747 5213

Tie to D-D'

Tie to E-E'

INDEX MAP



EXPLANATION

- 4148 Base of moderately saline water (elevation in feet) (dash line = uncertain pick)
- Top of Tertiary Wasatch Formation
- Top of Cretaceous Mesaverde Group
- Top of Cretaceous Mancos Shale
- "Non-saline" water below (see plate 3)

Note: < or > in front of elevation indicates uncertain absolute BMSW pick due to incomplete log (i.e., BMSW is somewhere above/below this value). The cross section elevation was picked from the BMSW elevation map (plate 1).

Note: Only the gamma ray log is shown, salinity calculations were made using multiple other log traces which could include depths not covered by the gamma ray log.

UTAH GEOLOGICAL SURVEY
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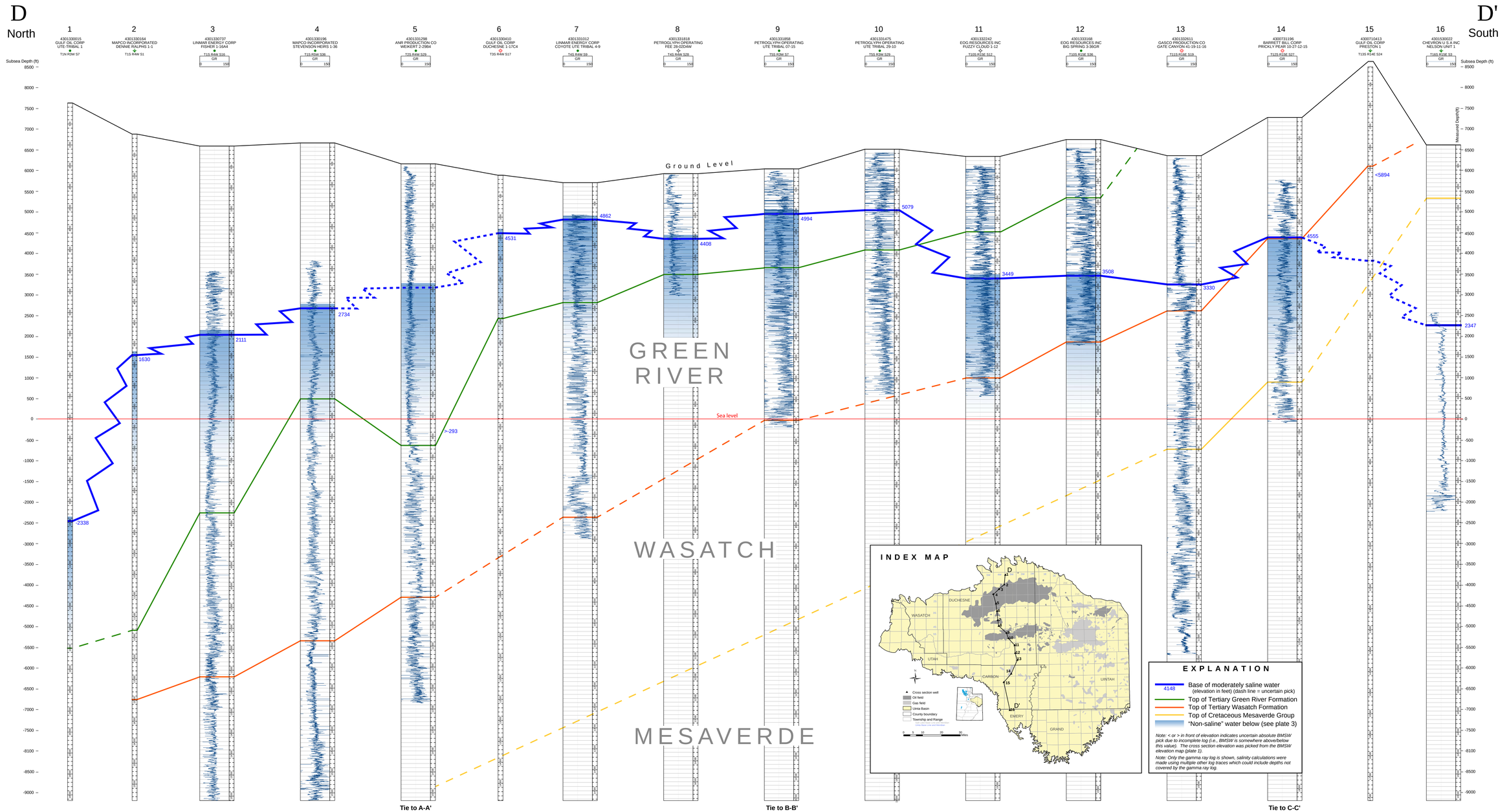
D-D' NORTH TO SOUTH CROSS SECTION (WESTERN)

Plate 8
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah



UTAH GEOLOGICAL SURVEY
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D-D' NORTH TO SOUTH CROSS SECTION (EASTERN)

Plate 7
Utah Geological Survey Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

E — North

E' — South

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
4304730878 SNYDER OIL CORP WEST WALKER STATE 2-32 T6S R20E S32	4304734403 SHENANDOAH ENERGY SU BRENNAN W 15W-18-7-22 T7S R22E S18	4304734762 QEP UINTA BASIN INC OVER & UNDER GLEN BE 12W-4-8-22 T8S R22E S4	4304734340 SHENANDOAH ENERGY WONSITS VALLEY 9W-24-8-21 T8S R21E S24	4304733583 EOG RESOURCES INC CHAPITA NORTH 111-32 T8S R22E S32	4304739371 KERR-MCGEE O&G ON LP NATURAL BUTTES UNIT 922-18G T9S R22E S18	4304730493 CIG EXPLORATION 22 CIGE 24-29-9 T9S R22E S29	4304737546 KERR-MCGEE O&G ON LP NATURAL BUTTES UNIT 1022-17J T10S R22E S17	4304734774 WESTPORT O&G CO LP BITTER CREEK 4-2 T11S R22E S4	4304736045 WESTPORT O&G CO LP LIZZARD 1122-21D T11S R22E S21	4304732839 ROSEWOOD RES INC ROSEWOOD FEDERAL 4-6 T12S R22E S6	4304730357 AMOCO PROD CO BUCK CAMP 1 T12S R22E S22	4304730165 TEXACO INCORPORATED TEXACO-SKYLINE-GOVT 1 T13S R22E S11	4304736731 SUMMIT OPERATING LLC SEEP RIDGE UNIT 8 T13S R22E S23	4304738962 PIONEER NAT RES USA PINE SPRINGS STATE 15-36 T14S R22E S36	4304737706 PIONEER NAT RES USA MAIN CANYON 23-7-15S-23E T15S R23E S7	4304931448 BARRETT BILL CORP CEDAR CAMP 3-5-15-23 T16S R23E S5	4301930788 ODECARD RESOURCES THREE PINES UNIT 32-10 T16S R23E S32	4301911165 SUNRAY MID CONT OIL UNIT 3 T17S R23E S25	4301930770 TENNECO OIL CO DIAMOND CANYON 9 15-15 T16S R23E S15	4301930686 ANSCHUTZ CORP FEDERAL 418 1 T15S R23E S23

Subsea Depth (ft) — 8500 … −9000

Measured Depth (ft) — 8000 … −8100

Ground Level

GREEN RIVER

WASATCH

MESAVERDE

MANCOS

DAKOTA

Sea level

4202 3295 3194 >3330 >2139 1946 1961 2520 2563 3024 2824 2691 3955 3863 >4980 3896 4384 3837 3403 947

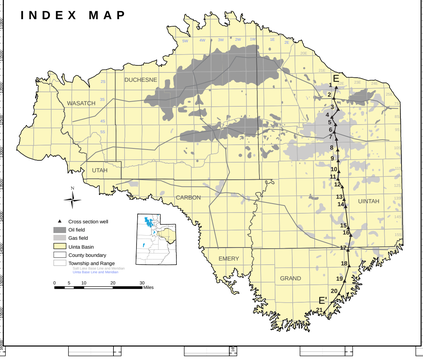
3295

Tie to A-A'

Tie to B-B'

Tie to C-C'

INDEX MAP



EXPLANATION

- 4148 — Base of moderately saline water (elevation in feet) (dash line = uncertain pick)
- Top of Tertiary Green River Formation
- Top of Tertiary Wasatch Formation
- Top of Cretaceous Mesaverde Group
- Top of Cretaceous Mancos Shale
- Top of Cretaceous Dakota Sandstone
- "Non-saline" water below (see plate 3)

Note: < or > in front of elevation indicates uncertain absolute BMSW pick due to incomplete log (i.e., BMSW is somewhere above/below this value). The cross section elevation was picked from the BMSW elevation map (plate 1).

Note: Only the gamma ray log is shown, salinity calculations were made using multiple other log traces which could include depths not covered by the gamma ray log.

Appendix A. *Water chemistry database*

Number	API	Sample Date	Well Name	Field Name	County	UTM E	UTM N	Elevation	Elevation Datum	Township	Range	Section	Meridian	Data Source	Sample Depth Top	Sample Depth Base	Formation	Sampled by	Type of Sample	Analysis Method	Lab Name	Rxo R_w	Temp Rxo R_w	TDS	pH	Specific Gravity	Ca	Na	K	Mg	CO_3	Cl	SO_4	Bicarbonate	Cation ratio	Used in Mapping BMSW	Comments
						NAD 83	NAD 83	ft							ft	ft						ohms-m	°F	mg/L			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L			
1	4300710481	20-Oct-1964	PETERS POINT UNIT 8	Peters Point	Carbon	576057	4397611	6853	GR	12S	16E	34	S	UGS Circular 87	8966	9004	Blackhawk	Humble Oil	DST	Lab		2.78	68	3238	9.0		56	1097	65	10	96	250	1015	1318	0.99975	No	Below BMSW from DST w HGCMW-questionable
2	4300711159		STONE CABIN UNIT 2		Carbon	558743	4402845	7755	KB	12S	14E	14	S	UGS Circular 87	5706	5732	Wasatch	Petan Co.	DST	Lab		3.60	68	2963	9.5		23	1065	0	5	456	180	1078	317	1.00061	No	From 20' of sl. gas cut mud, very poor sample
3	4300711159		STONE CABIN UNIT 2		Carbon	558743	4402845	7755	KB	12S	14E	14	S	UGS Circular 87	5076	5732	Wasatch	Petan Co.	DST	Lab		2.01	68	5099	7.8		532	1054	0	35	0	210	3160	220	1.00060	No	From 20' of sl. gas cut mud, very poor sample
4	4300711159		STONE CABIN UNIT 2		Carbon	558743	4402845	7755	KB	12S	14E	14	S	UGS Circular 87	5518	5530	Wasatch	Petan Co.	DST	Lab		1.95	68	5480	8.0		684	1013	0	28	0	170	3494	185	1.00089	No	DST#4 30' of SGCM
5	4300711160	16-Jul-1960	STONE CABIN UNIT 3	Stone Cabin	Carbon	557135	4405405	6256	KB	12S	14E	03	S	UGS Circular 87	1030	1200	Green River	Petan Co.	Production	Lab				1932	8.7	1.001	1	485	0	1	34	29	63	1320	1.17255	Yes	
6	4300715579	1-Jul-1956	JACK CANYON 5	Peters Point	Carbon	573682	4398263	6953	GR	12S	16E	32	S	UGS Circular 87	2961	3000	Wasatch	El Paso	Production	Lab		0.10	77	59469			1976	19888	0	580	0	32240	4598	380	0.99999	Yes	From prod. 14 days after frac; near BMSW
7	4300716045	1-Jan-2003	SHARPLES 1 GOVT PICKRELL	Nine Mile Canyon	Carbon	567928	4404913	5597	GR	12S	15E	11	S	DOGM well file	3782	4044	Wasatch	Bill Barrett	Production	Lab	Champion Technologies			2965	5076		2644	0	19720	155	1635	0.99999	Yes	No interval reported-assume perfed interval
8	4300716542	1-Aug-1952	STONE CABIN UNIT 1	Stone Cabin	Carbon	560332	4403057	7552	GR	12S	14E	13	S	USGS produced water database	8604	8789	Mesaverde	IP Test						12511	7.8		139			26		5600	1638	915	22.81668	No	History indicates depth 5305-17' - questionable
9	4300720352	27-Jun-1952	CANYON GOVT 1	Stone Cabin	Carbon	560464	4403013	7552	GR	12S	14E	13	S	UGS Circular 87	8505	8617	Mesaverde	Great Lakes Natural Gas	DST	Lab		0.31	77	23460			350	8100	0	64	0	11000	2500	1010	1.01022	Yes	DST 15, rec 375' SO&GCM, 2440' salt water
10	4300720352	9-Jul-1952	CANYON GOVT 1	Stone Cabin	Carbon	560464	4403013	7552	GR	12S	14E	13	S	UGS Circular 87	8604	8789	Mesaverde	Great Lakes Natural Gas	DST	Lab		0.54	77	13029			130	4500	0	26	60	5600	1600	910	1.01872	No	DST 17, rec 600' VSO&GCM, 450' WCM
11	4300730029	24-Jun-1977	JACK CANYON 9	Peters Point	Carbon	574396	4398543	6853	GR	12S	16E	33	S	UGS Circular 87	2898	3006	Wasatch	Reserve O&G	Production	Lab		0.13	77	59400			3500	18100	440	708	0	36000	590	159	0.99897	Yes	From prod. 2 yrs after IP - some concern about K; near BMSW
12	4300730119	4-Jan-1994	SHIMMIN TRUST 3	Castlegate	Carbon	519487	4403961	7590	KB	12S	10E	14	S	DOGM well file	3748	4290				Lab				8388	7.3	1.006	112	2441		17		1398	500	3904	1.00586	Yes	
13	4300730119	8-Dec-1994	SHIMMIN TRUST 3	Castlegate	Carbon	519487	4403961	7590	KB	12S	10E	14	S	DOGM well file	3748	4290				Lab	Exxon			8722	7.4		120	2531		18	0	1500	390	4148	1.00704	Yes	
14	4300730119	18-Apr-1995	SHIMMIN TRUST 3	Castlegate	Carbon	519487	4403961	7590	KB	12S	10E	14	S	DOGM well file	3748	4290				Lab	NALCO			5641	8.4	1.004	61	1724	22	22	312	522	184	2780	0.92673	No	Possible re-circulated waters
15	4300730120	4-Jan-1994	SHIMMIN TRUST 1	Castlegate	Carbon	520349	4404807	7332	GR	12S	10E	11	S	DOGM well file	4045	4482				Lab				13290	7.4	1.010	116	4075		41		3052	680	5307	1.00435	Yes	
16	4300730120	8-Dec-1994	SHIMMIN TRUST 1	Castlegate	Carbon	520349	4404807	7332	GR	12S	10E	11	S	DOGM well file	4045	4482				Lab	Exxon			13163			140	4009		37	0	3000	610	5368	1.00500	Yes	Calculated TDS
17	4300730120	18-Apr-1995	SHIMMIN TRUST 1	Castlegate	Carbon	520349	4404807	7332	GR	12S	10E	11	S	DOGM well file	4045	4482				Lab	NALCO			10622	7.9	1.011	110	3282	66	32	162	1962	144	4840	0.93771	Yes	
18	4300730121	4-Jan-1994	SHIMMIN TRUST 2	Castlegate	Carbon	520338	4403961	7546	GR	12S	10E	14	S	DOGM well file	3742	4276				Lab				8072	7.4	1.006	80	2361		10		1246	220	4148	1.00184	Yes	
19	4300730121	8-Dec-1994	SHIMMIN TRUST 2	Castlegate	Carbon	520338	4403961	7546	GR	12S	10E	14	S	DOGM well file	3742	4276				Lab	Exxon			8705	7.4		90	2531		24	0	1400	260	4392	1.00253	Yes	
20	4300730121	18-Apr-1995	SHIMMIN TRUST 2	Castlegate	Carbon	520338	4403961	7546	GR	12S	10E	14	S	DOGM well file	3742	4276				Lab	NALCO			7954	8.2	1.001	54	2482	39	15	396	894	165	3889	0.93534	No	Possible re-circulated waters
21	4300730122	4-Jan-1994	SHIMMIN TRUST 5-14-12-10	Castlegate	Carbon	519871	4404362	7420	GR	12S	10E	14	S	DOGM well file	3820	4335				Lab				9452	7.6	1.007	80	2767		20		1548	85	4941	1.00333	Yes	
22	4300730122	8-Dec-1994	SHIMMIN TRUST 5-14-12-10	Castlegate	Carbon	519871	4404362	7420	GR	12S	10E	14	S	DOGM well file	3820	4335				Lab	Exxon			9294	7.5		80	2746		24	0	1700	95	4636	1.00373	Yes	
23	4300730122	18-Apr-1995	SHIMMIN TRUST 5-14-12-10	Castlegate	Carbon	519871	4404362	7420	GR	12S	10E	14	S	DOGM well file	3820	4335				Lab	NALCO			8520	8.2	1.009	32	2618	14	228	788	60	4718	0.92019	No	Possible re-circulated waters
24	4300730123	4-Jan-1994	SHIMMIN TRUST 4	Castlegate	Carbon	519552	4404730	7413	KB	12S	10E	11	S	DOGM well file	4062	4485				Lab				9335	7.4	1.007	100	2826		15		2144	80	4148	1.00757	Yes	
25	4300730123	8-Dec-1994	SHIMMIN TRUST 4	Castlegate	Carbon	519552	4404730	7413	KB	12S	10E	11	S	DOGM well file	4062	4485				Lab	Exxon			9780	7.4		100	2967		24	0	2300	100	4270	1.00653	Yes	
26	4300730123	18-Apr-1995	SHIMMIN TRUST 4	Castlegate	Carbon	519552	4404730	7413	KB	12S	10E	11	S	DOGM well file	4062	4485				Lab	NALCO			10722	8.4	1.010	72	3517	82	30	522	2123	173	4182	0.92730	No	Possible re-circulated waters
27	4300730126	18-Mar-1994	FED 4-13	Castlegate	Carbon	520938	4404197	7460	KB	12S	10E	13	S	DOGM well file	3770	4308				Lab				13075	7.4	1.010	72	4036		127	54	3700	25	5020	0.99670	Yes	
28	4300730126	8-Dec-1994	FED 4-13	Castlegate	Carbon	520938	4404197	7460	KB	12S	10E	13	S	DOGM well file	3770	4308				Lab	Exxon			12372	7.4		80	3922		12	0	3400	29	4880	1.00511	Yes	
29	4300730126	18-Apr-1995	FED 4-13	Castlegate	Carbon	520938	4404197	7460	KB	12S	10E	13	S	DOGM well file	3770	4308				Lab	NALCO			8903	8.4	1.013	49	2749	44	16	318	1007	28	4657	0.93130	No	Possible re-circulated waters
30	4300730132	4-Jan-1994	ST 9-16	Castlegate	Carbon	517078	4403534	7808	KB	12S	10E	16	S	DOGM well file	3713	4240				Lab				6520	7.5	1.005	116	2011		17		1982	175	2196	1.00932	Yes	
31	4300730132	18-Apr-1995	ST 9-16	Castlegate	Carbon	517078	4403534	7808	KB	12S	10E	16	S	DOGM well file	3713	4240				Lab	NALCO			7579	7.6	1.010	125	2700	70	30	1	4127	268	238	0.98429	No	Possible re-circulated waters
32	4300730133	4-Jan-1994	ST 2-16	Castlegate	Carbon	516691	4404343	7596	GR	12S	10E	16	S	DOGM well file	4053	4482		Anadarko		Lab				12438	7.4	1.009	96	3845		17		2958	65	5441	1.00305	Yes	
33	4300730133	8-Dec-1994	ST 2-16	Castlegate	Carbon	516691	4404343	7596	GR	12S	10E	16	S	DOGM well file	4053	4482		Anadarko		Lab	Exxon			12175	7.4		100	3708		24	0	2700	78	5551	1.00283	Yes	
34	4300730133	18-Apr-1995	ST 2-16	Castlegate	Carbon	516691	4404343	7596	GR	12S	10E	16	S	DOGM well file	4053	4482		Anadarko		Lab	NALCO			11338	8.2	1.013	57	3753	72	20	474	2341	2	4584	0.92584	Yes	
35	4300730137	4-Jan-1994	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab				6427	7.5	1.005	92	1904		37		1594	40	2745	1.00365	No	
36	4300730137	8-Dec-1994	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab	Exxon			6961	7.5		90	2076		37	0	1700	55	2989	1.00289	No	
37	4300730137	5-Apr-1995	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab				7357	7.4			2206				1850		3090	1.07162	No	
38	4300730137	18-Apr-1995	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab	NALCO			7144	8.4	1.008	74	2384	40	31	330	2032	2	2195	0.94024	No	
39	4300730137	28-Aug-1995	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab				8092												No	
40	4300730137	3-Oct-2000	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab	Unichem			8696	6.5	1.007	880			316	0	4250	0	1525	2.07232	No	
41	4300730137	11-Jan-2002	CASTLEGATE FED 7-9-12-10	Castlegate	Carbon	516712	4405605	7310	GR	12S	10E	09	S	DOGM well file	4380	4818				Lab	Unichem			10356	7.6	1.008	80	3100	80	24		2500	0	4636	1.02552	Yes	Most recent sample - post-recirculation problems
42	4300730138	4-Jan-1994	FRANDSEN 4-15	Castlegate	Carbon	517428	4404382	7469	GR	12S	10E	15	S	DOGM well file	3888	4385				Lab				8446	7.6	1.006	100	2558		17		1982		3782	1.00202	Yes	
43	4300730138	8-Dec-1994	FRANDSEN 4-15	Castlegate	Carbon	517428	4404382	7469	GR	12S	10E	15	S	DOGM well file	3888	4385				Lab	Exxon			8795	7.6		100	2668		24	0	2100	50	3843	1.00173	Yes	
44	4300730138	18-Apr-1995	FRANDSEN 4-15	Castlegate	Carbon	517428	4404382	7469	GR	12S	10E	15	S	DOGM well file	3888	4385				Lab	NALCO			8569	8.0	1.010	100	2732	51	27	162	1874	82	3511	0.92273	No	Out of balance
45	4300730159	4-Jan-1994	JENSEN 9-10-12-10	Castlegate	Carbon	518680	4405363	7172	KB	12S	10E	10	S	DOGM well file	4144	4544				Lab				8013	7.8	1.006	68	2474		12	240	1666	50	3477	1.00916	No	
46	4300730159	8-Dec-1994	JENSEN 9-10-12-10	Castlegate	Carbon	518680	4405363	7172	KB	12S	10E	10	S	DOGM well file	4144	4544				Lab	Exxon			8261	7.4		80	2607		24	480	1800	75	3172	1.00773	No	
47	4300730159	18-Apr-1995	JENSEN 9-10-12-10	Castlegate	Carbon	518680	4405363	7172	KB	12S	10E	10	S	DOGM well file	4144	4544				Lab	NALCO			10192	8.0	1.004	85	3179	94	23	54	2396	2	4340	0.95736	No	
48	4300730159	11-Jan-2002	JENSEN 9-10-12-10	Castlegate	Carbon	518680	4405363	7172	KB	12S	10E	10	S	DOGM well file	4144	4544				Lab	Unichem			14115	7.5	1.010	88	4050	90	44	0	2100	0	7808	1.00389	Yes	Newer sample
49	4300730159	29-Jan-2002	JENSEN 9-10-12-10	Castlegate	Carbon	518680	4405363	7172	KB	12S	10E	10	S	DOGM well file	4144	4544				Lab	Unichem			10564	7.6	1.008	120	3174	78	0		2100	0	5124	0.98063	Yes	Newer sample
50	4300730161	4-Jan-1994	JENSEN 16-10	Castlegate	Carbon	518857	4404685	7279	KB	12S	10E	10	S	DOGM well file	3891	4316				Lab				7194	7.7	1.005	60	2139		24		1483	50	3416	1.00866	No	Newer nearby samples available
51	4300730161	8-Dec-1994	JENSEN 16-10	Castlegate	Carbon	518857	4404685	7279	KB	12S	10E	10	S	DOGM well file	3891	4316				Lab	Exxon			7297	7.6		80	2147		24	0	1500	50	3477	1.00955	No	Newer nearby samples available
52	4300730161	18-Apr-1995	JENSEN 16-10	Castlegate	Carbon	518857	4404685	7279	KB	12S	10E	10	S	DOGM well file	3891	4316				Lab	NALCO			12642	8.1	1.008	87	3826	69	35	246	4203	209	3950	1.11652	No	Newer nearby samples available
53	4300730162	17-Jul-2000	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	3881	4777	Blackhawk		Production	Lab	Acculabs			4170	7.5	1.002	82	1580	36	17	0	500	0	3200	0.88589	No	Out of balance
54	4300730162	4-Jan-1994	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab				4746	7.3	1.003	84	1310		17		717	40	2562	1.00759	No	
55	4300730162	18-Mar-1994	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab				9118	7.3	1.007	36	2788		173	186	2900		2989	0.99772	No	
56	4300730162	8-Dec-1994	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab	Exxon			5165	7.4		80	1456		18	0	850	60	2684	1.00559	No	
57	4300730162	18-Apr-1995	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab	NALCO			6929	8.3	1.008	64	2096	36	15	132	855	2	3694	0.92313	No	
58	4300730162	21-Aug-2000	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab				5190			74									No	
59	4300730162	11-Jan-2002	JENSEN 5-10-12-10	Castlegate	Carbon	517508	4405576	7231	GR	12S	10E	10	S	DOGM well file	4264	4713				Lab	Unichem			9260	7.4	1.007	80	2576	75	49	0	1060	0	5490	0.98266	Yes	Most recent sample
60	4300730163	5-Dec-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	3668	4565	Blackhawk		Production		Unichem			7921	7.6	1.008	48	2322		10	0	1060	0	4482	0.99172	Yes	Most recent
61	4300730163	4-Jan-1994	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab				7779	8.0	1.006	80	2345		22	360	1300	50	3599	1.00826	No	
62	4300730163	8-Dec-1994	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	Exxon			8043	7.8		80	2439		24	360	1400	61	3660	1.00598	No	
63	4300730163	18-Apr-1995	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	NALCO			8188	8.4	1.003	57	2585	58	17	378	1249	2	3804	0.93271	No	
64	4300730163	20-Jun-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	Acculabs			6410	7.2	1.005	89	2240	58	19	0	1230	0	3640	0.89931	No	
65	4300730163	27-Jul-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	Unichem			8344	8.1	1.008	160			0	0	1400	0	4392	13.96279	No	Out of balance
66	4300730163	21-Aug-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab				6190			63									No	
67	4300730163	1-Oct-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	Unichem			9494	7.8	1.024	200			1	0	1700	0	4880	12.75655	No	Out of balance
68	4300730163	1-Dec-2000	JENSEN 16-9-12-10	Castlegate	Carbon	517011	4404946	7342	GR	12S	10E	09	S	DOGM well file	4135	4566				Lab	Unichem			7923	7.6	1.008	48			10	0	1060	0	4482	32.11913	No	Out of balance
69	4300730164	4-Jan-1994	JENSEN 11-10-12-10	Castlegate	Carbon	517862	4405029	7305	GR	12S	10E	10	S	DOGM well file	4121	4491				Lab				8091	7.9	1.006	56	2552		7	240	1793	70	3355	1.00562	No	Older sample
70	4300730164	8-Feb-1994	JENSEN 11-10-12-10	Castlegate	Carbon	517862	4405029	7305	GR	12S	10E	10	S	DOGM well file	4121	4491				Lab	Exxon			10317	7.5		120	3186		12	0	2700	67	4209	1.00663	Yes	
71	4300730164	18-Apr-1995	JENSEN 11-10-12-10	Castlegate	Carbon	517862	4405029	7305	GR	12S	10E	10	S	DOGM well file	4121	4491				Lab	NALCO			8859	8.3	1.005	48	3295	88	23	162	5034	2	158	1.00112	No	Possible re-circulated waters
72	4300730165	18-Mar-1994	JENSEN 7-15	Castlegate	Carbon	518441	4404081	7577	KB	12S	10E	15	S	DOGM well file	3868	4306				Lab				14921	7.2	1.011	28	5121		129	174	6100	300	3044	0.99666	Yes	
73	4300730165	8-Dec-1994	JENSEN 7-15	Castlegate	Carbon	518441	4404081	7577	KB	12S	10E	15	S	DOGM well file	3868	4306				Lab	Exxon			9103	7.3		120	2850		50	120	2700	200	3050	1.00206	No	
74	4300730165	18-Apr-1995	JENSEN 7-15	Castlegate	Carbon	518441	4404081	7577	KB	12S	10E	15	S	DOGM well file	3868	4306				Lab	NALCO			4751	8.2	1.007	38	1385	26	10	150	196	2	2926	0.91978	No	
75	4300730166	4-Jan-1994	SHIMMIN TRUST 11-11-12-10	Castlegate	Carbon	519397	4405271	7230	GR	12S	10E	11	S	DOGM well file	4180	4588				Lab				7887	7.6	1.006	76	2319		15		1428	65	3965	1.00680	No	
76	4300730166	8-Dec-1994	SHIMMIN TRUST 11-11-12-10	Castlegate	Carbon	519397	4405271	7230	GR	12S	10E	11	S	DOGM well file	4180	4588				Lab	Exxon			8364	7.5		80	2486		12	0	1600	80	4087	1.00575	Yes	
77	4300730166	18-Apr-1995	SHIMMIN TRUST 11-11-12-10	Castlegate	Carbon	519397	4405271	7230	GR	12S	10E	11	S	DOGM well file	4180	4588				Lab	NALCO			11149	7.9	1.005	93	3312	77	37	1	3184	99	4328	1.05935	No	Possible re-circulated waters
78	4300730167	4-Jan-1994	SHIMMIN TRUST 10-11	Castlegate	Carbon	519975	4405174	7250	GR	12S	10E	11	S	DOGM well file	4147	4571				Lab				8091	7.9	1.006	56	2553		7	240	1793	70	3355	1.00524	Yes	
79	4300730167	16-Jan-1994	SHIMMIN TRUST 10-11	Castlegate	Carbon	519975	4405174	7250	GR	12S	10E	11	S	DOGM well file	2945	3122				Lab	Exxon			29484	10.5		28	11555		15	480	17000	300	0	0.99321	No	Possible annules communication w/ deep injection zones
80	4300730168	4-Jan-1994	SHIMMIN TRUST 12-12	Castlegate	Carbon	520901	4405268	7218	GR	12S	10E	12	S	DOGM well file	4102	4622		Anadarko		Lab				18716	7.0	1.014	100	6139		134	54	6800	50	5386	0.99953	Yes	
81	4300730168	8-Dec-1994	SHIMMIN TRUST 12-12	Castlegate	Carbon	520901	4405268	7218	GR	12S	10E	12	S	DOGM well file	4102	4622		Anadarko		Lab	Exxon			12331	7.4		100	3789		37	60	3000	50	5246	1.00480	Yes	
82	4300730168	18-Apr-1995	SHIMMIN TRUST 12-12	Castlegate	Carbon	520901	4405268	7218	GR	12S	10E	12	S	DOGM well file	4102	4622		Anadarko		Lab	NALCO			14933	8.1		65	4516	88	29	1	4312	90	5791	1.06918	Yes	
83	4300730169	16-Jan-1994	SHIMMIN TRUST 14-12-12-10	Castlegate	Carbon	521210	4404774	7232	GR	12S	10E	12	S	DOGM well file	2165	2370	Price River		Swab		Exxon Chemical Co			29484	10.5		28	11555		15	480	17000	300		0.99321	No	Older sample
84	4300730169	1-Apr-2001	SHIMMIN TRUST 14-12-12-10	Castlegate	Carbon	521210	4404774	7232	GR	12S	10E	12	S	DOGM well file	2165	2370	Price River		Swab		Unichem			7449	8.4	1.007	40	2759		10		3900	130		0.91770	No	
85	4300730169	4-Jan-1994	SHIMMIN TRUST 14-12-12-10	Castlegate	Carbon	521210	4404774	7232	GR	12S	10E	12	S	DOGM well file	3976	4410				Lab				14334	7.5	1.011	124	4561		17		3989	440	5185	1.00331	No	

Number	API	Sample Date	Well Name	Field Name	County	UTM E	UTM N	Elevation	Elevation Datum	Township	Range	Section	Meridian	Data Source	Sample Depth Top	Sample Depth Base	Formation	Sampled by	Type of Sample	Analysis Method	Lab Name	Rxo R_w	Temp Rxo R_w	TDS	pH	Specific Gravity	Ca	Na	K	Mg	CO_3	Cl	SO_4	Bicarbonate	Cation ratio	Used in Mapping BMSW	Comments
						NAD 83	NAD 83	ft							ft	ft						ohms-m	°F	mg/L			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L			
86	4300730169	8-Dec-1994	SHIMMIN TRUST 14-12-12-10	Castlegate	Carbon	521210	4404774	7232	GR	12S	10E	12	S	DOGM well file	3976	4410				Lab	Exxon			12335	7.4		120	3800		24	0	2900	420	5063	1.00148	Yes	
87	4300730169	18-Apr-1995	SHIMMIN TRUST 14-12-12-10	Castlegate

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1576	42047152564	Wet Rock	Uintah	44h54'42.58"N	109d58'25.58"W	4978	UCS Salt Lake District Office	5606	Green River - Upper	68f34'	6.68																				
1577	42047153466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1578	42047153564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1579	42047153566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1580	42047153664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1581	42047153666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1582	42047153764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1583	42047153766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1584	42047153864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1585	42047153866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1586	42047153964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1587	42047153966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1588	42047154064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1589	42047154066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1590	42047154164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1591	42047154166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1592	42047154264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1593	42047154266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1594	42047154364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1595	42047154366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1596	42047154464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1597	42047154466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1598	42047154564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1599	42047154566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1600	42047154664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1601	42047154666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1602	42047154764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1603	42047154766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1604	42047154864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1605	42047154866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1606	42047154964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1607	42047154966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1608	42047155064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1609	42047155066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1610	42047155164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1611	42047155166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1612	42047155264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1613	42047155266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1614	42047155364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1615	42047155366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1616	42047155464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1617	42047155466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1618	42047155564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1619	42047155566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1620	42047155664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1621	42047155666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1622	42047155764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1623	42047155766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1624	42047155864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1625	42047155866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1626	42047155964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1627	42047155966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1628	42047156064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1629	42047156066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1630	42047156164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1631	42047156166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1632	42047156264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1633	42047156266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1634	42047156364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1635	42047156366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1636	42047156464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1637	42047156466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1638	42047156564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1639	42047156566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1640	42047156664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1641	42047156666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1642	42047156764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1643	42047156766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1644	42047156864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1645	42047156866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1646	42047156964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1647	42047156966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1648	42047157064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1649	42047157066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1650	42047157164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1651	42047157166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1652	42047157264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1653	42047157266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1654	42047157364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1655	42047157366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1656	42047157464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1657	42047157466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1658	42047157564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1659	42047157566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1660	42047157664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1661	42047157666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1662	42047157764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1663	42047157766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1664	42047157864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1665	42047157866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				

1666	42047158164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1667	42047158166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1668	42047158264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1669	42047158266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1670	42047158364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1671	42047158366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1672	42047158464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1673	42047158466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1674	42047158564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1675	42047158566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1676	42047158664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1677	42047158666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1678	42047158764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1679	42047158766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1680	42047158864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1681	42047158866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1682	42047158964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1683	42047158966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1684	42047159064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1685	42047159066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1686	42047159164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1687	42047159166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1688	42047159264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1689	42047159266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1690	42047159364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1691	42047159366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1692	42047159464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1693	42047159466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1694	42047159564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1695	42047159566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1696	42047159664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1697	42047159666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1698	42047159764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1699	42047159766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1700	42047159864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1701	42047159866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1702	42047159964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1703	42047159966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1704	42047160064	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1705	42047160066	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1706	42047160164	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1707	42047160166	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1708	42047160264	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1709	42047160266	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1710	42047160364	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1711	42047160366	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1712	42047160464	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1713	42047160466	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1714	42047160564	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1715	42047160566	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1716	42047160664	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1717	42047160666	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1718	42047160764	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1719	42047160766	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1720	42047160864	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1721	42047160866	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1722	42047160964	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588	Green River - Lower	68f00'	6.53																				
1723	42047160966	Wet Rock	Uintah	44h53'56.21"N	109d57'44.35"W	4921	UCS Produced water database	5588

1627	42047277	23-Sep-2025	FREEMAN 9	Natural Bluffs	Bitterbush Bottom	Uintah	61945	6668	6992	Quesnel Esker	Uinta Gas Corp. (of California)	Production	4524	4625	Quesnel Esker	Uinta Gas Corp. (of California)	Production	Lab	18	S	21E	20	15	75	CAR	9S	4423246	4423246	4801	KEB	9S	20E	15

2115	40047534869	29-Wat-2023	Red Wash	Private	84536	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2116	40047534885	1-Nov-2006	NEW SOUTH	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2117	40047534892	8-Aug-2003	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2118	40047534900	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2119	40047534908	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2120	40047534916	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2121	40047534924	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2122	40047534932	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2123	40047534940	1-Nov-2006	FEDERAL	Private	50926	44.6	75	XLB	75	24E	22	S	DOCAL well file	Hillbilly	Lab	Hillbilly	5126	50	15	95	200	0	635	1000.24	Yes	Right K
2124	40047534963	7-Jun-2002	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2125	40047534971	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2126	40047534989	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2127	40047534997	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2128	40047535002	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2129	40047535010	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2130	40047535028	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2131	40047535036	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2132	40047535044	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2133	40047535052	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2134	40047535060	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2135	40047535078	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2136	40047535086	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2137	40047535094	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2138	40047535108	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2139	40047535116	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2140	40047535124	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2141	40047535132	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2142	40047535140	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2143	40047535157	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2144	40047535165	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2145	40047535173	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2146	40047535181	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2147	40047535199	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2148	40047535207	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2149	40047535215	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2150	40047535223	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2151	40047535231	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2152	40047535249	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2153	40047535257	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2154	40047535265	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2155	40047535273	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2156	40047535281	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2157	40047535299	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2158	40047535307	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2159	40047535315	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2160	40047535323	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2161	40047535331	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2162	40047535349	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2163	40047535357	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2164	40047535365	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2165	40047535373	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2166	40047535381	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2167	40047535399	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2168	40047535407	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2169	40047535415	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2170	40047535423	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2171	40047535431	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2172	40047535449	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2173	40047535457	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2174	40047535465	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2175	40047535473	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2176	40047535481	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2177	40047535499	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2178	40047535507	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2179	40047535515	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2180	40047535523	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2181	40047535531	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2182	40047535549	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2183	40047535556	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2184	40047535564	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2185	40047535572	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2186	40047535580	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2187	40047535598	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2188	40047535606	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2189	40047535614	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2190	40047535622	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2191	40047535630	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2192	40047535648	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2193	40047535656	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2194	40047535664	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2195	40047535672	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2196	40047535680	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2197	40047535698	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2198	40047535706	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2199	40047535714	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2200	40047535722	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2201	40047535730	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2202	40047535748	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2203	40047535756	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2204	40047535764	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2205	40047535772	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2206	40047535780	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2207	40047535798	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2208	40047535806	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2209	40047535814	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2210	40047535822	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2211	40047535830	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2212	40047535848	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2213	40047535856	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2214	40047535864	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2215	40047535872	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2216	40047535880	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2217	40047535898	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2218	40047535906	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2219	40047535914	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2220	40047535922	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2221	40047535930	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2222	40047535948	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	Hillbilly	5120	50	15	95	200	0	635	1000.24	Yes	Right K
2223	40047535956	30-Nov-2006	OC GB 16W-18-8-25	Private	77564	44.6	75	XLB	75	24E	22	S	Quesnel E&P	Hillbilly	Lab	H

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Appendix B. *TP-92 points "best guess" API number and location.*

Note: Unaltered, original picks of BMSW

[1]Some completion dates were a few years to tens of years after the logging date.

[2]Modifier: 1 = BMSW picked within logged interval; 2 = The BMSW was not found in the logged interval and the water appears to be saline in the shallowest part of the well log. Generally the top of the logged interval is also the depth/elevation given for the point. 3 = The well logs indicate "non-saline" water to the total logged depth. The total depth of the logged interval is the depth of the point. 4 = BMSW picked within logged interval, but the logs also indicate "non-saline" water more than 500 feet below the BMSW. 5 = Same as 2 above, but "non-saline" water is observed at depth in the well at least 500 feet below the picked BMSW.

API number	BMSW Elevation	BMSW Depth	UTM E	UTM N	Township	Range	Section	Meridian	Elevation	Elevation Datum	Total Depth	Completion Date[1]	Modifier[2]	Questionable Tie
	ft	ft	NAD 83	NAD 83					ft		ft			
4300710005	5013	2282	567764	4396052	130S	150E	11	S	7295	GR	5610	12/20/1962	1	
4300710342	3332	3337	582355	4401336	120S	170E	20	S	6669	KB	5136	7/30/1954	1	
4300710346	3617	2841	584790	4391948	130S	170E	21	S	6458	GR	3200	6/18/1954	1	
4300710413	5894		560537	4392367	130S	140E	24	S			2685		3	
4300710752	3821	5447	554832	4394965	130S	140E	09	S	9268	KB	9644	11/30/1965	1	
4300710753	3880	2894	545619	4403175	120S	130E	16	S	6774	KB	12646	10/23/1981	1	
4300711159	4760	2995	558743	4402845	120S	140E	14	S	7755	KB	5891	9/4/1959	1	
4300711160	3456	2800	557135	4405405	120S	140E	03	S	6256	KB	4500	7/16/1960	1	x
4300715393	2501	4511	578902	4393322	130S	160E	24	S	7012	DF	5140	2/16/1954	1	
4300715579	3916	3014	573682	4398263	120S	160E	32	S	6930	GR	3275	7/8/1965	1	
4300716045	3597	2000	567928	4404913	120S	150E	11	S	5597	GR	8450	12/19/1962	1	
4300720286	3971	2630	563372	4400331	120S	150E	29	S	6601	GR	17261		1	
4300730037	3754	3024	578507	4397807	120S	160E	35	S	6778	KB	4710	10/27/1976	1	
4300730054	3042	4609	557397	4402703	120S	140E	15	S	7651	GR	7204		1	
4300730055	2133	5662	560838	4378919	140S	140E	36	S	7795	GR	5680		3	
4300730070	4198	939	582566	4396678	130S	170E	05	S	5137	GR	3300	12/7/1981	1	
4301310176	1789	4567	531225	4455178	030S	070W	01	U	6356	KB	11850	2/14/1976	4	
4301310177	-4659	11955	572701	4484056	010N	020W	08	U	7296	KB	11938	3/28/1960	3	
4301310226	5491	364	549852	4442132	040S	050W	14	U	5855	GR	3032	4/29/1962	2	
4301310415	3706	4002	553818	4416108	070S	040W	07	U	7708	DF	4985	12/1/1959	1	
4301310417	5908	2417	548527	4420841	060S	050W	27	U	8325	DF	6200	7/27/1960	1	
4301310418	2499	4585	532587	4425559	060S	070W	12	U	7084	GR	4600	5/18/1965	3	
4301310484	2310	4259	573513	4409230	110S	160E	29	S	6569	DF	7950	12/2/1961	1	
4301310493	3944	3707	540190	4418791	060S	060W	35	U	7651	GR	5500	11/29/1961	1	
4301310496	3438	2317	583312	4473964	010S	010W	08	U	5755	GR	11482	12/22/1963	1	x
4301310660	2348	3260	585905	4409745	110S	170E	27	S	5608	GR	6004	11/20/1960	1	
4301310754	-3693	10687	525439	4449122	030S	070W	29	U	6994	GR	11674	6/5/1971	1	
4301310821	2756	4277	560431	4413140	110S	140E	12	S	7033	DF	4505	10/12/1960	1	
4301310898	2717	3615	581840	4416142	110S	170E	05	S	6332	DF	6310	10/14/1960	1	
4301310899	4228	1515	581419	4426556	090S	170E	31	S	5743	GR	5710	10/27/1965	1	
4301311004	2087	4773	543842	4410567	110S	130E	20	S	6860	KB	5733	11/29/1959	1	
4301311086	3655	3404	563892	4422422	060S	030W	20	U	7059	GR	10508	10/10/1961	1	
4301311126	-2445	9015	516612	4449941	030S	080W	20	U	6570	KB	12500	9/6/1971	4	
4301315409	4517	2584	548119	4424801	060S	050W	10	U	7101	KB	5870	1/31/1968	1	
4301316522	-5997	13346	572684	4484861	010N	020W	05	U	7349	GR	13354	6/13/1959	3	
4301320075	4190	1990	544579	4444458	040S	050W	08	U	6180	GR	9774	5/14/1971	2	
4301320100	3457	4000	553740	4418944	060S	040W	31	U	7457	GR	5370	10/5/1966	1	
4301320241	3164	3125	580683	4419303	100S	170E	30	S	6289	GR	5250	7/30/1967	1	
4301320242	2552	4366	575437	4416057	110S	160E	03	S	6918	GR	5287	8/27/1967	1	
4301320246	3227	3897	567631	4414831	110S	150E	02	S	7124	GR	4860	9/18/1967	1	
4301320269	3115	4254	559805	4419241	100S	140E	25	S	7369	GR	5800	9/1/1967	1	
4301320285	755	7165	558223	4484967	010N	040W	02	U	7920	GR	7165	11/22/1967	3	
4301320316	4177	1687	576905	4475089	010S	020W	03	U	5864	KB	15300	4/16/1976	4	
4301320356	5191		578478	4438620	080S	160E	26	S			2952		2	
4301330005	4002	1911	577913	4474860	010S	020W	02	U	5913	GR	10545	8/24/1968	1	x
4301330015	-2338	9983	561827	4483537	010N	030W	07	U	7645	KB	11140	8/30/1969	1	
4301330016	2169	4299	532263	4439617	040S	070W	25	U	6468	GR	6770	7/25/1969	1	
4301330021	4527	1392	577414	4474590	010S	020W	03	U	5919	GR	3150	10/11/1969	4	
4301330025	2664	3817	571507	4473248	010S	020W	07	U	6481	GR	15150	2/27/1972	4	
4301330026	3584	2285	581873	4474185	010S	010W	07	U	5869	GR	11660	1/31/1970	1	
4301330034	3849	2039	584247	4474996	010S	010W	04	U	5888	GR	11715	6/20/1970	4	
4301330038	2533	3770	559349	4460727	020S	040W	23	U	6303	KB	11232	1/29/1971	4	
4301330039	3391	2686	577838	4476639	010N	020W	35	U	6077	GR	12030	8/11/1970	4	x
4301330042	2157	4326	569952	4473209	010S	030W	12	U	6483	KB	15700	10/25/1970	1	
4301330043	4996	494	571616	4442894	040S	020W	18	U	5490	KB	9300	12/18/1970	1	
4301330045	2917	3465	539274	4433603	050S	060W	15	U	6436	GR	12000	10/17/1970	1	
4301330047	-2494	9960	554598	4482087	010N	040W	17	U	7466	KB	10765	11/24/1972	4	
4301330049	3649	2584	549903	4459205	020S	050W	26	U	6233	KB	13880	4/27/1971	4	
4301330052	3070	3109	559583	4464084	020S	040W	11	U	6179	GR	17766	8/29/1971	4	
4301330053	1956	6936	538174	4422795	060S	060W	15	U	8892	KB	6946	1/24/1971	3	
4301330054	2586	4307	546918	4467038	010S	050W	33	U	6893	GR	16300	10/12/1971	4	
4301330058	3547	2557	543242	4462019	020S	050W	18	U	6104	KB	17273	12/12/1971	4	
4301330060	2613	3822	561184	4469052	010S	040W	25	U	6435	KB	14490	10/9/1971	4	
4301330061	1180	4470	575433	4462188	020S	020W	16	U	5650	KB	10317	3/15/1975	4	
4301330062	2884	3370	559515	4465811	020S	040W	02	U	6254	GR	14040	10/10/1971	4	
4301330063	3106	3015	566183	4465696	020S	030W	04	U	6121	KB	13983	10/21/1971	4	
4301330065	3503	2467	557228	4456042	030S	040W	03	U	5970	GR	13493	11/7/1971	4	
4301330067	2460	4209	552909	4467199	010S	040W	31	U	6669	KB	14163	2/29/1972	4	
4301330068	-2150	8198	541806	4454059	030S	060W	12	U	6048	GR	10202	12/25/1971	4	
4301330073	2359	4604	565083	4478754	010N	030W	28	U	6963	KB	17764	7/16/1972	4	
4301330074	1708	5181	528093	4468471	010S	070W	27	U	6889	KB	14672	5/18/1972	4	
4301330080	4999	813	547029	4445694	040S	050W	04	U	5812	GR	8404	2/1/1972	2	
4301330082	2616	3665	566145	4470685	010S	030W	21	U	6281	GR	15000	5/25/1972	1	
4301330086	3269	2483	576538	4471780	010S	020W	15	U	5752	GR	14020	6/28/1972	1	
4301330093	2998	3288	562777	4467598	010S	030W	31	U	6286	KB	14500	5/21/1972	1	
4301330094	3724	1484	570205	4452515	030S	030W	13	U	5208	GR	12500	3/16/1972	5	
4301330097	2095	4515	553212	4463914	020S	040W	07	U	6610	GR	13600	5/21/1972	5	
4301330103	5419	500	542010	4452658	030S	060W	13	U	5919	KB	10500	5/11/1972	4	
4301330113	2262	2984	581625	4446155	040S	010W	06	U	5246	GR	11500	6/11/1972	2	
4301330114	3246	2666	527470	4442357	040S	070W	16	U	5912	GR	9029	5/25/1972	4	
4301330121	-741	7788	546714	4463687	020S	050W	09	U	7047	GR	15337	10/7/1972	4	
4301330151	473	5591	585977	4478415	010N	010W	27	U	6064	GR	17373	7/6/1973	4	
4301330152	5358	1563	523064	4458794	020S	080W	25	U	6921	GR	14870	4/24/1973	4	
4301330156	3048	2504	578344	4467432	010S	020W	35	U	5552	GR	13800	2/8/1974	5	x
4301330163	931	5351	543495	4455917	030S	050W	06	U	6282	KB	11510	2/7/1980	4	
4301330164	1630	5263	560891	4475332	010S	040W	01	U	6893	GR	17914	10/15/1973	4	
4301330169	3141	3240	571745	4468992	010S	020W	30	U	6381	GR	15500	4/21/1973	1	
4301330212	2958	2779	573961	4465407	020S	020W	05	U	5737	GR	13300	9/25/1973	4	
4301330228	3141	5100	566994	4489147	020N	030W	22	U	8241	KB	5100	9/1/1973	3	
4301330237	2475	2817	580212	4464236	020S	020W	12	U	5292	KB	12506	11/2/1973	5	
4301330241	-3033	9372	540417	4454382	030S	060W	11	U	6339	KB	10750	12/23/1973	1	
4301330250	2980	2491	581643	4468647	010S	010W	30	U	5471	GR	13600	1/17/1974	4	
4301330251	2921	2986	570041	4462053	020S	030W	13	U	5907	KB	12700	12/21/1973	2	
4301330306	2211	4418	566051	4475625	010S	030W	04	U	6629	GR	17450	8/2/1975	4	
4301330311	2914	2600	576640	4462604	020S	020W	15	U	5514	KB	12393	8/7/1974	1	
4301330312	5273	1598	529086	4447796	030S	070W	34	U	6871	GR	10870	10/24/1974	4	
4301330315	4147	1080	585096	4464505	020S	010W	09	U	5227	GR	12700	9/11/1974	4	
4301330322	1724	5109	553223	4470700	010S	040W	19	U	6833	GR	16991	11/20/1974	4	
4301330327	2613	3579	582716	4418961	100S	170E	29	S	6192	KB	12390	3/1/1975	1	
4301330331	3368	2822	554032	4407098	110S	140E	32	S	6190	GR	6435	9/21/1974	1	
4301330339	2972	2500	577044	4461055	020S	020W	22	U	5472	KB	12070	5/17/1975	2	
4301330340	3841	2046	547925	4458146	020S	050W	27	U	5887	KB	4205	1/4/1975	1	
4301330346	3473	2245	575495	4468772	010S	020W	28	U	5718	GR	3500	12/11/1974	1	x
4301330350	3614	4170	582500	4489612	020N	010W	20	U	7784	KB	6674	2/5/1975	4	
4301330358	2796	2463	585042	4468899	010S	010W	28	U	5259	GR	13150	5/3/1975	5	
4301330359	1105	4000	586173	4462897	020S	010W	15	U	5105	KB	12500	7/9/1975	1	
4301330362	2619	4177	549974	4467467	010S	050W	35	U	6796	GR	4650	4/10/1975	4	x
4301330367	5016	150	585714	4464910	020S	010W	10	U	5166	KB	2513	6/11/1975	1	
4301330368	2631	3785	562850	4467571	010S	030W	31	U	6416	KB	4800	11/10/1975	1	
4301330371	3362	2772	554805	4457485	020S	040W	32	U	6134	GR	4000	4/17/1975	1	x
4301330372	5484	336	541937	4450719	030S	060W	24	U	5820	GR	4002	11/20/1975	1	
4301330378	2820	3556	573400	4480004	010N	020W	20	U	6376	GR	17310	1/21/1977	4	
4301330384	-3429	10184	541121	4472473	010S	060W	12	U	6755	GR	10295	11/5/1975	3	
4301330387	1707	4653	535307	4453498	030S	060W	08	U	6360	GR	11400	1/19/1976	4	x
4301330388	3729	2046	545169	4452698	030S	050W	17	U	5775	GR	3710	9/2/1975	1	x
4301330395	5948	585	533947	4447837	030S	060W	31	U	6533	GR	8704	11/25/1975	2	
4301330398	2468	4156	570031	4476611	010N	030W	36	U	6624	GR	17093	4/4/1976	4	
4301330400	2784	2480	583084	4463000	020S	010W	17	U	5264	GR	12803	8/26/1976	2	
4301330408	3196	3182	519938	4446464	040S	080W	03	U	6378	KB	9700	6/16/1977	1	
4301330410	4531	1382	554754	4452829	030S	040W	17	U	5913	GR	6040	2/3/1977	1	
4301330414	4646	997	559781	4444800	040S	040W	11	U	5643	GR	8850	11/28/1978	2	
4301330416	-3191	9432	537027	4455161	030S	060W	04	U	6241	GR	12310	12/7/1977	4	
4301330420	2505	3584	538510	4460909	020S	060W	22	U	6089	GR	13841	10/27/1977	4	
4301330422	4988	882	542017	4448066	030S	060W	36	U	5870	GR	9304	7/29/1977	1	
4301330431	943	6314	538395	4456374	020S	060W	34	U	7257	GR	12463	4/1/1978	1	
4301330432	3048	2569	575573	4462725	020S	020W	16	U	5617	GR	12709	1/9/1978	4	
4301330444	5580	1191	538641	4441689	040S	060W	22	U	6771	GR	7570	3/10/1979	1	
4301330446	3319	2893	572998	4428914	090S	160E	29	S	6212	GR	8006	7/29/1978	1	
4301330451	5330	520	570444	4435779	080S	150E	36	S	5850	KB	7165	10/28/1978	2	
4301330462	5661	1347	541470	4439187	040S	060W	25	U	7008	GR	7500	7/27/1979	1	
4301330467	5196	631	539684	4445967	040S	060W	02	U	5827	GR	8000	11/30/1978	2	
4301330476	4938	1997	538846	4465441	020S	060W	03	U	6935	GR	15810	10/10/1979	1	
4301330486	3241	2668	560430	4407100	110S	140E	36	S	5909	GR	6383	11/22/1979	1	
4301330495	4915	2681	525392	4423059	060S	070W	17	U	7596	GR	4005	8/14/1979	1	
4301330506	5142	288	582123	4431038	090S	170E	17	S	5430	GR	6200	1/27/1983	1	x
4301330528	4121	2468	527359	4452461	030S	070W	16	U	6589	GR	12525	12/28/1981	4	
4301330538	2772	4461	530610	4423427	060S	070W	14	U	7233	GR	18003	9/30/1981	1	
4301330541	493	5913	550374	4433009	050S	050W	14	U	6406	GR	10837	4/12/1981	1	
4301330544	4480	1032	557102	4448308	030S	040W	34	U	5512	GR	9705	3/22/1981	2	
4301330550	4903	1001	544528	4450498	030S	050W	20	U	5904	GR	10305	2/6/1981	4	
4301330573	4494	1540	552958	4455805	030S	040W	06	U	6034	KB	11900	9/27/1981	4	
4301330576	4746	1048	553421	4448565	030S	040W	30	U	5794	KB	10000	1/29/1982	5	
4301330589	3711	2151	566157	4460634	020S	030W	21	U	5862	GR	12679	1/15/1982	1	x
4301330610	3041	3459	575045	4418849	100S	160E	28	S	6500	GR	11102	1/11/1982	1	
4301330630	3051	2645	576907	4432533	090S	160E	10	S	5696	GR	6085	5/15/1982	1	x

API number	BMSW Elevation	BMSW Depth	UTM E	UTM N	Township	Range	Section	Meridian	Elevation	Elevation Datum	Total Depth	Completion Date[1]	Modifier[2]	Questionable Tie
4301330634	2885	2837	576139	4431715	090S	160E	15	S	5722	GR	5699	4/8/1982	1	x
4301330659	3358	1898	580173	4478323	010N	020W	25	U	5256	GR	16630	10/9/1982	4	
4301330690	4984	300	583258	4439478	080S	170E	20	S	5284	KB	6985	12/29/1982	1	
4301330704	3249	2966	565234	4466797	010S	030W	33	U	6215	GR	13845	3/25/1983	1	x
4301330707	-4830	11073	584249	4479958	010N	010W	21	U	6243	GR	17419	9/20/1983	4	
4301330711	5584	120	565226	4440799	040S	030W	21	U	5704	KB	7400	10/18/1984	1	
4301330719	1083	5984	545977	4463249	020S	050W	09	U	7067	GR	14397	7/12/1983	2	x
4301330739	2358	2897	581103	4453844	030S	010W	07	U	5255	GR	11600	5/7/1983	2	
4301330743	5267	354	570426	4439728	040S	030W	25	U	5621	GR	6625	7/29/1983	1	
4301330762	5705	240	566241	4437033	050S	030W	04	U	5945	GR	6698	8/8/1983	2	x
4301330783	1790	3320	582097	4459724	020S	010W	30	U	5110	KB	12703	3/16/1984	1	
4301330786	2861	2473	578847	4455399	030S	020W	02	U	5334	GR	10209	9/17/1983	2	
4301330799	1914	4841	566191	4420100	100S	150E	22	S	6755	GR	5203	9/12/1983	1	
4301330803	6106	421	563276	4430938	050S	030W	19	U	6527	GR	6665	1/8/1984	2	
4301330806	4488	2076	565336	4428961	050S	030W	33	U	6564	GR	6534	1/9/1984	1	
4301330842	5834	544	557600	4432579	050S	040W	15	U	6378	GR	6250	6/9/1984	1	x
4301330915	2714	3609	557568	4468313	010S	040W	27	U	6323	GR	15917	9/29/1984	1	
4301330942	3265	3002	583374	4479948	010N	010W	20	U	6267	GR	17255	5/31/1985	4	
4301330964	4938	1499	555235	4430504	050S	040W	29	U	6437	GR	5832	8/21/1985	1	
4301510800	-494	5306	575424	4352625	170S	160E	27	S	4812	GR	8480	11/8/1962	1	
4301530014	-4815	11077	572291	4348082	180S	160E	08	S	6262	GR	12894	8/20/1984	1	
4301530022	-1743	8378	565649	4368651	160S	150E	03	S	6635	GR	8752	10/6/1975	1	x
4301530080	-1347	7177	569803	4362970	160S	150E	24	S	5830	GR	12706	8/31/1983	1	
4301915671	3043	4610	621652	4364443	160S	210E	15	S	7653	KB	10301	1/4/1962	1	
4301915673	-1401	9548	620193	4357366	170S	210E	04	S	8147	GR	9842	9/25/1963	1	
4301930240	4846	3597	652240	4367480	160S	240E	02	S	8443	GR	7600	8/13/1975	1	x
4301930398	132	8802	613281	4343348	180S	200E	23	S	8934	GR	10786	1/24/1979	1	
4301930421	3654	4132	621322	4359553	160S	210E	34	S	7786	KB	10350	11/7/1978	1	
4301930653	2475	4966	629808	4364634	160S	220E	16	S	7441	KB	10011	3/6/1981	1	
4301930654	3457	4394	634453	4362126	160S	220E	24	S	7851	GR	9477	11/24/1980	1	
4301930682	-1580	9875	618683	4354776	170S	210E	17	S	8295	KB	9867	10/17/1980	3	
4301930727	5335	3817	613151	4340325	180S	200E	35	S	9152	GR	8932	8/29/1981	3	
4301931148	4770	3389	641716	4365988	160S	230E	11	S	8159	GR	8205	9/12/1984	1	
4304710015	1561	3408	635968	4458407	060S	220E	26	S	4969	GR	6617	6/1/1962	1	
4304710016	2073	3857	637349	4453474	070S	220E	12	S	5930	DF	6190	7/17/1962	3	
4304710032	822	4776	663730	4438072	080S	250E	34	S	5598	GR	6610	9/5/1965	1	x
4304710033	3998	1079	605194	4439801	040S	020E	28	U	5077	KB	6839	9/26/1964	4	
4304710053	253	4832	633170	4476594	040S	220E	34	S	5085	KB	4845	6/1/1965	3	
4304710078	-4878	10423	663352	4457289	070S	250E	03	S	5545	DF	10423	11/30/1954	3	
4304710093	2091	3473	611550	4409240	110S	200E	29	S	5564	DF	8830	4/27/1961	1	
4304710099	2591	2349	644348	4469274	050S	230E	26	S	4940	KB	2350	10/5/1965	3	
4304710101	-1517	7447	612278	4475812	040S	200E	33	S	5930	KB	7446	10/11/1960	3	
4304710114	-439	5809	638961	4453478	070S	230E	07	S	5370	KB	3196	10/29/1957	3	x
4304710206	-316	5644	648626	4447856	070S	240E	31	S	5328	KB	5645	4/11/1963	3	
4304710261	920	4802	662007	4412053	110S	250E	22	S	5722	GR	6300	8/1/1961	1	x
4304710263	2357	4038	653013	4403628	120S	240E	15	S	6395	GR	4350		1	
4304710332	1261	3779	635506	4479122	040S	220E	24	S	5040	DF	3769	8/15/1956	3	
4304710583	239	5154	618640	4471366	050S	210E	18	S	5393	DF	6013	9/27/1947	1	
4304710586	-717	7247	591300	4485506	010N	010E	06	U	6530	DF	7250	6/28/1956	3	
4304710631	38	5368	619529	4468576	050S	210E	29	S	5406	KB	7265	9/27/1961	1	
4304710702	249	5534	628485	4486908	030S	220E	30	S	5783	KB	5522	10/31/1953	3	
4304710735	615	4795	658767	4423424	100S	250E	18	S	5410	GR	6509	12/13/1962	1	
4304710785	3723	2009	665211	4419754	100S	250E	35	S	5732	GR	3983	8/24/1960	1	
4304710812	387	5070	656190	4432335	090S	240E	24	S	5457	DF	7215	7/19/1959	1	
4304710870	1689	3428	633901	4456837	060S	220E	34	S	5117	GR	6600	3/10/1964	1	x
4304710874	2003	3242	627214	4448872	070S	210E	25	S	5245	DF	8002	6/10/1962	1	
4304710875	1486	3390	623122	4449944	070S	210E	21	S	4876	DF	6800	3/13/1963	1	
4304710920	1681	5597	589699	4384101	140S	170E	13	S	7278	KB	9000	9/1/1963	1	
4304710937	874	4762	627214	4489451	030S	220E	19	S	5636	KB	4820	11/10/1964	3	
4304710939	-3111	8312	635632	4474231	050S	220E	01	S	5201	GR	7968	3/30/1965	3	
4304711014	2012	3667	601548	4409544	110S	190E	29	S	5679	DF	8638	12/30/1962	1	
4304711116	3684	3418	605693	4381354	140S	190E	27	S	7102	GR	5000	4/26/1963	1	
4304711119	3414	3646	604452	4384553	140S	190E	15	S	7060	GR	7370	7/19/1962	1	
4304711146	-700	5993	646921	4458894	060S	230E	25	S	5293	DF	5994	5/15/1965	3	
4304711408	2917	2252	646322	4465855	060S	230E	01	S	5169	KB	2252	12/4/1957	3	
4304715128	-634	6392	657078	4448395	070S	240E	36	S	5758	KB	5124	3/15/1965	3	
4304715134	3183	1860	623012	4457281	060S	210E	33	S	5043	GR	7750	6/23/1965	1	x
4304715179	1429	4141	637820	4449858	070S	220E	25	S	5570	GR	6329	12/31/1956	1	
4304715300	-42	5542	641802	4448133	070S	230E	33	S	5500	KB	5592	7/22/1964	1	x
4304715590	-3569	8632	614464	4463941	060S	200E	10	S	5063	GR	8633	11/6/1952	3	
4304715675	1770	4017	663576	4407610	120S	250E	02	S	5787	GR	8300	12/12/1968	1	
4304715797	2113	3822	627244	4406661	120S	210E	01	S	5935	GR	5827	6/16/1962	1	
4304715799	2860	2510	636331	4413975	110S	220E	13	S	5370	KB	5349	4/7/1963	1	
4304715804	4412	284	614472	4442444	080S	200E	15	S	4696	KB	6379	7/12/1964	2	
4304715805	2820	2490	649192	4415404	110S	240E	08	S	5310	GR	6569	11/6/1961	1	
4304715814	3021	2525	640826	4416557	110S	230E	04	S	5546	GR	6505	12/13/1961	1	
4304715815	3093	2629	644993	4412406	110S	230E	23	S	5722	GR	5850	1/30/1962	1	
4304715883	641	4994	650431	4418497	100S	240E	32	S	5635	GR	7028	6/20/1962	1	
4304715927	1918	3982	652527	4407319	120S	240E	03	S	5900	DF	5735	4/11/1962	1	
4304715931	2386	3378	651192	4408940	110S	240E	33	S	5764	KB	3378	1/15/1964	3	
4304716199	-17	5865	652528	4453537	070S	240E	10	S	5848	KB	5865	6/10/1960	3	
4304720014	559	4952	650674	4445105	080S	240E	08	S	5511	GR	10050	6/21/1966	4	
4304720067	1026	4703	658193	4452861	070S	250E	18	S	5729	KB	4703	6/5/1966	3	
4304720074	2261	3300	659647	4465916	060S	250E	05	S	5561	KB	3300	7/17/1966	3	
4304720139	1435	4101	656783	4465573	060S	250E	06	S	5536	KB	4101	10/26/1966	3	
4304720202	728	4552	607194	4463822	060S	190E	12	S	5280	GR	5894	3/1/1968	1	x
4304720229	1116	4319	656186	4464993	060S	240E	12	S	5435	GR	4333	6/11/1967	3	
4304720281	1095	4139	613117	4468077	050S	200E	27	S	5234	GR	9100	12/7/1967	1	
4304720366	3991	3513	608405	4491157	030S	200E	07	S	7504	GR	3508	9/17/1949	3	
4304720374	-281	6367	612553	4477685	040S	200E	28	S	6086	GR	6370		3	
4304720402	-855		627230	4472622	050S	210E	12	S			6133	11/19/1949	3	
4304720408	-1918	7118	627948	4474397	050S	220E	06	S	5200	GR	2349		3	x
4304720434	477	4545	621618	4462920	060S	210E	09	S	5022	GR	9002	7/27/1952	1	
4304720438	1085	3774	629050	4458950	060S	220E	30	S	4859	GR	8944	5/29/1952	4	x
4304720490	2481	4180	653119	4395130	130S	240E	15	S	6661	GR	4177		3	
4304720494	2925	4129	599209	4386552	140S	180E	01	S	7054	GR	5512	8/29/1953	1	
4304720506	2328	3557	623182	4385204	140S	210E	09	S	5885	GR	4205	9/14/1952	1	
4304720514	4695	434	589280	4444674	040S	010W	12	U	5129	GR	8000	8/18/1968	5	
4304730031	2791	2096	632516	4463549	060S	220E	09	S	4887	KB	9350	7/2/1969	1	
4304730042	-266	5954	640196	4488227	030S	230E	28	S	5688	GR	6208	3/25/1969	3	
4304730043	3430	1526	590505	4443047	040S	010W	13	U	4956	KB	5400	4/6/1969	2	
4304730066	982	4585	662509	4438875	080S	250E	34	S	5567	GR	14125	1/21/1971	4	x
4304730067	2559	2395	640385	4465284	060S	230E	05	S	4954	GR	5929	12/9/1969	4	
4304730085	3279	1714	587180	4449152	030S	010W	27	U	4993	KB	8964	10/19/1970	4	
4304730086	2786	2250	600922	4449263	030S	020E	30	U	5036	GR	8585	10/6/1970	4	
4304730090	-3156	8990	617206	4481814	040S	200E	12	S	5834	KB	8990	12/3/1970	3	
4304730096	168	6815	631414	4481407	040S	220E	16	S	6983	GR	5165	12/12/1979	3	
4304730103	2082	3330	633794	4449804	070S	220E	27	S	5412	GR	5888	6/18/1971	1	x
4304730106	404	4960	633421	4447788	070S	220E	34	S	5364	GR	5866	8/28/1971	1	
4304730114	3283	5250	609778	4486536	030S	200E	29	S	8533	KB	5251	6/21/1972	3	
4304730124	3485	1652	648924	4433790	090S	240E	18	S	5137	KB	8600	6/1/1973	1	
4304730127	-10080	15972	594074	4478643	010N	010E	28	U	5892	GR	16000	2/7/1986	3	
4304730128	-638	6090	607241	4472352	050S	190E	12	S	5452	GR	15004	10/7/1972	4	
4304730130	2125	3319	660342	4445240	080S	250E	08	S	5444	GR	4400	1/23/1973	1	
4304730135	2916	3918	634375	4387931	140S	220E	03	S	6834	GR	12154	4/10/1973	1	
4304730143	3384	2278	623920	4390331	130S	210E	27	S	5662	GR	10605	10/23/1973	1	
4304730148	2356	3183	619195	4415246	110S	210E	07	S	5539	GR	9829	2/3/1973	1	
4304730149	-9326	15049	652245	4450439	070S	240E	21	S	5723	GR	18607	7/14/1974	3	
4304730153	1261	3700	616316	4426432	100S	200E	02	S	4961	GR	11100	6/25/1973	1	x
4304730155	1764	3212	615242	4462377	060S	200E	14	S	4976	KB	14015	4/6/1975	1	
4304730156	2730	2471	646632	4431437	090S	230E	24	S	5201	GR	8500	12/20/1973	1	x
4304730159	2225	4555	601559	4487246	020N	020E	32	U	6780	KB	4555	1/8/1974	3	
4304730163	773	4748	660313	4446854	080S	250E	05	S	5521	GR	4561	12/10/1973	3	x
4304730165	2691	3810	635047	4395923	130S	220E	11	S	6501	KB	12073	8/3/1974	1	
4304730166	2867	3496	633580	4392813	130S	220E	22	S	6363	GR	10537	2/22/1975	1	
4304730169	903	4391	591352	4465620	020S	010E	06	U	5294	GR	12700	5/22/1974	4	
4304730170	2779	3482	620252	4392916	130S	210E	20	S	6261	KB	12260	9/19/1974	1	
4304730173	-8920	14473	592881	4474191	010S	010E	08	U	5553	GR	14500	1/29/1975	3	
4304730184	-796	5552	642540	4476486	040S	230E	34	S	4756	KB	5552	10/28/1974	3	
4304730190	1468	3705	596262	4466115	020S	010E	03	U	5173	GR	12387	3/31/1975	4	x
4304730198	-1007	6008	596502	4457810	020S	010E	34	U	5001	KB	12606	9/8/1975	2	
4304730220	1345	3676	589904	4460633	020S	010W	24	U	5021	GR	12150	10/3/1975	1	
4304730226	3154	3224	624109	4402114	120S	210E	22	S	6378	GR	15666	7/21/1976	1	
4304730228	-1222	7164	596444	4482637	010N	010E	15	U	5942	KB	7175	9/30/1976	3	
4304730230	1816	3214	646810	4439372	080S	230E	25	S	5030	GR	9282	7/31/1977	1	
4304730233	4800	186	633240	4430663	090S	220E	21	S	4986	GR	6500	3/23/1977	2	
4304730247	4288	3551	650715	4374493	150S	240E	17	S	7839	GR	8600	6/17/1977	1	
4304730254	2750	2170	602493	4450930	030S	020E	20	U	4920	GR	8200	8/1/1977	4	
4304730260	1825	3092	603407	4422399	100S	190E	16	S	4917	KB	8210		1	
4304730269	3911	823	617569	4451967	070S	200E	13	S	4734	GR	7170	9/15/1977	2	
4304730271	3101	3921	640474	4383632	140S	230E	20	S	7022	KB	9728	9/28/1977	1	
4304730280	358	4888	651025	4426195	100S	240E	05	S	5246	GR	6500	8/1/1977	1	
4304730288	3728	1109	638456	4433402	090S	230E	18	S	4837	KB	7180	4/22/1978	1	
4304730295	1750	3127	620337	4429163	090S	210E	30	S	4877	GR	6707	10/17/1977	1	
4304730298	4448	626	644473	4432500	090S	230E	15	S	5074	GR	9170	12/2/1978	1	x
4304730300	977	4193	602164	4466299	050S	190E	33	S	5170	GR	9137	5/6/1978	1	
4304730321	2963	2348	591011	4425843	100S	180E	06	S	5311	GR	7995	10/25/1977	1	
4304730326	4574	200	615908	4433977	090S	200E	11	S	4774	KB	6690	1/11/1978	2	
4304730329	-362	5461	631751	4470042	050S	220E	21	S	5099	GR	5475	1/28/1978	3	
4304730331	6200	1311	659797	4391063	130S	250E	29	S	7511	GR	5792	10/13/1978	1	
4304730338	4640	90	624907	4437380	080S	210E	34	S	4730	GR	10227	1/11/1979	5	
4304730339	2902	2235	652454	4435525	090S	240E	09	S	5137	GR	6470	9/5/1978	1	
4304730341	309	5288	646222	4448618	070S	230E	25	S	5597	GR	5700	10/18/1978	1	x
4304730354	2319	2659	645311	4434563	090S	230E	11	S	4978	GR	7693	4/3/1978	1	
4304730355	2614	4505	626389	4377488	150S	210E	02	S	7119	GR	10300	7/22/1978	1	

API number	BMSW Elevation	BMSW Depth	UTM E	UTM N	Township	Range	Section	Meridian	Elevation	Elevation Datum	Total Depth	Completion Date[1]	Modifier[2]	Questionable Tie
4304730357	2824	3165	634015	4402779	120S	220E	22	S	5989	GR	15082	6/15/1978	1	
4304730361	828	4352	620714	4421486	100S	210E	19	S	5180	KB	6141	4/4/1978	1	
4304730369	1535	3800	640587	4423927	100S	230E	17	S	5335	GR	7085	5/13/1978	1	x
4304730386	2306	4084	643731	4390088	130S	230E	34	S	6390	GR	9837	11/17/1981	1	
4304730412	1922	3074	613399	4422688	100S	200E	16	S	4996	GR	8350	11/14/1979	1	x
4304730419	1784	3168	637812	4428008	090S	220E	36	S	4952	GR	7303	9/5/1978	1	
4304730425	1771	3272	636299	4426461	100S	220E	02	S	5043	GR	7000	11/10/1978	1	
4304730445	6666	433	664386	4390024	130S	250E	35	S	7099	GR	6120	9/30/1979	1	
4304730448	4644	3031	651365	4376414	150S	240E	09	S	7675	GR	9007	4/22/1981	1	
4304730458	1208	4167	634148	4450275	070S	220E	22	S	5375	GR	6801	4/16/1981	1	x
4304730460	6712	586	654116	4385065	140S	240E	14	S	7298	GR	6057	9/27/1979	1	
4304730487	-372	7149	612419	4483308	040S	200E	04	S	6777	KB	4740	10/24/1978	3	
4304730488	1678	3496	606283	4423876	100S	190E	11	S	5174	GR	6800	8/6/1979	1	
4304730493	1946	2988	630803	4429109	090S	220E	29	S	4934	GR	6000	10/25/1978	1	
4304730512	1644	3416	627765	4426561	100S	210E	01	S	5060	GR	6200	2/5/1979	1	
4304730516	4587	2193	615163	4386756	140S	200E	03	S	6780	GR	7906	12/7/1978	1	
4304730522	627	4907	644616	4449047	070S	230E	26	S	5534	GR	5700	6/20/1979	1	x
4304730549	4531	226	626103	4432953	090S	210E	14	S	4757	GR	7000	5/23/1979	2	x
4304730552	2868	2536	589754	4468920	010S	010W	25	U	5404	GR	12993	7/16/1981	1	
4304730566	2427	2805	652953	4434307	090S	240E	10	S	5232	KB	6165	6/19/1980	1	
4304730573	4127	571	617601	4437873	080S	200E	36	S	4698	GR	7765	1/24/1980	2	
4304730582	3949	3491	646177	4380943	140S	230E	25	S	7440	GR	8750	9/24/1979	1	
4304730593	213	5242	600725	4472304	010S	020E	18	U	5455	GR	14154	12/15/1979	4	
4304730597	7249	284	665833	4382585	140S	250E	25	S	7533	KB	4568	10/9/1980	1	
4304730599	3195	3788	632428	4383891	140S	220E	16	S	6983	GR	8121	9/17/1979	1	
4304730603	1627	3253	620413	4429787	090S	210E	30	S	4880	GR	6920	3/18/1980	1	x
4304730618	4816	2898	643028	4375650	150S	230E	15	S	7714	GR	8427	8/28/1980	1	
4304730620	4958	3184	657563	4372006	150S	250E	30	S	8142	GR	8056	12/16/1981	1	
4304730623	2307	3080	640310	4442478	080S	230E	17	S	5387	KB	10012	6/22/1980	1	
4304730632	2142	3188	642825	4426343	100S	230E	04	S	5330	KB	8670	5/27/1989	1	
4304730644	3420	4080	630265	4370581	150S	220E	32	S	7500	KB	9900	1/28/1980	1	
4304730647	4591	208	614277	4432304	090S	200E	15	S	4799	GR	5060	11/12/1980	1	x
4304730672	1973	2962	597050	4428339	090S	180E	26	S	4935	GR	5356	5/17/1980	1	
4304730697	-3145	8272	637026	4483680	040S	230E	07	S	5127	GR	8285	9/12/1980	3	
4304730701	-494	6006	653509	4457391	060S	240E	34	S	5512	KB	6006	11/18/1980	3	
4304730714	-1992	6867	637383	4471039	050S	230E	18	S	4875	GR	6880	10/20/1980	3	
4304730715	3322	1594	634007	4437561	080S	220E	34	S	4916	KB	7254	2/14/1981	1	
4304730732	203	4710	634269	4443586	080S	220E	10	S	4913	GR	6061	6/15/1981	1	x
4304730746	6082	592	635345	4378308	150S	220E	02	S	6674	GR	6010	11/27/1980	2	
4304730773	2899	3777	649557	4389828	130S	240E	32	S	6676	GR	9472	6/6/1981	1	
4304730777	616	4542	605617	4460988	060S	190E	14	S	5158	KB	9249	1/26/1981	1	
4304730798	4789	60	624122	4443453	080S	210E	10	S	4849	KB	5510	3/31/1981	2	
4304730820	-8368	13770	596315	4472354	010S	010E	15	U	5402	GR	13800	4/2/1981	3	
4304730826	2586	2381	597326	4424409	100S	180E	11	S	4967	GR	4818	11/24/1982	1	x
4304730843	-4958	10371	598960	4472047	010S	010E	13	U	5413	GR	10418	3/18/1981	4	
4304730852	5180	988	610785	4396568	130S	200E	05	S	6168	GR	8605	9/21/1983	2	
4304730859	2800	3086	614005	4400615	120S	200E	27	S	5886	GR	8256	4/4/1981	1	
4304730860	3168	3147	618096	4391913	130S	200E	24	S	6315	GR	7649	5/14/1981	1	
4304730861	1855	3570	630823	4419467	100S	220E	29	S	5425	GR	7100	7/14/1984	1	
4304730879	1411	3656	624808	4447917	070S	210E	34	S	5067	GR	13066	8/30/1981	4	
4304730881	64	5054	595917	4464610	020S	010E	10	U	5118	GR	12505	6/29/1981	1	
4304730894	-205	5663	646122	4454597	070S	230E	12	S	5458	GR	5675	7/9/1981	3	x
4304730959	4353	514	607752	4454941	070S	190E	01	S	4867	GR	4401	8/10/1981	2	x
4304731018	4765	194	614912	4452286	070S	200E	15	S	4959	GR	7514	6/25/1981	2	x
4304731026	1567	3609	613934	4414359	110S	200E	10	S	5176	GR	6900	8/23/1981	1	
4304731043	4124	3376	641278	4377700	150S	230E	04	S	7500	GR	8785	10/14/1981	1	
4304731045	4077	2898	653136	4375784	150S	240E	15	S	6975	GR	8271	1/28/1982	1	
4304731057	2780	3441	652111	4406080	120S	240E	10	S	6221	GR	3449	10/24/1981	3	
4304731067	3845	1763	629439	4414386	110S	220E	08	S	5608	GR	7200	2/25/1982	1	
4304731068	1512	4055	626280	4415919	110S	210E	01	S	5567	GR	7300	2/8/1982	1	
4304731071	2802	4478	624672	4374465	150S	210E	15	S	7280	GR	10215	9/19/1981	1	
4304731084	1388	3968	626366	4420394	100S	210E	26	S	5356	GR	6200	3/28/1982	1	
4304731108	2280	3342	606292	4414383	110S	190E	11	S	5622	KB	8300	1/26/1982	1	
4304731113	4150	498	609314	4435154	090S	200E	06	S	4648	GR	7548	4/26/1982	2	
4304731128	4365	340	603067	4431718	090S	190E	16	S	4705	GR	7475	2/4/1982	2	x
4304731134	3207	3089	666920	4396978	130S	260E	07	S	6296	KB	6990	6/17/1982	2	
4304731136	2472	2461	607679	4456599	060S	190E	36	S	4933	GR	4593	8/4/1982	1	
4304731178	958	4176	613476	4415751	110S	200E	03	S	5134	GR	6700	5/12/1982	1	
4304731180	3592	3703	616468	4380367	140S	200E	26	S	7295	GR	5700	5/6/2008	1	
4304731186	2984	3300	655274	4407429	120S	240E	01	S	6284	KB	3400	12/3/1982	3	
4304731198	3741	1306	594594	4430707	090S	180E	21	S	5047	GR	5870	8/31/1982	1	
4304731200	4471	306	600566	4431637	090S	190E	18	S	4777	GR	5860	1/14/1983	1	x
4304731213	2638	3057	587711	4473662	010S	010W	11	U	5695	GR	15871	11/4/1982	4	
4304731233	4700	210	627156	4430227	090S	210E	26	S	4910	GR	7800	7/28/1983	2	
4304731273	3097	2963	615948	4392775	130S	200E	23	S	6060	KB	6080	3/30/1983	1	
4304731274	4786	242	592549	4433556	090S	180E	08	S	5028	GR	6070	11/4/1983	2	
4304731276	283	4804	611321	4462287	060S	200E	17	S	5087	GR	4820	12/6/1982	1	
4304731300	-473	5747	634890	4453828	070S	220E	11	S	5274	GR	6186	5/26/1983	1	x
4304731307	-1835	7972	665170	4408940	110S	250E	36	S	6137	GR	8502	6/24/1983	1	
4304731330	1808	3255	610485	4423594	100S	200E	07	S	5063	GR	6661	8/24/1983	1	
4304731344	2473	2906	654834	4439691	080S	240E	26	S	5379	GR	4323	7/29/1983	1	
4304731380	4758	295	587324	4436714	080S	170E	35	S	5053	GR	6200	1/27/1984	2	x
4304731410	4544	295	596079	4436406	080S	180E	34	S	4839	GR	6237	2/7/1984	2	x
4304731597	2374	3576	666362	4404733	120S	250E	13	S	5950	GR	7686	3/9/1985	1	
4304730798	4789	60	624122	4443453	080S	210E	10	S	4849	KB	5510	3/31/1981	2	
4305110452	2959	5297	481302	4443127	040S	120W	15	U	8256	GR	5300	9/1/1965	3	
4305110747	6971	1169	507829	4425059	060S	090W	09	U	8140	DF	6500	9/14/1962	1	
4305110880	334	7453	491798	4452451	030S	110W	14	U	7787	GR	7466	10/6/1964	1	
4305111360	601	7012	491260	4446683	030S	110W	35	U	7613	DF	7015	10/4/1952	1	
4305120103	2804	6046	486699	4433540	050S	110W	18	U	8850	GR	6066	10/18/1966	3	
4305120151	-1570	10000	503864	4461689	020S	100W	13	U	8430	GR	10000	5/7/1953	3	
4305120157	-1227	10015	489752	4437084	040S	110W	34	U	8788	GR	10017		3	
4305120159	3032	5602	502342	4429389	050S	100W	26	U	8634	GR	5600		3	
4305130001	-1747	9196	497882	4442004	040S	100W	16	U	7449	KB	9196	8/15/1970	3	
4305130003	-2425	9023	508360	4442470	040S	090W	16	U	6598	GR	12264	9/27/1971	3	
4305130004	-4973	12851	506555	4447557	030S	090W	32	U	7878	KB	12583	4/17/1972	3	
4305130007	5179	2861	492243	4468036	010S	110W	26	U	8040	GR	9290	8/27/1980	1	
4305130008	4176	3728	485432	4438891	040S	110W	30	U	7904	GR	19993	1/29/1981	4	
4305130012	-5360	14176	484893	4432521	050S	120W	13	U	8816	GR	14201	8/6/1982	3	
4304715592	726	726	634674	4469222	050S	220E	23	S	4898	KB	4172	7/20/1963	3	
4304710474	562	562	634316	4468634	050S	220E	26	S	4955	KB	4393	5/23/1949	3	

Gridding Report – Plate 1 BMSW contours – also used to construct plate 4

Mon Apr 30 17:36:29 2012
Elasped time for gridding: 228.7 seconds

Data Source

Source Data File Name:
X Column: D
Y Column: E
Z Column: B

Data Counts

Active Data: 598

Original Data: 598
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0
Superseded Data: 0

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: First
X Duplicate Tolerance: 0.023
Y Duplicate Tolerance: 0.018

No duplicate data were found.

Breakline Filtering

Breakline Filtering: Not In Use

Data Counts

Active Data: 598

Univariate Statistics

	X	Y	Z
Count:	598	598	598
1%%-tile:	489864.3125	4343348	-3429
5%%-tile:	529085.536	4369121	-473
10%%-tile:	541745.375	4384552.518	473
25%%-tile:	566144.835	4410567.257	1978
50%%-tile:	607193.885	4433599.5	2921
75%%-tile:	635345.219	4453498.18	3955
90%%-tile:	651793.375	4468077.418	4938
95%%-tile:	658150.75	4474397.476	5330
99%%-tile:	665112.8125	4483536.875	6237
Minimum:	473345.375	4333583	-5360
Maximum:	666361.816	4489612.219	7249
Mean:	599785.772307	4430236.44873	2805.97658863
Median:	607217.3865	4433601	2922
Geometric Mean:	598229.772272	4430123.5472	N/A
Harmonic Mean:	596632.226415	4430010.3256	N/A
Root Mean Square:	601298.718537	4430349.02997	3362.50466051
Trim Mean (10%%):	601346.290941	4431442.15458	2906.73469388
Interquartile Mean:	603940.868196	4433528.45201	2961.090301
Midrange:	569853.5955	4411597.6095	944.5
Winsorized Mean:	601110.494898	4431211.95027	2902.95986622
TriMean:	603969.456	4432816.10925	2943.75
Variance:	1820220098.23	999206538.901	3438683.28253
Standard Deviation:	42664.0375285	31610.2283905	1854.36870189
Interquartile Range:	69200.384	42930.923	1977
Range:	193016.441	156029.219	12609
Mean Difference:	48501.4907681	35580.5988847	1985.14571744
Median Abs. Deviation:	33256.7565	21400.687	989
Average Abs. Deviation:	36189.3790757	25282.0163729	1341.20735786
Quartile Dispersion:	0.0575954697	0.00484325429512	N/A
Relative Mean Diff.:	0.0808646903735	0.00803130923066	N/A
Standard Error:	1744.66223611	1292.63836577	75.8307753655
Coef. of Variation:	0.0711321266664	0.00713511090352	N/A
Skewness:	-0.460901975994	-0.581561243568	-1.04027948215
Kurtosis:	2.38908860761	2.88282048956	5.33150560354
Sum:	358671891.84	2649281396.34	1677974
Sum Absolute:	358671891.84	2649281396.34	1817496
Sum Squares:	2.16212969051e+014	1.17375395313e+016	6761249680
Mean Square:	361560148914	1.96279925273e+013	11306437.592

Inter-Variable Covariance

	X	Y	Z
X:	1.8202201e+009	-3.5131411e+008	-11757689
Y:	-3.5131411e+008	9.9920654e+008	-17927167
Z:	-11757689	-17927167	3438683.3

Inter-Variable Correlation

	X	Y	Z
X:	1.000	-0.260	-0.149
Y:	-0.260	1.000	-0.306
Z:	-0.149	-0.306	1.000

Inter-Variable Rank Correlation

	X	Y	Z
X:	1.000	-0.262	-0.246
Y:	-0.262	1.000	-0.282
Z:	-0.246	-0.282	1.000

Principal Component Analysis

	PC1	PC2	PC3
X:	0.346383062042	0.346383062042	0.0106730734233
Y:	0.937783459932	0.937783459932	0.0217523492753
Z:	-0.0241030414546	-0.0241030414546	0.0217523492753
Lambda:	1950037573.11	869904664.081	2923083.225

Planar Regression: Z = AX+BY+C

Fitted Parameters

A	B	C

Parameter Value:	-0.0106446349181	-0.0216839833601	105255.6506
Standard Error:	0.00170210602743	0.00229731701191	10490.2436496

Inter-Parameter Correlations

	A	B	C
A:	1.000	0.260	-0.350
B:	0.260	1.000	-0.996
C:	-0.350	-0.996	1.000

ANOVA Table

Source	df	Sum of Squares	Mean Square	F
Regression:	2	306791558.659	153395779.33	52.2709840723
Residual:	595	1746102361.01	2934625.81683	
Total:	597	2052893919.67		

Coefficient of Multiple Determination (R^2): 0.149443454296

Nearest Neighbor Statistics

	Separation	|Delta Z|
1%%-tile:	77.8318700922	1
5%%-tile:	884.223985172	36
10%%-tile:	1313.59116655	83
25%%-tile:	2021.61102641	208
50%%-tile:	2893.90549258	596
75%%-tile:	3922.46497666	1352
90%%-tile:	5231.87875187	2548
95%%-tile:	6392.74286228	3422
99%%-tile:	10805.9853908	6749
Minimum:	0.0849999999627	0
Maximum:	15093.7947375	9536
Mean:	3219.39356131	1051.38461538
Median:	2895.63561824	600
Geometric Mean:	2573.86835201	N/A
Harmonic Mean:	14.9573277911	N/A
Root Mean Square:	3742.86553917	1673.26137391
Trim Mean (10%%):	3037.52727026	868.304267161
Interquartile Mean:	2922.81847492	662.27090301
Midrange:	7546.93986877	4768

Winsorized Mean:	3043.60518009	894.434782609
TriMean:	2932.97174706	688
Variance:	3650652.31146	1697232.19688
Standard Deviation:	1910.66802754	1302.77864462
Interquartile Range:	1900.85395024	1144
Range:	15093.7097375	9536
Mean Difference:	1931.86043873	1190.95330611
Median Abs. Deviation:	918.370575758	440
Average Abs. Deviation:	1302.12151953	801.334448161
Quartile Dispersion:	0.319789644221	N/A
Relative Mean Diff.:	0.600069672109	1.13274751093
Standard Error:	78.133025998	53.2745805356
Coef. of Variation:	0.593486938193	1.23910757829
Skewness:	1.88949037591	2.69001019423
Kurtosis:	9.10122985953	12.5674196962
Sum:	1925197.34966	628728
Sum Absolute:	1925197.34966	628728
Sum Squares:	8377407381.7	1674282568
Mean Square:	14009042.4443	2799803.62542

Complete Spatial Randomness

Lambda:	1.98564197935e-008
Clark and Evans:	0.907307581217
Skellam:	1045.17845642

Gridding Rules

Gridding Method:	Kriging
Kriging Type:	Point
Polynomial Drift Order:	0
Kriging std. deviation grid:	no

Semi-Variogram Model

Component Type:	Linear
Anisotropy Angle:	0
Anisotropy Ratio:	1
Variogram Slope:	1

Search Parameters

Search Ellipse Radius #1:	124000
Search Ellipse Radius #2:	124000
Search Ellipse Angle:	0
Number of Search Sectors:	4
Maximum Data Per Sector:	16
Maximum Empty Sectors:	3
Minimum Data:	8

Maximum Data:	64

Output Grid

Grid File Name:	
Grid Size:	1577 rows x 1931 columns
Total Nodes:	3045187
Filled Nodes:	3045187
Blanked Nodes:	0
Blank Value:	1.70141E+038

Grid Geometry

X Minimum:	473345.375
X Maximum:	666329.8125
X Spacing:	99.991936528497
Y Minimum:	4333583
Y Maximum:	4491147.238
Y Spacing:	99.977308375634

Univariate Grid Statistics

	Z
Count:	3045187
1%%-tile:	-3175.10160813
5%%-tile:	-1219.52837507
10%%-tile:	-70.0646992418
25%%-tile:	2176.74089884
50%%-tile:	3090.63727084
75%%-tile:	3764.64880179
90%%-tile:	4539.3349822
95%%-tile:	5048.2262997
99%%-tile:	5964.23479692
Minimum:	-5322.90045866
Maximum:	7242.5953638
Mean:	2697.61496639
Median:	3090.63727084
Geometric Mean:	N/A
Harmonic Mean:	N/A
Root Mean Square:	3262.77170523
Trim Mean (10%%):	2819.17157446
Interquartile Mean:	3062.33824558
Midrange:	959.847452571
Winsorized Mean:	2776.83377081
TriMean:	3030.66606058
Variance:	3368553.7998

Standard Deviation:	1835.36203508
Interquartile Range:	1587.90790296
Range:	12565.4958225
Mean Difference:	N/A
Median Abs. Deviation:	770.845714307
Average Abs. Deviation:	1274.29136743
Quartile Dispersion:	N/A
Relative Mean Diff.:	N/A
Standard Error:	1.05175542406
Coef. of Variation:	N/A
Skewness:	-1.20871148144
Kurtosis:	4.65663918143
Sum:	8214742026.65
Sum Absolute:	9130052727
Sum Squares:	3.24180839075e+013
Mean Square:	10645679.2005

Gridding Report – Plate 2 water samples >10k TDS, elevation of top interval

Tue Apr 17 15:37:16 2012
Elasped time for gridding: 459.9 seconds

Data Source

Source Data File Name:
X Column: G
Y Column: H
Z Column: F

Data Counts

Active Data: 963

Original Data: 966
Excluded Data: 0
Deleted Duplicates: 3
Retained Duplicates: 3
Artificial Data: 0
Superseded Data: 0

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: First
X Duplicate Tolerance: 0.021
Y Duplicate Tolerance: 0.014

Deleted Duplicates: 3
Retained Duplicates: 3
Artificial Data: 0

X	Y	Z	ID	Status
515979.22	4402773	3000	971	Retained
515979.22	4402773	2200	972	Deleted

518967.44	4407163.5	1678	359	Retained
518967.44	4407163.5	1478	360	Deleted
631267.06	4456301.5	-757	487	Retained
631267.06	4456301.5	-1075	488	Deleted

Breakline Filtering

Breakline Filtering: Not In Use

Data Counts

Active Data: 963

Univariate Statistics

	X	Y	Z
Count:	963	963	963
1%%-tile:	518626.375	4378689.5	-8883
5%%-tile:	536912.375	4401963	-5766
10%%-tile:	551520.242449	4409369.9961	-4464
25%%-tile:	572473.8125	4428897.5	-1106
50%%-tile:	592456.75	4436332.5	219
75%%-tile:	628873.0625	4450555.5	1344
90%%-tile:	640309.4375	4467258.5	3000
95%%-tile:	646425.4375	4472235	3349
99%%-tile:	653830.625	4477229	3875
Minimum:	485888.011548	4368677.5	-11774
Maximum:	665587.187546	4491491.49372	4645
Mean:	597143.800077	4437788.57175	-282.516095535
Median:	592456.75	4436332.5	219
Geometric Mean:	596113.026135	4437740.84304	N/A
Harmonic Mean:	595069.496449	4437693.05638	N/A
Root Mean Square:	598160.581776	4437836.24284	2753.75881866
Trim Mean (10%%):	598050.949756	4438273.50228	-97.7309468822
Interquartile Mean:	598408.591932	4438037.65313	209.55186722
Midrange:	575737.599547	4430084.49686	-3564.5
Winsorized Mean:	598178.763716	4438429.16393	-133.208722741
TriMean:	596565.09375	4438029.5	169
Variance:	1216626992.45	423550482.943	7511172.05042
Standard Deviation:	34880.1805106	20580.3421484	2740.6517565
Interquartile Range:	56399.25	21658	2450
Range:	179699.175998	122813.99372	16419
Mean Difference:	39757.7609698	22654.9226111	2909.57327565

Median Abs. Deviation:	28895.25	11585	1179
Average Abs. Deviation:	29968.2599562	15334.1043806	1936.13914849
Quartile Dispersion:	0.0469466822395	0.0024391142112	N/A
Relative Mean Diff.:	0.0665798773506	0.0051050026933	N/A
Standard Error:	1123.99810814	663.192257062	88.3162685592
Coef. of Variation:	0.0584116933075	0.00463752200349	N/A
Skewness:	-0.253395741046	-0.378024702664	-1.14997192867
Kurtosis:	2.17378534087	3.59788598649	4.41052346326
Sum:	575049479.474	4273590394.6	-272063
Sum Absolute:	575049479.474	4273590394.6	1876813
Sum Squares:	3.44557626572e+014	1.8965698069e+016	7302609689
Mean Square:	357796081591	1.96943905182e+013	7583187.63136

Inter-Variable Covariance

	X	Y	Z
X:	1.216627e+009	-82706870	6548850.4
Y:	-82706870	4.2355048e+008	-31509903
Z:	6548850.4	-31509903	7511172.1

Inter-Variable Correlation

	X	Y	Z
X:	1.000	-0.115	0.069
Y:	-0.115	1.000	-0.559
Z:	0.069	-0.559	1.000

Inter-Variable Rank Correlation

	X	Y	Z
X:	1.000	-0.120	-0.070
Y:	-0.120	1.000	-0.544
Z:	-0.070	-0.544	1.000

Principal Component Analysis

PC1	PC2	PC3

X:	0.103240615883	0.103240615883	-0.000267280083702
Y:	0.991853841573	0.991853841573	0.0750430705545
Z:	-0.0746145574848	-0.0746145574848	0.0750430705545
Lambda:	1225238464.07	417312052.973	5138130.40272

Planar Regression: Z = AX+BY+C

Fitted Parameters

	A	B	C
Parameter Value:	0.00032978490241	-0.074330284567	329382.642281
Standard Error:	0.00211739245743	0.00358862017912	16120.3835565

Inter-Parameter Correlations

	A	B	C
A:	1.000	0.115	-0.192
B:	0.115	1.000	-0.997
C:	-0.192	-0.997	1.000

ANOVA Table

Source	df	Sum of Squares	Mean Square	F
Regression:	2	2255216406.26	1127608203.13	217.784347763
Residual:	960	4970531106.24	5177636.569	
Total:	962	7225747512.5		

Coefficient of Multiple Determination (R^2): 0.312108387729

Nearest Neighbor Statistics

	Separation	|Delta Z|
1%%-tile:	5	6
5%%-tile:	249.72384748	25
10%%-tile:	366.150242387	56
25%%-tile:	535.989738708	198
50%%-tile:	812	582
75%%-tile:	1455.64865266	1546
90%%-tile:	2559.47167476	3342

95%%-tile:	3932.27987242	5181
99%%-tile:	9815.63761451	9024
Minimum:	0.170238068522	2
Maximum:	35583.429317	11378
Mean:	1328.63776054	1301.22845275
Median:	812	582
Geometric Mean:	793.568780363	503.260145087
Harmonic Mean:	54.6678451874	96.7997403256
Root Mean Square:	2346.23859411	2269.992347
Trim Mean (10%%):	1048.08535997	1010.52078522
Interquartile Mean:	863.006554488	686.663900415
Midrange:	17791.7997775	5690
Winsorized Mean:	1068.93714408	1039.16510903
TriMean:	903.909597843	727
Variance:	3743444.51539	3463266.09952
Standard Deviation:	1934.79831388	1860.98524968
Interquartile Range:	919.658913955	1348
Range:	35583.2590789	11376
Mean Difference:	1315.74873393	1630.86585795
Median Abs. Deviation:	361.648158521	481
Average Abs. Deviation:	831.26031277	1062.39979232
Quartile Dispersion:	0.461759985116	0.772935779817
Relative Mean Diff.:	0.99029906646	1.25332784916
Standard Error:	62.348004299	59.969411548
Coef. of Variation:	1.45622710067	1.43017565113
Skewness:	7.87656004278	2.64267263055
Kurtosis:	111.655273614	10.7042900437
Sum:	1279478.1634	1253083
Sum Absolute:	1279478.1634	1253083
Sum Squares:	5301156625.48	4962209241
Mean Square:	5504835.54048	5152865.25545

Complete Spatial Randomness

Lambda:	4.36347354515e-008
Clark and Evans:	0.555076396773
Skellam:	1453.39228833

Gridding Rules

Gridding Method:	Kriging
Kriging Type:	Point
Polynomial Drift Order:	0
Kriging std. deviation grid:	no

Semi-Variogram Model

Component Type:	Linear

Anisotropy Angle:	0
Anisotropy Ratio:	1
Variogram Slope:	1

Search Parameters

Search Ellipse Radius #1:	109000
Search Ellipse Radius #2:	109000
Search Ellipse Angle:	0
Number of Search Sectors:	4
Maximum Data Per Sector:	16
Maximum Empty Sectors:	3
Minimum Data:	8
Maximum Data:	64

Output Grid

Grid File Name:	
Grid Size:	1577 rows x 1931 columns
Total Nodes:	3045187
Filled Nodes:	3045187
Blanked Nodes:	0
Blank Value:	1.70141E+038

Grid Geometry

X Minimum:	473345.375
X Maximum:	666329.8125
X Spacing:	99.991936528497
Y Minimum:	4333583
Y Maximum:	4491147.238
Y Spacing:	99.977308375634

Univariate Grid Statistics

	Z
Count:	3045187
1%%-tile:	-10413.0213121
5%%-tile:	-6588.94650118
10%%-tile:	-5138.47137106
25%%-tile:	-2131.80647595
50%%-tile:	33.9099836666
75%%-tile:	1400.11083351
90%%-tile:	2312.66447803
95%%-tile:	2607.66740371
99%%-tile:	3012.53760888
Minimum:	-13549.4678284

Maximum:	4639.04386209
Mean:	-767.452066624
Median:	33.9099836666
Geometric Mean:	N/A
Harmonic Mean:	N/A
Root Mean Square:	3081.01555103
Trim Mean (10%%):	-523.378346679
Interquartile Mean:	-142.934306791
Midrange:	-4455.21198315
Winsorized Mean:	-589.158894071
TriMean:	-165.968918776
Variance:	8903677.07497
Standard Deviation:	2983.90299356
Interquartile Range:	3531.91730946
Range:	18188.5116905
Mean Difference:	N/A
Median Abs. Deviation:	1734.70778527
Average Abs. Deviation:	2222.03874114
Quartile Dispersion:	N/A
Relative Mean Diff.:	N/A
Standard Error:	1.70992757743
Coef. of Variation:	N/A
Skewness:	-1.2142049569
Kurtosis:	4.34472562121
Sum:	-2337035056.41
Sum Absolute:	6767221173.34
Sum Squares:	2.8906915161e+013
Mean Square:	9492656.82568

Gridding Report – Plate 3 non-saline water analyses

Tue Nov 01 11:36:05 2011
Elasped time for gridding: 0.14 seconds

Data Source

Source Data File Name:
X Column: G
Y Column: H
Z Column: F

Data Counts

Active Data: 414

Original Data: 414
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0
Superseded Data: 0

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: First
X Duplicate Tolerance: 0.022
Y Duplicate Tolerance: 0.013

No duplicate data were found.

Breakline Filtering

Breakline Filtering: Not In Use

Data Counts

Active Data: 414

Univariate Statistics

	X	Y	Z
Count:	414	414	414
1%%-tile:	517011.375	4399005	-8915
5%%-tile:	521210.40625	4404730.5	-6514
10%%-tile:	538663.125	4417258	-5663
25%%-tile:	557927	4425013	-3643
50%%-tile:	611763.9375	4449571.5	472
75%%-tile:	639762.25	4460423	3678
90%%-tile:	647361.625	4467377.5	4010
95%%-tile:	650270.4375	4471739	4385
99%%-tile:	655028.4375	4475492	5226
Minimum:	474357.21875	4372506	-10480
Maximum:	660732.75	4485506.5	7003
Mean:	598965.146126	4443121.65367	-34.3888888889
Median:	612297.4375	4449621.5	472
Geometric Mean:	597298.940193	4443072.85087	N/A
Harmonic Mean:	595600.924899	4443023.97916	N/A
Root Mean Square:	600594.101431	4443170.38725	3884.98915778
Trim Mean (10%%):	600412.712121	4443698.95608	98.6085790885
Interquartile Mean:	604625.726582	4444668.41361	690.420289855
Midrange:	567544.984375	4429006.25	-1738.5
Winsorized Mean:	599984.670205	4443915.41937	31.7173913043
TriMean:	605304.28125	4446144.75	244.75
Variance:	1958759703.55	434109467.796	15128500.4319
Standard Deviation:	44257.8773051	20835.2938015	3889.53730307
Interquartile Range:	81835.25	35410	7321
Range:	186375.53125	113000.5	17483
Mean Difference:	49775.1635991	23543.2260454	4368.83769052
Median Abs. Deviation:	34272.375	16384.25	3278
Average Abs. Deviation:	40275.2036443	17334.4187971	3213.45652174
Quartile Dispersion:	0.0683276150304	0.00398517304047	N/A
Relative Mean Diff.:	0.0831019366002	0.00529880293194	N/A
Standard Error:	2175.15600171	1023.99882505	191.1603295
Coef. of Variation:	0.0738905720831	0.00468933678292	N/A
Skewness:	-0.36237366177	-0.444735202292	-0.526112593704
Kurtosis:	1.70844995678	2.39576819219	2.08750019276
Sum:	247971570.496	1839452364.62	-14237
Sum Absolute:	247971570.496	1839452364.62	1350139
Sum Squares:	1.49335295715e+014	8.17308991933e+015	6248560273
Mean Square:	360713274674	1.97417630902e+013	15093140.756

Inter-Variable Covariance

	X	Y	Z
X:	1.9587597e+009	-1.8228323e+008	73546278
Y:	-1.8228323e+008	4.3410947e+008	-65390645
Z:	73546278	-65390645	15128500

Inter-Variable Correlation

	X	Y	Z
X:	1.000	-0.198	0.427
Y:	-0.198	1.000	-0.807
Z:	0.427	-0.807	1.000

Inter-Variable Rank Correlation

	X	Y	Z
X:	1.000	-0.202	0.349
Y:	-0.202	1.000	-0.823
Z:	0.349	-0.823	1.000

Principal Component Analysis

	PC1	PC2	PC3
X:	0.122991714598	0.122991714598	-0.0241619915415
Y:	0.983003456806	0.983003456806	0.140266463616
Z:	-0.136298356734	-0.136298356734	0.140266463616
Lambda:	1983561688.86	420369242.101	4066740.82162

Planar Regression: Z = AX+BY+C

Fitted Parameters

A	B	C

Parameter Value:	0.0244863398357	-0.140349843557	608890.57599
Standard Error:	0.00231617274115	0.00491996369101	22176.201043

Inter-Parameter Correlations

	A	B	C
A:	1.000	0.198	-0.257
B:	0.198	1.000	-0.998
C:	-0.257	-0.998	1.000

ANOVA Table

Source	df	Sum of Squares	Mean Square	F
Regression:	2	4534098180.28	2267049090.14	543.624344657
Residual:	411	1713972498.11	4170249.38714	
Total:	413	6248070678.39		

Coefficient of Multiple Determination (R^2): 0.725679719975

Nearest Neighbor Statistics

	Separation	|Delta Z|
1%%-tile:	5.65685424949	1
5%%-tile:	221.081432961	9
10%%-tile:	359.517732525	27
25%%-tile:	582.352559801	133
50%%-tile:	1212.34689755	475
75%%-tile:	1779.5208987	1128
90%%-tile:	2906.03871275	3519
95%%-tile:	5397.73971214	4746
99%%-tile:	14008.0054122	9032
Minimum:	5	0
Maximum:	26715.0346078	10220
Mean:	1831.50672388	1149.35748792
Median:	1214.7794379	477
Geometric Mean:	1032.29946544	N/A
Harmonic Mean:	194.558694389	N/A
Root Mean Square:	3360.5966684	2139.605211
Trim Mean (10%%):	1351.71825942	862.08847185
Interquartile Mean:	1200.47481475	541.526570048
Midrange:	13360.0173039	5110

Winsorized Mean:	1336.90501543	924.1352657
TriMean:	1196.6418134	552.75
Variance:	7958416.31587	3264773.75083
Standard Deviation:	2821.06652099	1806.86849295
Interquartile Range:	1197.1683389	995
Range:	26710.0346078	10220
Mean Difference:	1923.59804248	1526.23583769
Median Abs. Deviation:	612.05111833	417.5
Average Abs. Deviation:	1193.91055	

Gridding Report – Figure 7. Difference map – new data points gridding.

Tue May 01 09:46:27 2012
Elasped time for gridding: 0.62 seconds

Data Source

Source Data File Name:
X Column: D
Y Column: E
Z Column: B

Data Counts

Active Data: 236

Original Data: 236
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0
Superseded Data: 0

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: First
X Duplicate Tolerance: 0.022
Y Duplicate Tolerance: 0.016

No duplicate data were found.

Breakline Filtering

Breakline Filtering: Not In Use

Data Counts

Active Data: 236

Univariate Statistics

	X	Y	Z
Count:	236	236	236
1%%-tile:	498245.53125	4335511	28
5%%-tile:	534085.0625	4365078	638
10%%-tile:	541802.3125	4376173.5	1618
25%%-tile:	573617.4375	4404666	2383
50%%-tile:	619617.9375	4424309	3130
75%%-tile:	640645.375	4441157.5	4177
90%%-tile:	653442.6875	4453624	4980
95%%-tile:	659705.625	4460454.5	5213
99%%-tile:	664743.5625	4471470	6237
Minimum:	473345.375	4333583	-1205
Maximum:	665600.75	4474877	6383
Mean:	607511.61348	4421119.50212	3195.22457627
Median:	619894.46875	4424755.25	3151
Geometric Mean:	605988.643872	4421021.06518	N/A
Harmonic Mean:	604406.025014	4420922.29123	N/A
Root Mean Square:	608974.644277	4421217.60282	3471.95706851
Trim Mean (10%%):	609326.013498	4422309.18075	3203.20657277
Interquartile Mean:	615571.648634	4424651.55882	3155.95798319
Midrange:	569473.0625	4404230	2589
Winsorized Mean:	608418.332097	4421886.94703	3236.15254237
TriMean:	613374.671875	4423610.375	3205
Variance:	1787330292.92	871130721.886	1852876.96637
Standard Deviation:	42276.8292676	29514.9237147	1361.20423389
Interquartile Range:	67027.9375	36491.5	1794
Range:	192255.375	141294	7588
Mean Difference:	47216.2680795	32768.8826001	1523.54060584
Median Abs. Deviation:	27404.4375	18325.75	835.5
Average Abs. Deviation:	33941.2180879	22987.7648305	1056.91101695
Quartile Dispersion:	0.0552005190392	0.00412528013927	N/A
Relative Mean Diff.:	0.0777207662073	0.00741189705105	N/A
Standard Error:	2751.98718104	1921.25788805	88.6068484166
Coef. of Variation:	0.0695901581625	0.00667589367367	N/A
Skewness:	-0.727702417882	-0.750166207308	-0.154618138284
Kurtosis:	2.62815557879	3.30053318435	3.16090474797
Sum:	143372740.781	1043384202.5	754073
Sum Absolute:	143372740.781	1043384202.5	757045
Sum Squares:	8.75206276999e+013	4.61313096159e+015	2844858669
Mean Square:	370850117372	1.95471650915e+013	12054485.8856

Inter-Variable Covariance

	X	Y	Z
X:	1.7873303e+009	-2.3426839e+008	-21289467
Y:	-2.3426839e+008	8.7113072e+008	-7226561
Z:	-21289467	-7226561	1852877

Inter-Variable Correlation

	X	Y	Z
X:	1.000	-0.188	-0.370
Y:	-0.188	1.000	-0.180
Z:	-0.370	-0.180	1.000

Inter-Variable Rank Correlation

	X	Y	Z
X:	1.000	-0.161	-0.342
Y:	-0.161	1.000	-0.200
Z:	-0.342	-0.200	1.000

Principal Component Analysis

	PC1	PC2	PC3
X:	0.233874369805	0.233874369805	0.0134857027983
Y:	0.972154706331	0.972154706331	0.011941179747
Z:	-0.0147650298288	-0.0147650298288	0.011941179747
Lambda:	1843952691.7	814881780.79	1479419.2855

Planar Regression: Z = AX+BY+C

Fitted Parameters

A	B	C

Parameter Value:	-0.0134735632959	-0.0119189816229	64075.8128521
Standard Error:	0.00191923376003	0.00274908784389	12426.0906917

Inter-Parameter Correlations

	A	B	C
A:	1.000	0.188	-0.277
B:	0.188	1.000	-0.996
C:	-0.277	-0.996	1.000

ANOVA Table

Source	df	Sum of Squares	Mean Square	F
Regression:	2	87649884.2932	43824942.1466	29.3614440489
Residual:	233	347776202.804	1492601.72877	
Total:	235	435426087.097		

Coefficient of Multiple Determination (R^2): 0.201296814524

Nearest Neighbor Statistics

	Separation	|Delta Z|
1%%-tile:	1207.7305163	1
5%%-tile:	2081.37094243	34
10%%-tile:	2325.43272939	82
25%%-tile:	2897.3657439	194
50%%-tile:	3925.84330162	457
75%%-tile:	5473.22683615	1037
90%%-tile:	7247.19806309	1897
95%%-tile:	9525.3990607	3100
99%%-tile:	13774.9566333	3872
Minimum:	823.452488004	1
Maximum:	34111.5522137	4687
Mean:	4691.11868719	800.275423729
Median:	3935.69992748	457
Geometric Mean:	4042.37366869	393.722158305
Harmonic Mean:	3574.79067425	43.9441100353
Root Mean Square:	5835.86102462	1220.024741
Trim Mean (10%%):	4252.72391559	677.112676056
Interquartile Mean:	3962.44480889	506.268907563
Midrange:	17467.5023509	2344

Winsorized Mean:	4271.42621321	683.792372881
TriMean:	4055.56979582	536.25
Variance:	12101958.8481	851628.208925
Standard Deviation:	3478.7869794	922.837043538
Interquartile Range:	2575.86109226	843
Range:	33288.0997257	4686
Mean Difference:	2801.94914238	883.560944825
Median Abs. Deviation:	1197.28126325	310
Average Abs. Deviation:	1843.86668317	588.978813559
Quartile Dispersion:	0.307727447922	0.684809098294
Relative Mean Diff.:	0.597288052001	1.10407107182
Standard Error:	226.449744191	60.0715748555
Coef. of Variation:	0.74156874114	1.15314929857
Skewness:	4.85337522504	2.02176137116
Kurtosis:	36.7829157785	7.06637579132
Sum:	1107104.01018	188865
Sum Absolute:	1107104.01018	188865
Sum Squares:	8037516640.1	351276647
Mean Square:	34057273.8987	1488460.36864

Complete Spatial Randomness

Lambda:	8.68779955703e-009
Clark and Evans:	0.874503018344
Skellam:	438.744359107

Gridding Rules

Gridding Method:	Kriging
Kriging Type:	Point
Polynomial Drift Order:	0
Kriging std. deviation grid:	no

Semi-Variogram Model

Component Type:	Linear
Anisotropy Angle:	0
Anisotropy Ratio:	1
Variogram Slope:	1

Search Parameters

No Search (use all data):	true

Output Grid

Grid File Name:	
Grid Size:	316 rows x 387 columns
Total Nodes:	122292
Filled Nodes:	122292

Blanked Nodes:	0
Blank Value:	1.70141E+038

Grid Geometry

X Minimum:	473345.375
X Maximum:	666329.8125
X Spacing:	499.95968264249
Y Minimum:	4333583
Y Maximum:	4491147.238
Y Spacing:	500.20393015873

Univariate Grid Statistics

	Z
Count:	122292
1%%-tile:	502.896474249
5%%-tile:	1615.13580036
10%%-tile:	2021.99389788
25%%-tile:	2677.73886448
50%%-tile:	3393.9576918
75%%-tile:	4042.35324882
90%%-tile:	4490.64493428
95%%-tile:	4708.19904549
99%%-tile:	5330.38984853
Minimum:	-1138.59911402
Maximum:	6328.97353155
Mean:	3301.2553844
Median:	3393.97347721
Geometric Mean:	N/A
Harmonic Mean:	N/A
Root Mean Square:	3449.2916841
Trim Mean (10%%):	3333.29262409
Interquartile Mean:	3368.70364317
Midrange:	2595.18720877
Winsorized Mean:	3329.63485162
TriMean:	3377.00187423
Variance:	999334.180672
Standard Deviation:	999.667034903
Interquartile Range:	1364.61438434
Range:	7467.57264557
Mean Difference:	N/A
Median Abs. Deviation:	678.537392474
Average Abs. Deviation:	796.308953048
Quartile Dispersion:	N/A
Relative Mean Diff.:	N/A
Standard Error:	2.85861946896

Coef. of Variation:	N/A
Skewness:	-0.478453121891
Kurtosis:	3.36836647234
Sum:	403717123.469
Sum Absolute:	403908386.562
Sum Squares:	1.45498290392e+012
Mean Square:	11897613.122

Appendix II: Task 3 Final Report

Geological Characterization of the Birds Nest Aquifer, Uinta Basin, Utah: Assessment of the Aquifer's Potential as a Saline Water Disposal Zone

by:

Michael D. Vanden Berg, Danielle R. Lehle, Stephanie M. Carney, and Craig D. Morgan

Utah Geological Survey

July 2012

(Will be published as UGS Special Study 145 in fall 2012)

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EXECUTIVE SUMMARY

As petroleum production increases in the Uinta Basin, Utah, operators are pressed to establish suitable saline water disposal plans. Several natural gas operators have identified the Birds Nest aquifer in central Uintah County as a possible large-scale, saline water disposal zone; however, disposal into this aquifer poses unique challenges and risks.

The Birds Nest aquifer formed from the dissolution of saline minerals within a saline zone in the upper Green River Formation's Parachute Creek Member. Through the examination of core, outcrop, and geophysical logs, it was determined that the aquifer is separated into an upper zone, covering about 410 square miles with an average thickness of 79 feet, and a more extensive lower zone, covering about 719 square miles with an average thickness of 84 feet. Several maps were generated showing the aquifer's areal extent, thickness, outcrop extent, and depth.

Federal and state regulations stipulate that produced saline water can only be injected into an underground aquifer that already contains water having >10,000 mg/L total dissolved solids (TDS) concentration. Using water chemistry data collected from various sources, a 10,000 mg/L TDS boundary line was determined for the Birds Nest aquifer. Basically, water in the southeast portion of the aquifer averages less than 10,000 mg/L TDS, down to a low of 1000 mg/L TDS, whereas water in the northwest portion averages higher than 10,000 mg/L TDS and locally exceeds 100,000 mg/L TDS. Since disposal can only take place north of the 10,000 mg/L TDS boundary line, the available areas suitable for saline water disposal within the upper and lower Birds Nest aquifer are reduced to 360 and 499 square miles, respectively.

Gilsonite, a solid hydrocarbon, occurs in veins ranging in thickness from a couple inches to tens of feet and originates from the rich oil shale beds of the upper Green River Formation, continuing up to the surface, cross-cutting the Birds Nest aquifer. Questions remain as to how these veins might affect groundwater movement through the Birds Nest aquifer – whether they act as barriers to flow or whether they create vertical and/or horizontal pathways for water transmission. The assessment provided herein includes anecdotal evidence for both cases, barrier and conduit, depending on the type of gilsonite in the vein, vein thickness, and abundance of associated fractures. Unfortunately, very little is known about the gilsonite veins and fractures at depth in the areas suitable for saline water disposal.

The fact that the Birds Nest aquifer lies within the Uinta Basin's oil shale horizon raises questions as to how large-scale, saline water disposal into this zone might impact potential future oil shale development. Currently, all companies in Utah looking to develop an oil shale property are focused on areas near the outcrop of the Mahogany zone with plans to develop a surface/underground mine and surface retort, or employ surface modified *in-situ* technologies. Since disposal can only take place north of the 10,000 mg/L TDS boundary, active disposal will be several tens of miles northwest and down-dip of any proposed oil shale development site.

Oil shale technology could potentially advance to the point where the deeper deposits, located adjacent to active Birds Nest disposal operations, might become economic. If advances in *in-situ* technologies (retorting the oil shale within the ground) allow exploitation of these deeper deposits, the oil recovery zone will be limited to the lower R-8 rich oil shale zone and below, leaving 70-90 feet of impermeable oil shale between the retort zone and the lower Birds Nest aquifer, purposely avoiding the aquifer and problems associated with retorting shale within a zone filled with water and saline minerals. Therefore, the lean oil shale within the Birds Nest has little to no economic value. In addition, if technologies advance to the point where deep underground mines prove economic (oil prices would also need to be favorably high), the mined interval would most likely be centered on the Mahogany zone, roughly 1500-3000 feet deep in the area where saline water disposal can take place, with about 300 feet of impermeable oil shale between the mining horizon and the aquifer. The most pressing question is whether water in the Birds Nest aquifer can migrate vertically through thick sequences of impermeable oil shale by way of fractures or gilsonite veins, potentially flooding operations stratigraphically below the Birds Nest zone. Any kind of water infiltration into the mining horizon could greatly affect the

economics of these deeper deposits. The likelihood of such a scenario is remote but plausible, and will only increase as saline water disposal becomes more widespread.

INTRODUCTION

As Uinta Basin petroleum production increases – natural gas production increased 208% in the past 10 years, while oil production increased 160% – so has associated saline water production, increasing the need for economic and environmentally responsible disposal plans (figure 1) (DOGM, 2012). In fact, U.S. Bureau of Land Management (BLM) records indicate that up to 25,000 new wells have been proposed for drilling in the basin (figure 2) (U.S. BLM, 2012). Many Uinta Basin operators claim that petroleum production cannot reach its full potential until a suitable, long-term water disposal solution is determined.

Currently there are three main ways to dispose of produced saline water in the Uinta Basin: 1) treat and re-use the water, 2) place the water in an evaporation pond, or 3) re-inject the water underground. Treatment and re-use, while applicable in some cases (Anadarko, 2010), is often uneconomic and typically more water is produced than can be re-used. Evaporation ponds are considered by many as a last resort since they pose several environmental risks (brine concentration, potential for shallow groundwater contamination, potential hazard to wildlife, and potential for increase in volatile organic compound and ozone emissions) and have limited capacities (Energy Dynamic Laboratory, 2012; NETL, 2012). The method preferred by most operators and regulators, as well as the method with the largest storage volume potential, is re-injection into deep underground saline aquifers (U.S. EPA, 2012).

Saline water from oil and gas wells can only be injected into aquifers containing water having >10,000 mg/L total dissolved solids (TDS) salinity (U.S. EPA, 2012; U.S. NARA, 2012). This practice was implemented as a means to protect "freshwater" (0-10,000 mg/L TDS), a priority in the arid Uinta Basin. Current water disposal wells are near capacity and permitting for new wells has been delayed because of insufficient technical data regarding potential disposal aquifers and questions concerning contamination of freshwater sources. Eastern Uinta Basin natural gas producers have identified the Birds Nest aquifer, located in the Parachute Creek Member of the Green River Formation, as one of the most promising reservoirs suitable for large-volume saline water disposal. Drilling companies indicate that the Birds Nest aquifer creates a zone of lost circulation when accessing deeper natural gas deposits – this is often cited as evidence for large storage volume potential. In fact, three petroleum companies have already commenced limited saline water disposal into the Birds Nest aquifer; Anadarko currently operates eight disposal wells (with two more proposed), EOG Resources operates nine disposal wells, and Questar operates one (with an additional well proposed) (table 1).

Our research focused on defining the Birds Nest aquifer's geologic characteristics (i.e., the origin of the aquifer, its thickness, areal extent, and outcrop exposure), defining the area with potential for saline water disposal, and analyzing the possible effects water disposal could have on a future oil shale industry. Except for a detailed analysis of the aquifer's water chemistry and an attempt to calculate the available storage space, determining the Birds Nest aquifer's other hydrogeologic characteristics was beyond the scope of this study.

PREVIOUS RESEARCH

Previous studies of the Birds Nest aquifer were limited to the area surrounding the 1974 federal oil shale lease tracts U-a and U-b, located mostly in T. 10 S., R. 24 E., Salt Lake Base Line and Meridian (SLBLM), on the far eastern side of the Uinta Basin (figure 2). Oil shale-related drilling within and surrounding these tracts provided limited subsurface data on the aquifer, but its overall areal extent was unknown. The first comprehensive study of the hydrology of the Birds Nest aquifer, within this limited

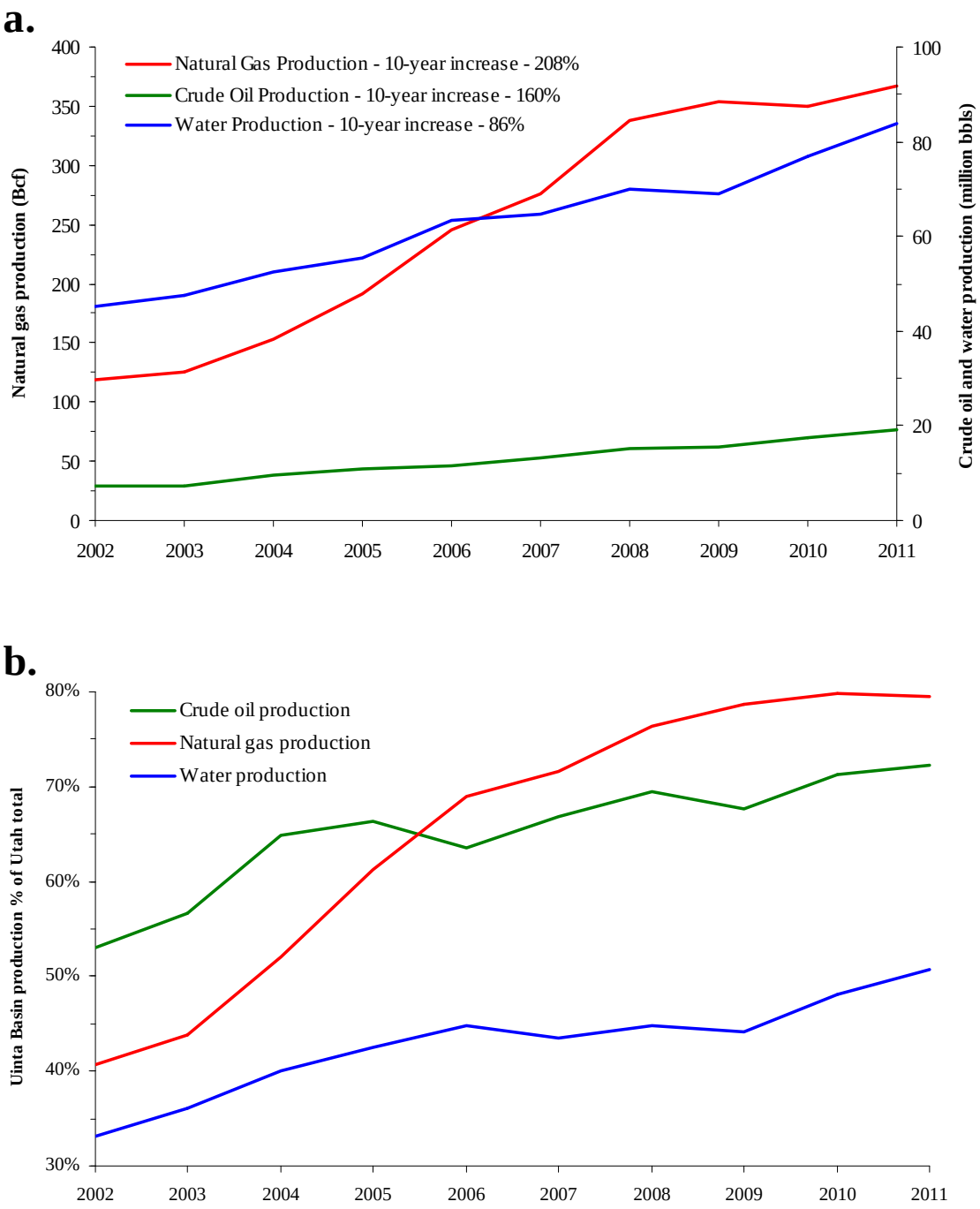

Figure 1. *a. Natural gas, crude oil, and water production in the Uinta Basin, Utah, 2002-2011 (DOGM, 2012). b. Percentage of Utah's total natural gas, crude oil, and water production from the Uinta Basin.*

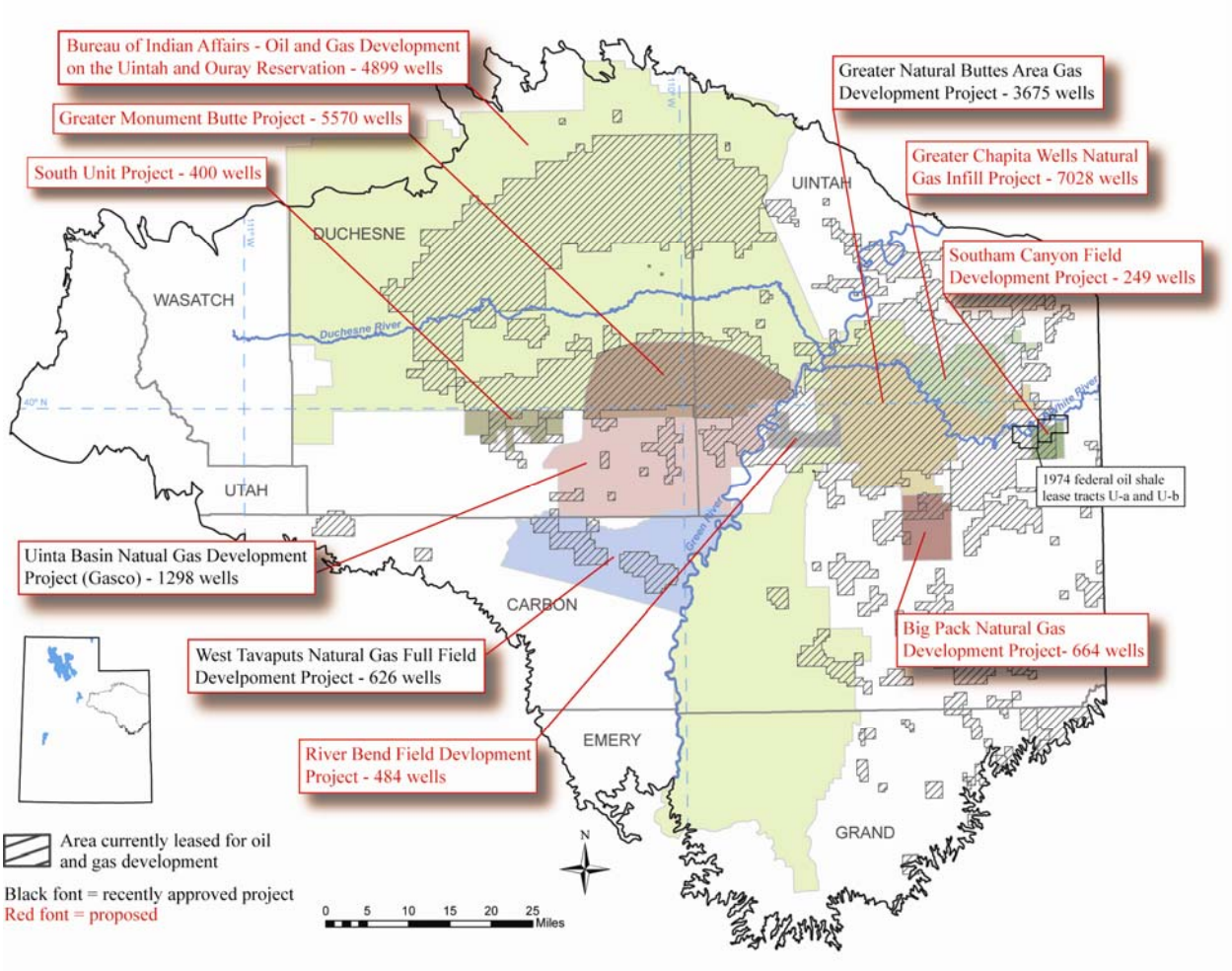

Figure 2. *Proposed oil and gas drilling projects in the Uinta Basin comprise more than 25,000 new wells (U.S. BLM, 2012). This potential future drilling will greatly increase the amount of produced water needing proper disposal.*

Table 1. *Active and proposed Birds Nest aquifer saline water disposal wells.*

API	Operator	Well Name	Status	Completion date	Twn	Rng	Sec	Mrd	UTM E	UTM N	Water Chemistry[1]	TD	Disposal Zone		Notes
			as of May 2012						NAD 83	NAD 83		ft	top - ft	base - ft	
4304737309	Questar	RWS 12 SWD 5-9-24	proposed		9S	24E	5	SL	649726	4436250	No	8105			current gas well
4304738875	Questar	NBE 12-10-9-23	active	29-Nov-2007	9S	23E	10	SL	643288	4434526	Yes	2070	1803	2070	
4304750290	EOG	Hoss 901-36	active	1-Apr-2009	8S	22E	36	SL	638083	4437416	Yes	2376			
4304750302	EOG	Hoss 903-36	active	2-Jul-2009	8S	22E	36	SL	637646	4437660	Yes	2150			
4304750304	EOG	Hoss 904-36	active	25-Jul-2009	8S	22E	36	SL	637074	4437408	Yes	2158	2143		
4304750303	EOG	Hoss 905-31	active	14-Sep-2009	8S	23E	31	SL	638759	4437381	Yes	2365	2094		
4304750300	EOG	Hoss 906-31	active	24-Sep-2009	8S	23E	31	SL	639426	443768	Yes	2365	2104		
4304750301	EOG	Hoss 907-31	active	6-Oct-2009	8S	23E	31	SL	639436	4437129	Yes	2345	2071		
4304733116	EOG	Chapita 550	active	25-Jun-2009	9S	23E	30	SL	639392	4430427	No[2]	5930	1620	1955	recompleted gas well, injection also above BN
4304738434	EOG	CWU SWD 2-29	active	8-Nov-2007	9S	23E	29	SL	640711	4430297	Yes	1940	1723	1830	
4304750806	EOG	Coyote SWD 1-16	active	1-Apr-2011	9S	23E	16	SL	642958	4433213	Yes	1970	1706	1964	
4304740254	Anadarko	NBU 921-34H	active	6-May-2011	9S	21E	34	SL	625402	4428106	Yes	1955	1641	1955	
4304736394	Anadarko	NBU 921-33J	active	2-Jun-2011	9S	21E	33	SL	623436	4427695	No	9400	1664	1957	recompleted gas well
4304740255	Anadarko	NBU 921-34L	active	15-Jan-2010	9S	21E	34	SL	624156	4427885	Yes	2260	1674	1932	recompleted gas well
4304736389	Anadarko	NBU 921-34K	active	5-Jun-2009	9S	21E	34	SL	624721	4427872	Yes	9650	1632	1960	recompleted gas well
4304731915	Anadarko	CIGE 114	active	12-Jun-2009	9S	21E	34	SL	625471	4427699	Yes	6150	1654	1959	recompleted gas well
4304740253	Anadarko	NBU 921-33F	active	20-Nov-2009	9S	21E	33	SL	622955	4428184	Yes	2260	1645	1970	
4304731996	Anadarko	NBU 159	active	9-Aug-1991	9S	21E	35	SL	626227	4427765	Yes	6049	1601	1927	
4304751396	Anadarko	NBU 921-35J	active	17-Nov-2011	9S	21E	35	SL	626821	4427616	Yes	1869	1533	1869	
4304736393	Anadarko	NBU 921-33I	proposed		9S	21E	33	SL	623762	4427746	No	9750	1662	1957	keeping as producing gas well for now
4304751099	Anadarko	922-17A3D	permitted, but not drilled		9S	22E	17	SL	631647	4433395	No				

[1]Available in appendix B

[2]Original disposal was into formations above Birds Nest, then later the permit was amended to include Birds Nest, so a Birds Nest specific water sample could not be collected

area, was included in a U.S. Environmental Protection Agency (EPA) Environmental Baseline Report prepared for the White River Shale Project (U-a and U-b) (VTN, 1977). Following this report, a master's thesis by Phillips (1979, University of Arizona) detailed the hydrogeology of the Birds Nest aquifer surrounding the federal lease tracts, mainly using data from the VTN (1977) report, supplemented with some outcrop examinations. Also in the mid-1970s, the U.S. Geological Survey (USGS) drilled six test wells south of the U-a and U-b tracts in order to investigate the shallow bedrock aquifers (Holmes, 1980). Only two of the six USGS wells penetrated the Birds Nest aquifer (with minimal water influx) and both were cased through this zone in order to perform aquifer testing on the underlying Douglas Creek aquifer. Lindskov and Kimball (1984) subsequently presented a summary of the extensive hydrologic investigations performed under the direction of the EPA and the USGS between 1974 and 1980 in the southeastern Uinta Basin, while Holmes and Kimball (1987) went one step further and generated various computer models simulating conditions and flows within the Birds Nest aquifer and underlying Douglas Creek aquifer, but again, the models were limited to the far eastern side of the Uinta Basin.

In the mid-1980s, the price of oil crashed and interest in developing oil shale greatly diminished. In fact, the federal U-a and U-b oil shale lease tracts reverted back to BLM ownership. The disinterest in developing an oil shale industry also stopped all research related to the Birds Nest aquifer. In 2001, the BLM commissioned the Dynamac Corporation to collect, organize, and present monitoring-well, groundwater-quality, and aquifer-characteristic data from the U-a and U-b tracts in order to facilitate well closure and abandonment measures (Dynamac, 2002). Dynamac located and sampled several old wells in the area. However, only two wells were found to be completed in the Birds Nest aquifer; other wells were completed in the alluvial aquifer or included other bedrock aquifers along with the Birds Nest. The data collected from the two wells completed in the Birds Nest were consistent with earlier reports of TDS concentrations.

Only in the past few years has there been a resurgence in interest in the Birds Nest aquifer. With the 2005 run-up in the price of oil, interest in oil shale development was renewed, and the BLM awarded a Research, Demonstration, and Development lease to the Oil Shale Exploration Company (which in 2011 sold the lease to Enefit American Oil) for the area surrounding the old White River mine project. As was the case with companies in the past, Enefit American Oil is keenly interested in how the Birds Nest aquifer might influence their oil shale development plans. Also, as natural gas production increases in the Uinta Basin, the search for suitable saline water disposal zones has increased the interest in the Birds Nest aquifer in the deeper part of the basin.

GEOLOGICAL CHARACTERIZATION

The Green River Formation is the record of an Eocene, continental interior, periodically terminal lake basin system that covered a significant area across northeastern Utah, western Colorado (Uinta-Piceance Basin respectively, Lake Uinta), and southwestern Wyoming (Greater Green River Basin, Lake Gosiute) (figure 3). In Utah, the lower Green River Formation, consisting of fluvial deltaic sands interbedded with lacustrine high-organic muds, is one of the most important conventional oil and natural gas-producing plays in the Uinta Basin, along with the stratigraphically lower Wasatch and Mesaverde Formations (figure 4) (Morgan, 2009a, 2009b). The upper Green River Formation's Parachute Creek Member, composed of alternating organic-rich ("R" zones) and organic-lean ("L" zones) marlstone (figure 4), hosts a vast, but mostly thermogenically immature, oil shale resource estimated at 1.32 trillion barrels in-place (USGS, 2010a) with approximately 77 billion barrels of oil as a potentially economic resource (Vanden Berg, 2008) (figure 5).

During deposition of the upper Green River Formation, Utah's Lake Uinta transitioned from a balanced-filled basin dominated by organic-rich, laminated marlstone, to an underfilled restricted basin (Carroll and Bohacs, 1999; Smith and others, 2008). During this time, as Lake Uinta began to shrink, the saline mineral nahcolite ($NaHCO_3$) formed within the deeper-lake sediments (depocenter in central

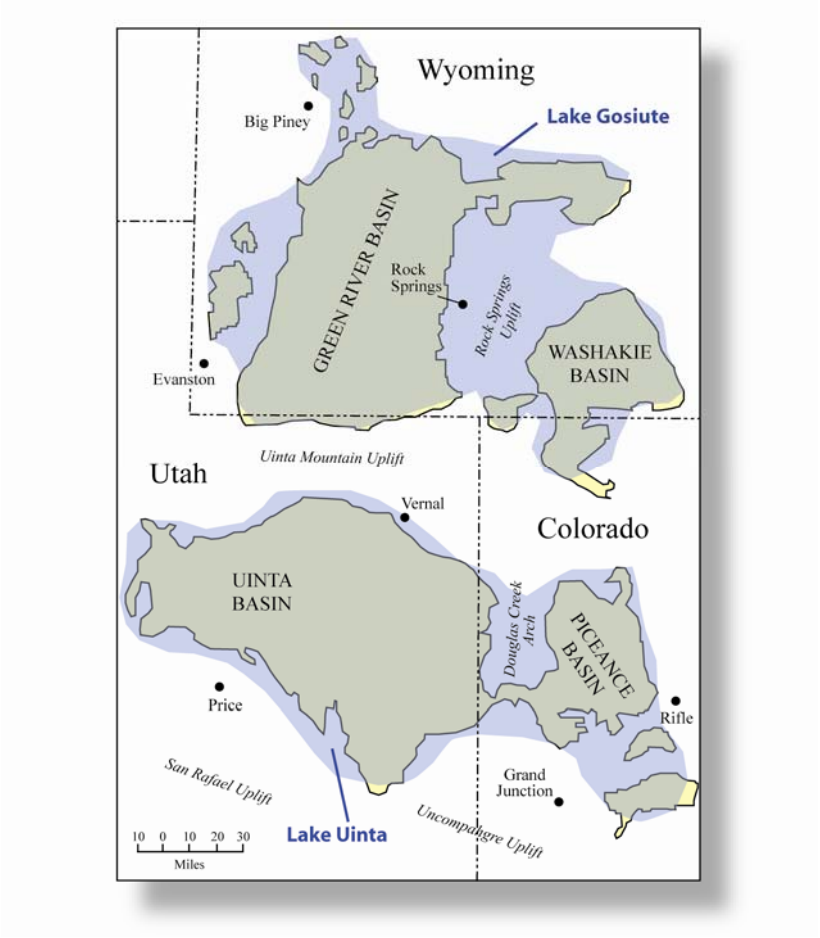

Figure 3. *Paleogeography of Eocene lake system, with modern basin margins in Utah, Colorado, and Wyoming.*

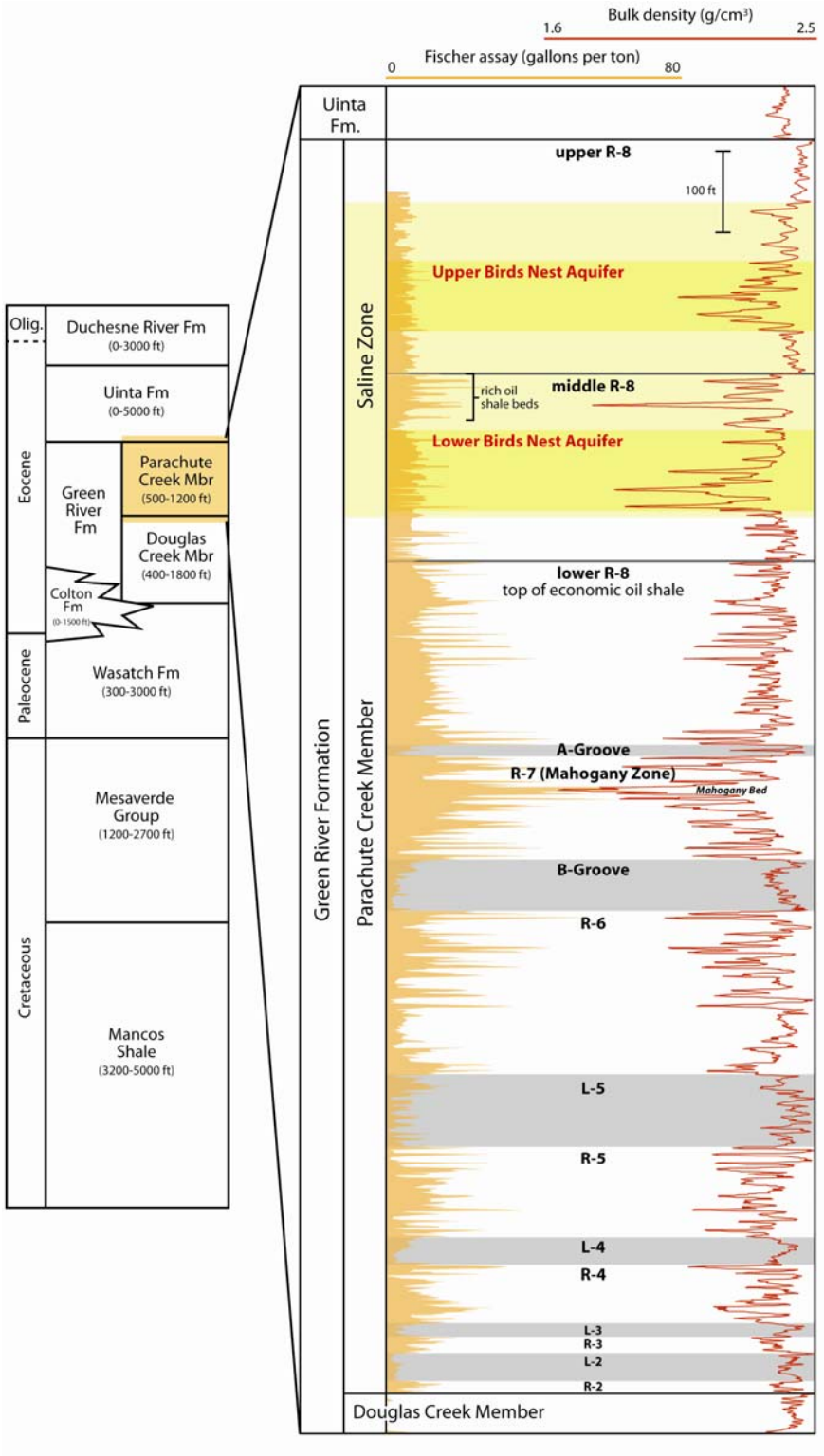

Figure 4. *General Upper Cretaceous through Oligocene stratigraphic column for the Uinta Basin (after Bradley, 1931; Cashion and Donnell, 1974; Hintze, 1988) and a composite section of the upper Green River Formation, highlighting the alternating rich and lean oil shale zones and stratigraphic position of the saline zone.*

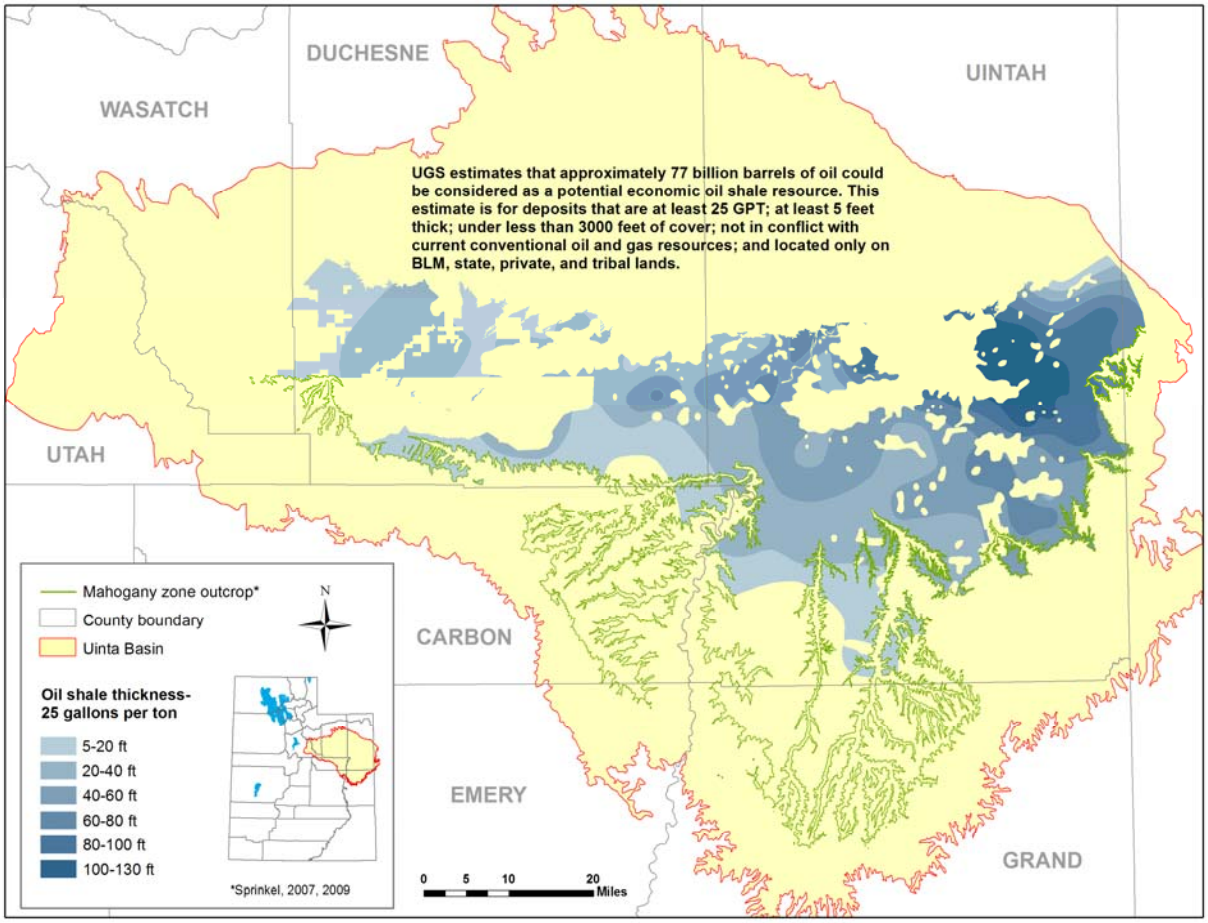

Figure 5. *Oil shale resource assessment in the Uinta Basin (from Vanden Berg, 2008).*

Uintah County) as isolated crystals, nodules ranging up to one foot in diameter, and beds ranging from less than an inch to 1-2 feet thick. Post-deposition, the saline mineral shortite ($Na_2Ca_2(CO_3)$) was deposited in fracture zones several feet thick within the nahcolite-bearing interval (much of the shortite may now be replaced by calcite). More recently, the movement of fresher groundwater through the saline zone dissolved significant amounts of the saline minerals, creating the Birds Nest aquifer.

The Birds Nest aquifer is more similar to a fractured rock aquifer than it is to a traditional sandstone aquifer and maintains unique advantages and challenges. The large macro-porosity created by the dissolution of large saline nodules within an otherwise very impermeable oil shale creates significant space for water storage and thus defines the area of the Birds Nest aquifer suitable for saline water disposal (figure 6). The permeability of the aquifer is most likely the result of fracturing of the rock along structural weakness created from the growth of the saline minerals (figure 7). In addition, significant permeability is created as groundwater dissolves the shortite/calcite minerals deposited in a fracture-fill type texture (figure 8).

The Birds Nest aquifer is typically separated into two distinct zones within an overall saline zone in the upper Green River Formation (figure 4). The more extensive lower zone represents the first deposition of large saline nodules and is overlain by a thick sequence of organic-lean oil shale with only minor saline mineral deposition – mostly small crystals and shortite. A more restricted upper Birds Nest zone records a second period of large saline nodule deposition followed again by a sequence of organic-lean oil shale with only minor small saline crystals. The saline zone is overlain by saline-free lacustrine marlstone before the transition to the fluvial sands of the Uinta Formation. Radiating out from the basin's paleo-depocenter, the overall saline zone thins and contains much smaller saline mineral crystals (<1 inch) as compared to the large (up to 1 foot) nodules found near the basin's center. This transition is confirmed to the south where cores and outcrop exposures are present and it is presumed that the same transition to small saline crystals exists to the north and west, but no cores exist to confirm this suspicion.

The lateral and stratigraphic extent of the saline zone and the Birds Nest aquifer, as mapped on plate 1, was determined through the examination of core, outcrop, and geophysical log traces. The following sections describe each method in detail.

Core Evaluation

The most precise way of examining the Birds Nest aquifer at depth is through the examination of core. Thanks to the oil shale industry of the late 1970s and early 1980s, several oil shale cores were drilled which captured all or part of the Birds Nest aquifer and/or saline zone (no Birds Nest core from conventional oil and gas wells exists since the target formations are far below the upper Green River Formation). Out of the 22 cores located, 21 were examined (the DP core was not examined due to its very close proximity to the X-13 core and its poor condition), and detailed core logs were generated with special attention made to the type and size of saline minerals present (plate 1, table 2). Each core log was then plotted with all available geophysical logs and Fischer assay oil shale data (plates 2-22) (Vanden Berg and others, 2006). Oil shale tops were picked for all horizons including the Mahogany zone, the richest and most prospective oil shale horizon, and the top of the Big Three rich oil shale beds, selected as the top of economic oil shale averaging at least 15 gallons of oil per ton of rock (figure 4, more detail in the "Birds Nest aquifer and oil shale" section below). For several of the cores, high-resolution photographs were taken of the entire saline zone/Birds Nest interval, as well as close-up photographs of saline minerals and other interesting structures.

Four cores (EX-1, Utah State 1, Coyote Wash 1, and P-4; plates 2, 3, 9, and 15), used to construct a 24 mile west-east cross section, were examined in much more detail as part of a separate study to help define the evolution of Lake Uinta (Birgenheier and Vanden Berg, 2011). The core logs from these wells display very detailed sedimentological information as well as information on sedimentary structures, textures, and preserved fossils.

Figure 6. *Photographs of nahcolite nodules in core and outcrop. a. The Birds Nest aquifer in outcrop along Evacuation Creek, eastern Uinta Basin, Utah. The cavities were created by the dissolution of nahcolite nodules. b. The Birds Nest aquifer in the 42-34 core (1648-1671 ft). The slips of paper (red circles) represent 0.5- to 1.0-foot gaps in the core created from the dissolution of nahcolite nodules. c. Dissolved nahcolite nodule in the 13X-2 core (1528 ft). d. Intact nahcolite nodule in the Utah State 1 core (1825 ft).*

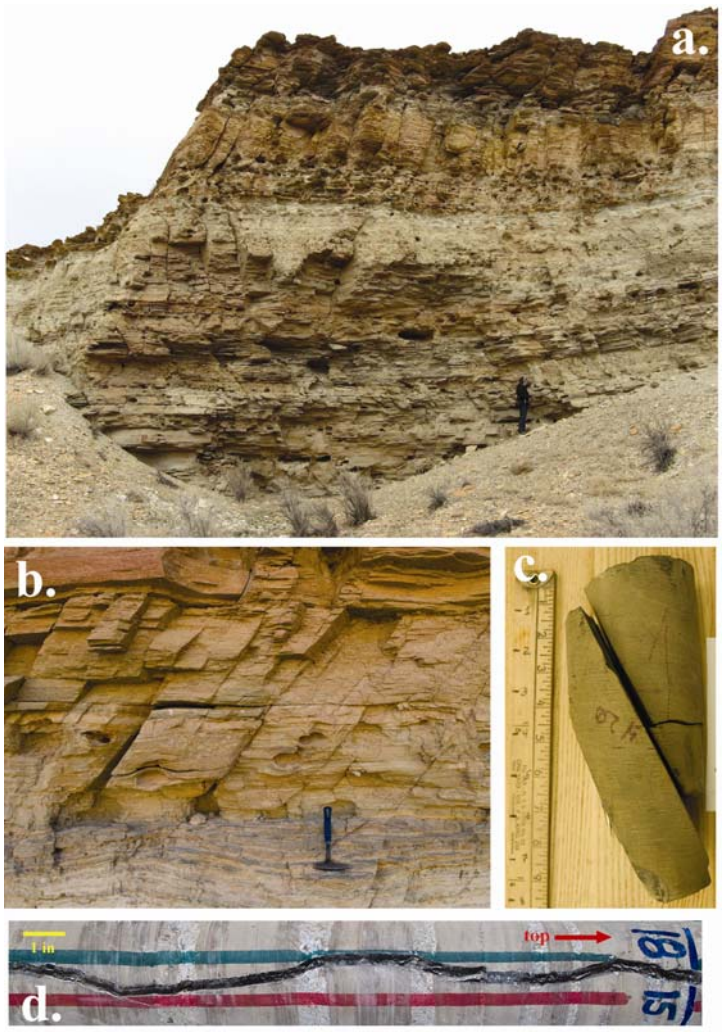

Figure 7. *Photographs of fractures within the Birds Nest aquifer. a. Extensive high-angle fracturing within the Birds Nest aquifer near Evacuation Creek, eastern Uinta Basin, Utah. b. High-angle fractures associated with dissolved saline nodules, near Watson, Utah. c. High-angle fracture in the P-1 core (420 ft) d. Near-vertical fracture filled with nahcolite in the 42-34 core (1815 ft).*

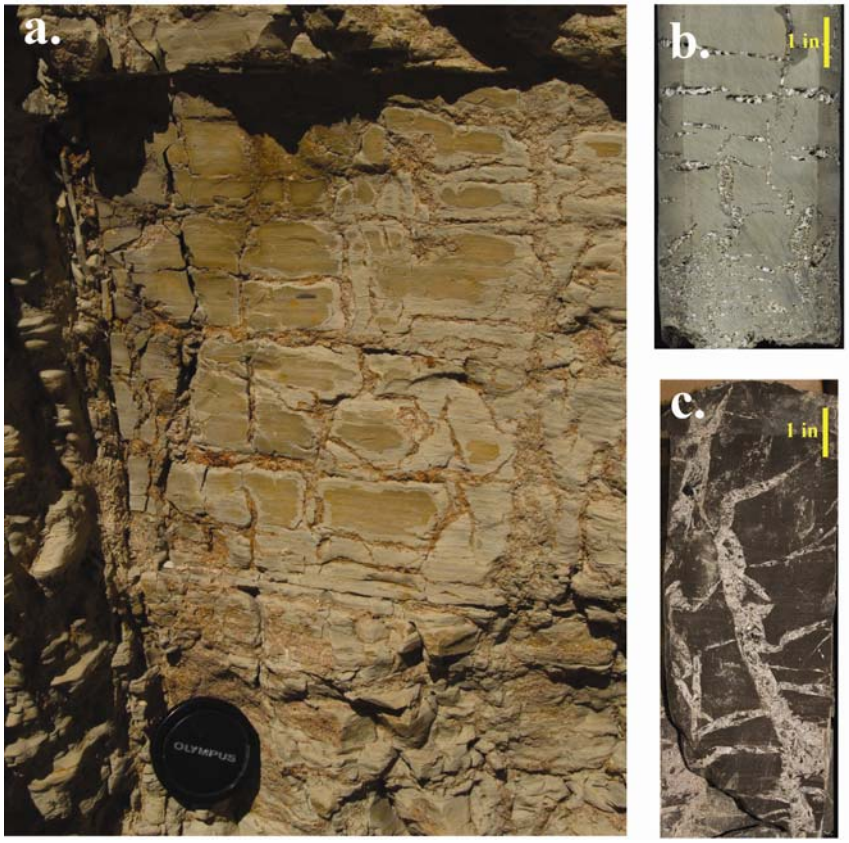

Figure 8. *Photographs of shortite fracture fill within the Birds Nest aquifer. a. Saline-mineral (most likely shortite or calcite after shortite) fracture fill near Long Draw, southeastern Uinta Basin, Utah. b. Dissolved saline-mineral fracture fill in the P-4 core (365 ft). c. Intact saline-mineral fracture fill in the 13X-2 core (1580 ft).*

Table 2. *Core capturing all or part of the Birds Nest aquifer.*

USGS #	Well Name	Operator	Area	Twn	Rng	Sec	Mrd	UTM E	UTM N	Cored interval		Saline zone		Upper Birds Nest aquifer		Lower Birds Nest aquifer		Big Three	Mahogany zone	Fischer assays	Geo	
								NAD 83	NAD 83	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Top		Density	Sonic
U043	EX-1	Western Oil Shale	Depocenter	9S	20E	36	SL	618562	4427091	1767	2969	na	1974	na	na	na	1963	2050	2267	y	y	y
U102	Utah State 1	TOSCO	Depocenter	9S	21E	26	SL	626967	4430197	1570	2600	1590	1965	1659	1746	1862	1960	2037	2274	y	y	
U113	42-34	TOSCO	Depocenter	9S	21E	34	SL	625568	4428012	14	2683	1511	1912	1556	1655	1803	1903	1982	2210		y	
U110	14X-34	Shell Oil Co.	Depocenter	9S	21E	34	SL	624255	4427363	1750	2597	na	1954	1618[1]	1712[1]	1846	1946	2026	2252	y	y	
U108	14-36	Shell Oil Co.	Depocenter	9S	21E	36	SL	627444	4427386	1850	2508	na	1888	1577[1]	1671[1]	1786[1]	1881	1960	2186	y	y	y
U112	13X-2	TOSCO	Depocenter	10S	21E	2	SL	625850	4426165	120	2191	1408	1797	1476	1570	1690	1789	1872	2091		y	
U045	Red Wash 1	USGS	Northeast depocenter	9S	22E	1	SL	637362	4436212	2160	2970	na	2267	2001[1]	2063[1]	2175	2261	2347	2599	y	y	y
U044	Coyote Wash 1	USGS	Northeast depocenter	9S	23E	22	SL	644096	4431654	1817	3460	na	1875	1610[1]	1658[1]	1772[1]	1865	1945	2191	y	y	y
U028	Corehole 2	National Farmer's Union	Eastside	9S	25E	32	SL	659784	4428684	30	560	57	188	–	–	103	180	265	476	y		
U056	P-1	White River Shale Co.	Eastside	10S	24E	12	SL	656732	4424894	74	1240	325	436	–	–	331	431	513	722	y	y	y
U057	P-2	White River Shale Co.	Eastside	10S	24E	17	SL	651084	4422804	94	1292	398	522	–	–	427	513	585	793	y	y	
	DP[2]	White River Shale Co.	Eastside	10S	24E	22	SL	653858	4421249	5	1416	na	na	–	–	na	na	808	1009		y	
U130	X-13	White River Shale Co.	Eastside	10S	24E	22	SL	654044	4421465	13	1125	630	728	–	–	649	720	na	998	y		
U058	P-3	White River Shale Co.	Eastside	10S	24E	26	SL	655414	4419858	70	1220	407	507	–	–	446	507	582	775	y	y	y
U059	P-4	White River Shale Co.	Eastside	10S	25E	19	SL	659365	4422017	214	1173	283	418	–	–	348	411	487	683	y	y	y
U029	Corehole 9	National Farmer's Union	Eastside	10S	25E	32	SL	659586	4418979	240	1123	250	340	–	–	272	338	417	603	y		
	Skyline 16	UGS	Eastside	11S	25E	10	SL	661445	4415109	20	1006	94	188	–	–	126	182	259	430		y	
U086	Asphalt Wash 1	USGS	Southside	11S	24E	7	SL	647934	4415544	307	1364	na	322	–	–	--	–	392	553	y	y	y
U124	Corehole 10	National Farmer's Union	Southside	11S	24E	32	SL	649269	4408511	370	660	na	444	–	–	--	–	511	641	y		
U087	Suicide Canyon 1	Arco	Southside	12S	23E	36	SL	646039	4399044	104	576	na	188	–	–	--	–	285	431	y		
U055	CRU-1	USGS	Southside	12S	24E	3	SL	653097	4408125	14	498	104	239	–	–	--	–	308	435	y		
U080	SUB 12	U.S. ERDA-LERC	Southside	12S	24E	19	SL	647985	4402283	91	621	132	270	–	–	--	–	332	470	y		

[1]Depth picked off bulk density log

[2]Core not examined due to very close proximity to X-13 and poor core condition

na=not available; y=available in UGS OFR-469

Note: All depths in feet.

Comparing the cores to available geophysical logs revealed that the large to medium sized saline mineral nodules and the saline mineral beds are recorded as low-density spikes on the bulk density log (1.7 to 2.0 g/cm^3, compared to typical organic-lean oil shale with a density near 2.5 g/cm^3) (figure 9). However, smaller nodules as well as small saline mineral crystals had little to no effect on the bulk density reading. Therefore, for wells lacking core but having bulk density logs, the upper and lower Birds Nest zones could be picked, but the overall saline zone could not be defined. However, organic-rich oil shale also records low bulk density values (2.0 to 1.5 g/cm^3) and could be mistaken for saline minerals. Luckily, the organic-rich oil shale beds occur in very regular stratigraphic horizons and create distinct, traceable patterns on the bulk density log. For example, six to seven thin organic-rich oil shale beds are located within the saline-zone interburden between the upper and lower Birds Nest zones and can easily be traced throughout the paleo-depocenter (figure 9). These beds, recorded as spikes to low density, might be confused with saline mineral nodules or beds if core and Fischer assay data were not available to confirm that they are in fact rich oil shale beds.

Depocenter Cores

Six cores were examined from the basin's paleo-depocenter: EX-1, Utah State 1, 42-34, 14X-34, 14-36, and 13X-2, of which only Utah State 1, 42-34, and 13X-2 capture the entire saline zone (figure 10, table 2, plates 2-7). The saline zone within the center of the basin is between 375 and 401 feet thick and contains both an upper and lower Birds Nest aquifer zone. The upper Birds Nest zone is between 87 and 99 feet thick and is primarily made up of large to medium nahcolite nodules within organic-lean oil shale. The lower Birds nest zone is between 95 and 100 feet thick and contains large to medium nahcolite nodules as well as 1-2 foot thick nahcolite beds, again within a matrix of organic-lean oil shale. The saline zone interburden, the area between the upper and lower Birds Nest zones, is composed mostly of impermeable organic-lean oil shale with few to abundant small disseminated saline crystals (nahcolite, shortite, and possibly other saline mineral species). The interburden also contains a package of six to seven thin organic-rich oil shale beds which can be easily traced throughout the basin's paleo-depocenter. In a few wells (42-34, 14X-34, Utah State 1), large to medium nahcolite nodules were observed within the above-mentioned oil shale beds. These nodules seem to correlate to low-density spikes beyond that of the rich oil shale beds. Since they are only limited to a small lateral area (possibly the very center of the depocenter near T. 9 S., R. 21 E., SLBLM) and are separated stratigraphically by 20-30 feet, they are not included in the lower Birds Nest zone as defined in this study.

EX-1: The EX-1 well was drilled in 1969 by the Western Oil Shale Corporation and is the study's westernmost core capturing the saline zone and underlying rich oil shale beds (plate 2) (Smith and others, 1972). Drillers recovered 1202 feet of core from this well, starting in the middle of the saline zone and continuing to the R-4 rich oil shale zone. The core captures the lower Birds Nest aquifer at a depth of ~1870 to 1963 feet (93 feet thick) – the upper boundary is approximately located due to lack of a bulk density log through this interval, and the inability to pick a distinct boundary on core. The upper Birds Nest interval should be present in this well, but without core and/or a bulk density log through the upper part of the drillhole, the depth and thickness are unknown. The lower Birds Nest aquifer is characterized by organic-lean oil shale with large nahcolite nodules and relatively thick nahcolite beds (1-2 feet thick) near the base (represented by spikes to low density on the bulk density log and washouts recorded by the caliper log), with a gradual upward transition to smaller saline nodules. Only very minor saline mineral dissolution is present in this core. The saline zone interburden is comprised mainly of lean oil shale with few, relatively thin, silty beds. A zone of richer-oil shale beds is present from 1805-1847 feet, as seen on the Fischer assay oil yield log. The saline minerals within the saline zone interburden are dominated by smaller nahcolite crystals and shortite fracture fill. The top of the Big Three oil shale beds is at a depth of 2050 feet and the top of the Mahogany zone is at a depth of 2267 feet, providing interburden interval thicknesses of 87 and 304 feet, respectively.

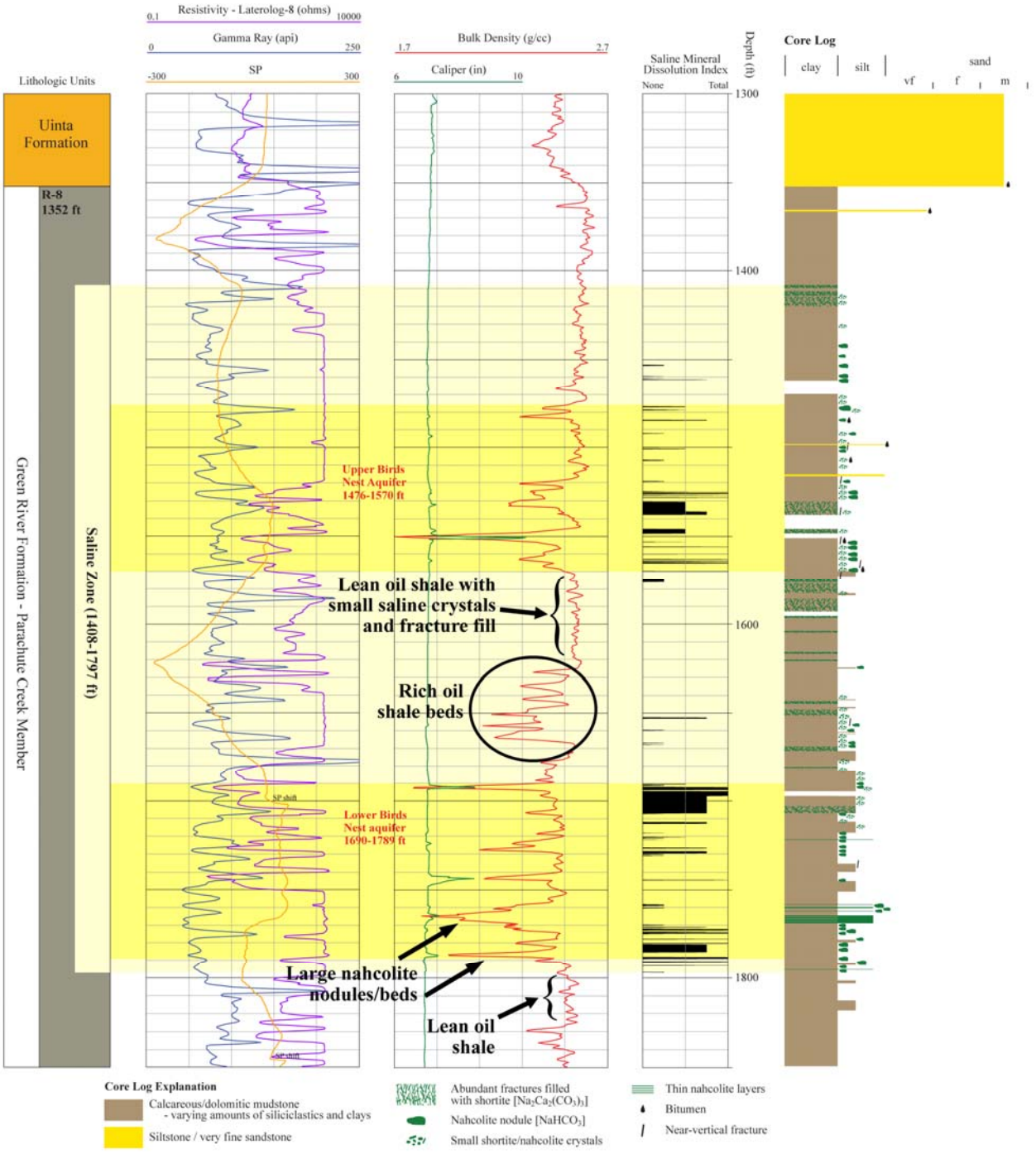

Figure 9. *Geophysical, core, and dissolution logs through the Birds Nest aquifer from the 13X-2 core located in the basin's paleo-depocenter. Notice the spikes to low density representing medium to large nahcolite nodules or beds. Smaller saline mineral crystals, saline mineral fracture fill, and small saline nodules are not recognized by the bulk density log, as seen in the zone between the upper and lower Birds Nest aquifers. The rich oil shale beds between the upper and lower Birds Nest are very consistent and can be traced throughout the basin.*

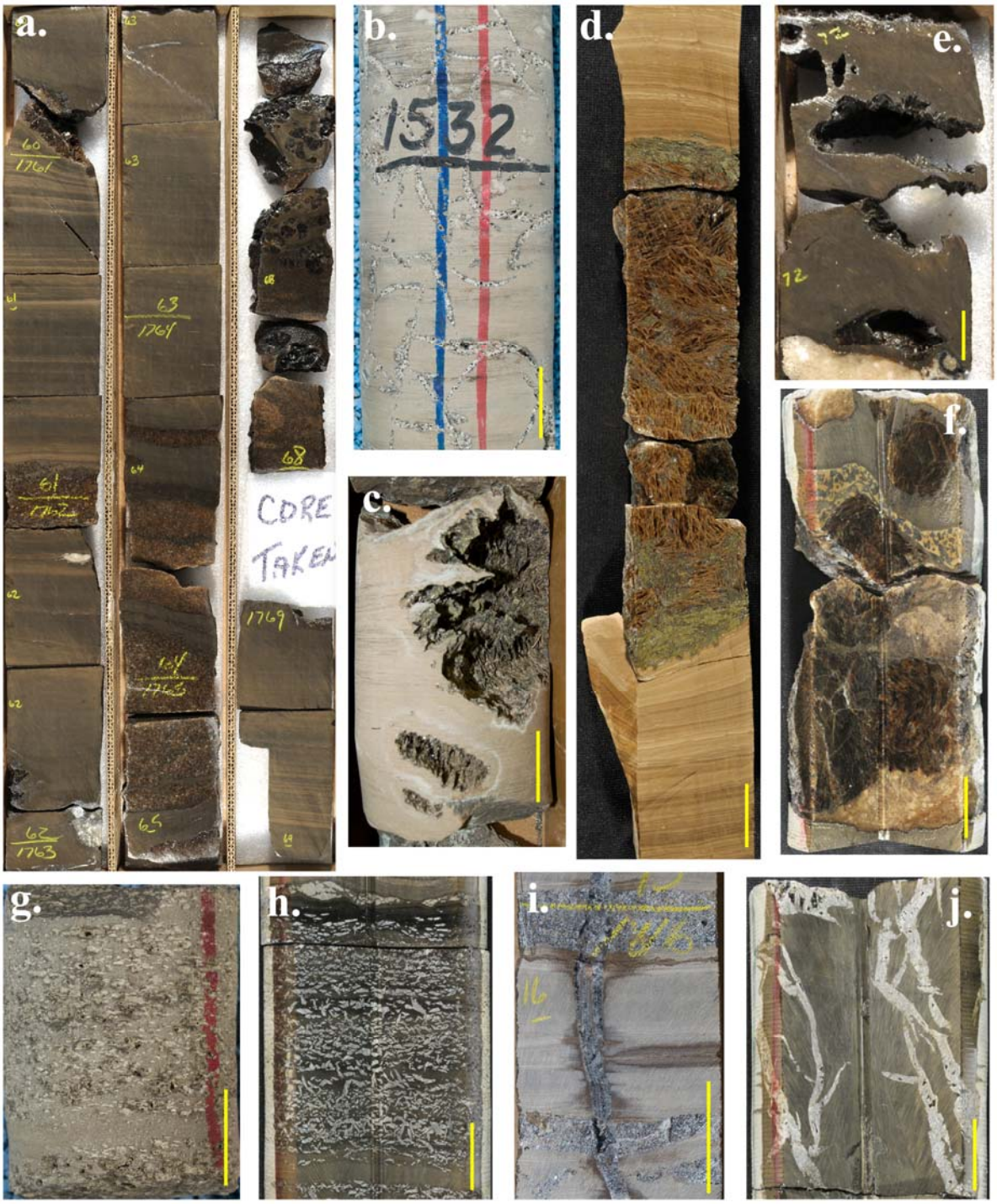

Figure 10. *Photographs of core within the saline zone from the basin's paleo-depocenter, yellow bars represent one inch. a. Nahcolite beds, 13X-2, 1760-1769 ft. b. Partially dissolved shortite fracture fill, 13X-2, 1532 ft. c. Dissolved nahcolite nodule lined with pyrite, 13X-2, 1774 ft. d. Nahcolite nodule coated with pyrite, EX-1, 1923 ft. e. Dissolved nahcolite nodule, 13X-2, 1772 ft. f. Nahcolite nodule, notice the warped sediment beds, Utah State 1, 1825 ft. g. Partially dissolved small saline mineral crystals, 42-34, 1657 ft. h. Small saline mineral (shortite?) crystals, Utah State 1, 1814 ft. i. Cross-cutting shortite fracture fill, 42-34, 1813 ft. j. Shortite fracture fill, Utah State 1, 1753 ft.*

Utah State 1: The Utah State 1 well was drilled in 1974 by the TOSCO Development Corporation as part of a feasibility study for an underground oil shale mine in the area (plate 3). Drillers recovered 1030 feet of core, starting just above the saline zone and continuing down to the middle R-6. The 375-foot saline zone is between 1590 and 1965 feet deep, with the upper Birds Nest zone at 1659-1746 feet and the lower Birds Nest zone at 1862-1960 feet. Both Birds Nest zones are characterized by large nahcolite nodules and individual nahcolite beds, both easily observed in the core and on the bulk density log. The top of the Big Three oil shale beds is at a depth of 2037 feet and the top of the Mahogany zone is at a depth of 2274 feet, providing interburden interval thicknesses of 77 and 314 feet, respectively. The Utah State 1 core displays no saline mineral dissolution, suggesting that an actual aquifer does not exist in this area. In short, it is believed that a prominent gilsonite vein located just south of this well might play a role in limiting access to groundwater in the area. This topic is further discussed in the "Influence of Gilsonite Veins" section below.

42-34: The 42-34 well was drilled in 1981, also by the TOSCO Development Corporation, as part of a feasibility study for an underground oil shale mine in the area (plate 4). The well was cored from near the surface (14 feet) to a depth of 2683 feet, recovering 2669 feet of core. The core captures a large portion of the Uinta Formation along with the entire saline zone within the upper Green River Formation, and continues down to the L-5 lean oil shale zone. The 401-foot saline zone is between 1511 and 1912 feet deep, with the upper Birds Nest zone at 1556-1655 feet and the lower Birds Nest zone at 1803-1903 feet. Both zones are characterized by large to medium nahcolite nodules within organic-lean oil shale with several minor thin silty beds (could help increase permeability in the area). Significant saline mineral dissolution was observed in the core within both the upper and lower Birds Nest zones. The top of the Big Three oil shale beds is at a depth of 1982 feet and the top of the Mahogany zone is at a depth of 2210 feet, providing interburden interval thicknesses of 79 and 307 feet, respectively. This well is located very close to Anadarko's already permitted and active Birds Nest saline water disposal wells.

14X-34: The 14X-34 well was drilled by Shell Oil Company in 1964 to help characterize the oil shale resource in the area (plate 5). The well was cored from a depth of 1750 feet, roughly 50 feet below the upper Birds Nest zone, to 2597 feet, within the middle R-6 oil shale zone. Unfortunately, roughly every other box of core (3 feet of core per box) is missing, making useful observation difficult. Stratigraphic picks were made using a formation density log. The upper Birds Nest zone (picked solely using a formation density log) is located at depths of 1618-1712 feet and the lower Birds Nest zone (only partially verified with core) is located at 1846-1946 feet. Within the available core, saline mineral dissolution seems fairly extensive. The top of the Big Three oil shale beds is at a depth of 2026 feet and the top of the Mahogany zone is at a depth of 2252 feet, providing interburden interval thicknesses of 80 and 306 feet, respectively.

14-36: The 14-36 well was also drilled in 1964 by Shell Oil Company to help characterize the oil shale resource in the area (plate 6). The well was cored starting at a depth of 1850 feet, capturing only the lower 38 feet of the saline zone, down to 2508 feet at the base of the upper R-6 oil shale zone. Similar to the 14X-34 well, stratigraphic picks were made from a formation density log. The upper Birds Nest zone (picked solely using the formation density log) is located at depths of 1577-1671 feet and the lower Birds Nest zone (only the lower portion verified with core) is located at 1786-1881 feet. Significant saline mineral dissolution was present in the core. The top of the Big Three oil shale beds is at a depth of 1960 feet and the top of the Mahogany zone is at a depth of 2186 feet, providing interburden interval thicknesses of 79 and 305 feet, respectively.

13X-2: The 13X-2 well was drilled by the TOSCO Development Corporation in 1977 as part of a feasibility study for a possible underground oil shale mine (plate 7). Similar to the 42-34 well, 13X-2 was cored from near the surface (120 feet) to a depth of 2191 feet, recovering 2071 feet of core. The core captures a large portion of the Uinta Formation along with the entire saline zone within the upper Green

River Formation, down to the base of the Mahogany zone. The 389-foot saline zone is between 1408 and 1797 feet deep, with the upper Birds Nest zone at 1476-1570 feet and the lower Birds Nest zone at 1690-1789 feet. Both zones are characterized by large to medium nahcolite nodules within organic-lean oil shale, but only the lower zone contains beds of nahcolite. The top of the Big Three oil shale beds is at a depth of 1872 feet and the top of the Mahogany zone is at a depth of 2091 feet, providing interburden interval thicknesses of 83 and 302 feet, respectively. The excellent quality and completeness of this core made it possible to qualitatively rate the level of saline mineral dissolution on a scale of zero (no dissolution) to three (total dissolution). The generated dissolution log (displayed next to the core log) clearly identifies both the upper and lower Birds Nest aquifer zones within the overall saline zone. The bulk density log from this well was used as a reference when picking the upper and lower Birds Nest zones on logs from wells lacking core.

Northeast Depocenter Cores

Two cores were examined from the northeast side of the basin's paleo-depocenter, Red Wash 1 and Coyote Wash 1, neither of which captured the entire saline zone (table 2, plates 8 and 9). Based on bulk density logs, the upper Birds Nest zone in this area is between 40 and 60 feet thick, thinner than the basin center cores, while the lower Birds Nest zone is of similar thickness to the basin depocenter, between 85 and 100 feet thick. The lower zone is confirmed by the Red Wash 1 core to contain large to medium nahcolite nodules. The package of six to seven, thin, organic-rich oil shale beds within the saline zone interburden are still found in this area (correlatable using the bulk density log).

Red Wash 1: The Red Wash 1 well was drilled by the USGS in 1981, targeting the thickest and richest oil shale interval in the Uinta Basin (plate 8) (Scott and Pantea, 1982a). In addition, Red Wash 1 is the northernmost core capturing part of the saline zone. It is located close to EOG Resources already permitted and active Birds Nest saline water disposal wells. The Red Wash 1 core begins at a depth of 2160 feet, about 15 feet above the lower Birds Nest zone, and continues down to 2970 feet within the middle R-6. The upper Birds Nest zone, as measured from the bulk density log, is at depths of 2001-2063 feet, while the lower zone is located between 2175 and 2261 feet. The lower Birds Nest zone is characterized by medium to large nahcolite nodules within a matrix of lean oil shale, and displays only minor saline mineral dissolution. The top of the Big Three oil shale beds is at a depth of 2347 feet and the top of the Mahogany zone is at a depth of 2599 feet, providing interburden interval thicknesses of 86 and 338 feet, respectively.

Coyote Wash 1: The Coyote Wash 1 well was also drilled by the USGS in 1981 as a means to capture the richest and thickest section of oil shale in the Uinta Basin (plate 9) (Scott and Pantea, 1982b). It is one of the deepest oil shale cores available, capturing nearly the entire Parachute Creek Member of the upper Green River Formation (except the very top) as well as the upper portion of the Douglas Creek Member. The Coyote Wash 1 core begins at a depth of 1817 feet, about 50 feet above the base of the lower Birds Nest zone, and continues down to 3460 feet, within the Douglas Creek Member. The upper Birds Nest zone, as measured from the bulk density log, is at depths of 1610-1658 feet, while the lower zone is located between 1772 and 1865 feet. Unfortunately, about 25 feet of core is missing from the base of the lower Birds Nest zone, making accurate characterization difficult. The top of the Big Three oil shale beds is at a depth of 1945 feet and the top of the Mahogany zone is at a depth of 2191 feet, providing interburden interval thicknesses of 80 and 326 feet, respectively.

Eastern Basin Cores

Eight cores were examined from the east side of the basin's paleo-depocenter: Corehole 2, P-1, P-2, X-13, P-3, P-4, Corehole 9, and Skyline 16 (figure 11, table 2, plates 10-17). The saline zone on the eastern side of the basin is much closer to the surface and has significant outcrop exposures. Only the lower Birds Nest aquifer is present in this area, ranging in thickness from 54 to 100 feet. The overall

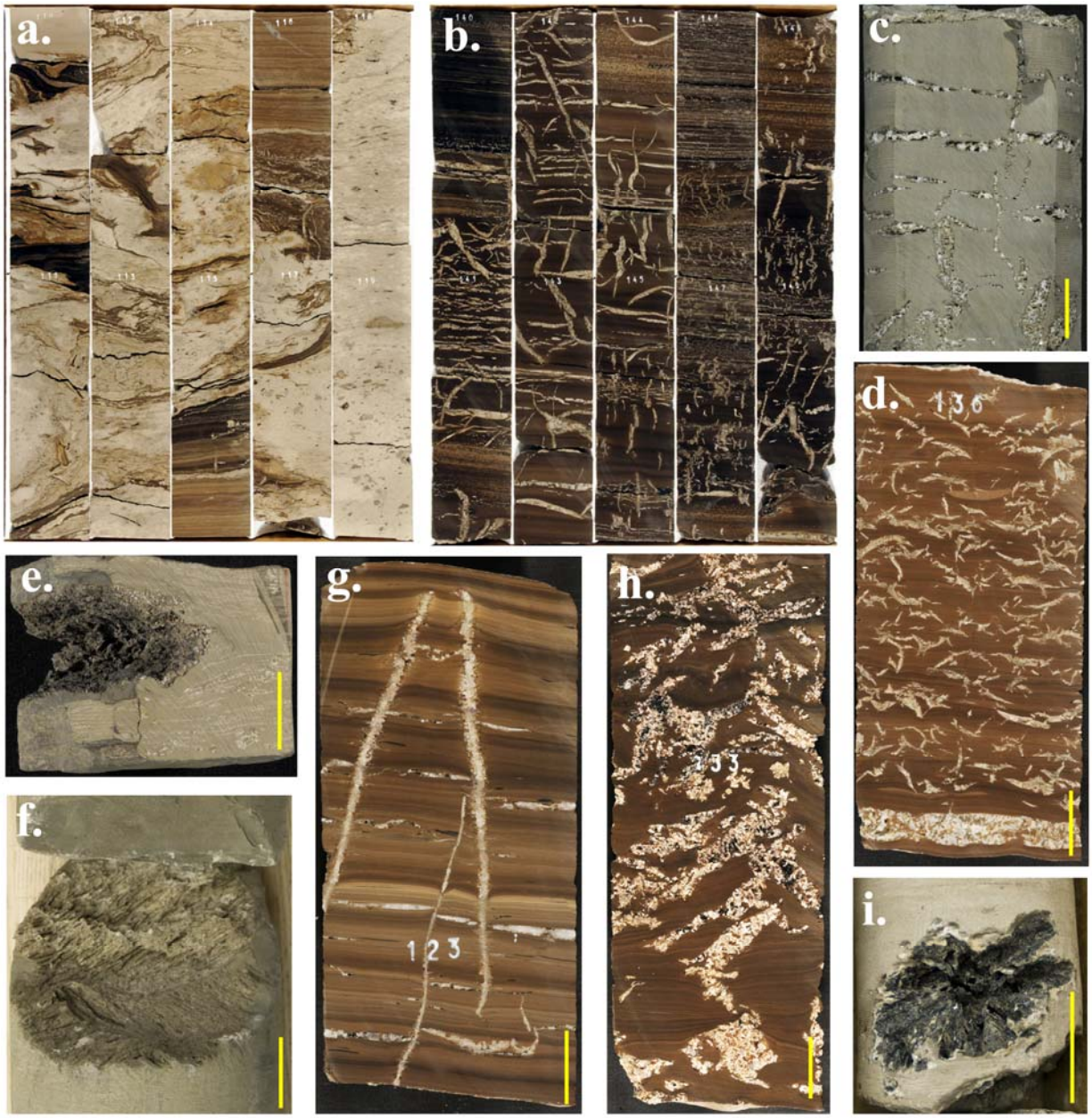

Figure 11. *Photographs of core within the saline zone from the basin's eastern margin, yellow bars represent one inch. a. Volcaniclastic debris flow ("Horsebench" Ss.), Skyline 16, 110-120 ft. b. Shortite fracture fill, Skyline 16, 140-150 ft. c. Partially dissolved shortite fracture fill, P-4, 365 ft. d. Saline mineral crystals (shortite?), Skyline 16, 136 ft. e. Dissolved nahcolite nodule, P-4, 354 ft. f. Dissolved nahcolite nodule, P-1, 324 ft. g. Partially dissolved shortite fracture fill, Skyline 16, 123 ft. h. Partially dissolved shortite fracture fill with inclusions of black tar (possibly gilsonite), Skyline 16, 133 ft. i. Dissolved nahcolite nodule lined with black tar (possibly gilsonite), X-13, 710 ft.*

saline zone ranges in thickness from 90 to 135 feet and is composed of large saline mineral nodules, smaller saline mineral crystals, and abundant zones of shortite fracture fill. Overlying the saline zone are deposits of volcaniclastic debris flow material (volcaniclastic matrix material with abundant mud rip-up clasts and organic debris). This material is very similar to the volcaniclastic deposits of the Sand Butte bed overlying the Green River Formation lake sediments in the Greater Green River Basin in Wyoming and northern Piceance Basin in Colorado (labeled as part of the Uinta Formation in Colorado) (Chetel and Carroll, 2010). After Lake Gosuite was filled and disappeared, the volcaniclastic material, brought in by river systems from the north, started filling in the Piceance Basin. Periodically, an accumulation of volcaniclastic material on the Douglas Creek Arch catastrophically let loose and flowed into the eastern Uinta Basin. These debris flows might also represent an influx of fresh water, which created a localized freshening of the lake on the far eastern side of the basin, shutting off saline mineral deposition. This localized freshening resulted in a much thinner saline zone, and hence only the lower Birds Nest aquifer. Saline deposition continued near the center of the basin as seen by a thicker saline zone in the basin center cores.

The volcaniclastic material has very high porosity and permeability (observed characteristic, no measurements were made) and most likely acts as a localized aquifer that is probably in communication with the Birds Nest aquifer due to their close stratigraphic relationship. In addition, the volcaniclastic material replaced the deposition of the five to six thin, rich oil shale beds seen in the saline zone interburden closer to the basin's depocenter.

Corehole 2: The Corehole 2 well was drilled in 1958 by the National Farmer's Union as a means to characterize the oil shale resource in the area (plate 10). Corehole 2 is also the northernmost well on the eastern side of the basin having core containing the Birds Nest zone. The Corehole 2 core begins near the surface at a depth of 30 feet, about 25 feet above the top of the saline zone, and continues down to 560 feet, near the base of the Mahogany zone. The lower Birds Nest zone is at a depth of 103-180 feet and is characterized by medium to large nahcolite nodules and abundant large nahcolite crystals. Significant saline mineral dissolution is present in this core. The number and density of the large nahcolite nodules begins to decrease starting near this core's location and continuing northward, as observed from outcrop exposures near Corehole 2. The top of the Big Three oil shale beds is at a depth of 265 feet and the top of the Mahogany zone is at a depth of 476 feet, providing interburden interval thicknesses of 85 and 296 feet, respectively.

P-1: The P-1 well was one of several wells drilled in the mid-1970s by the White River Shale Company to characterize the oil shale resource on the old U-a and U-b federal oil shale lease tracts (plate 11). The P-1 core begins near the surface at a depth of 74 feet, within the Uinta Formation, and continues down to 1240 feet, in the L-4 lean oil shale zone. The lower Birds Nest zone is measured from depths of 331-431 feet and is overlain by volcaniclastic debris flow material. The Birds Nest zone is characterized by abundant large to medium nahcolite nodules, abundant smaller saline crystals, and significant high-angle fractures. Extensive saline mineral dissolution is present in the core. The top of the Big Three oil shale beds is at a depth of 513 feet and the top of the Mahogany zone is at a depth of 722 feet, providing interburden interval thicknesses of 82 and 291 feet, respectively.

P-2: The P-2 well is the westernmost well drilled by the White River Shale Company to characterize the oil shale resource on the old U-a and U-b federal oil shale lease tracts (plate 12). The P-2 core begins near the surface at a depth of 94 feet, within the Uinta Formation, and continues down to 1292 feet, near the base of the R-5 oil shale zone. The lower Birds Nest zone is measured at depths of 427-513 feet and is overlain by relatively thin volcaniclastic debris flow material; the P-2 well is near the western extent of the debris flows. The Birds Nest zone is characterized by abundant large to medium nahcolite nodules, abundant smaller saline crystals, and significant high-angle fractures. Significant dissolution of the saline minerals is represented by numerous borehole widenings recorded on the caliper log and gaps of missing or rubblized core. The top of the Big Three oil shale beds is at a depth of 585 feet and the top of the

Mahogany zone is at a depth of 793 feet, providing interburden interval thicknesses of 72 and 280 feet, respectively.

X-13: The X-13 well was drilled in 1976 by the White River Shale Company at the site of the White River underground oil shale mine (plate 13). The X-13 core begins near the surface at a depth of 13 feet, within the Uinta Formation, and continues down to 1125 feet, within the B-groove. This core, despite not being slabbed, was in excellent condition and provided an exceptional view of the Birds Nest zone and surrounding rocks. The lower Birds Nest zone is measured from 649 to 720 feet and is overlain by 20-30 feet of volcaniclastic material. The Birds Nest zone is characterized by abundant large to medium nahcolite nodules, abundant smaller saline crystals, and significant high-angle fractures. Significant saline mineral dissolution is present in the core, but a complete assessment is difficult since the core is not slabbed (it is difficult to tell if the saline mineral dissolution is the result of groundwater or drilling fluids). The top of the Big Three oil shale beds is unknown (no bulk density log or Fischer assays were run through this interval) but the top of the Mahogany zone is at a depth of 998 feet, providing an interburden interval thickness of 278 feet.

P-3: The P-3 well was also drilled in 1974 by the White River Shale Company (plate 14). The P-3 core begins near the surface at a depth of 70 feet, within the Uinta Formation, and continues down to 1220 feet, within the R-5 oil shale zone. The lower Birds Nest zone is measured from 446 to 507 feet and is overlain by 15-20 feet of volcaniclastic material. The Birds Nest zone is characterized by abundant large to medium nahcolite nodules and abundant smaller saline crystals; both display signs of saline mineral dissolution. The top of the Big Three oil shale beds is at a depth of 582 feet and the top of the Mahogany zone is at a depth of 775 feet, providing interburden interval thicknesses of 75 and 268 feet, respectively.

P-4: Similarly, the P-4 well was drilled in 1974 by the White River Shale Company (plate 15). The P-4 core begins at a depth of 214 feet, below the Uinta Formation but above the saline zone, and continues down to 1173 feet, within the L-5 lean oil shale zone. The lower Birds Nest zone is measured between 348 and 411 feet and is overlain by two units of volcaniclastic material: the lower unit is about 20 feet thick and the upper unit is about 15 feet thick. The Birds Nest zone is characterized by abundant, mostly dissolved, large to medium nahcolite nodules and abundant small saline crystals. The top of the Big Three oil shale beds is at a depth of 487 feet and the top of the Mahogany zone is at a depth of 683 feet, providing interburden interval thicknesses of 76 and 272 feet, respectively.

Corehole 9: The Corehole 9 well was drilled in 1959 by the National Farmer's Union as a means to characterize the oil shale resource in the area (plate 16). The Corehole 9 core begins at a depth of 240 feet, about 10 feet above the top of the saline zone, and continues down to 1123 feet, within the R-4 oil shale zone. The lower Birds Nest zone is between 272 and 338 feet and is overlain by volcaniclastic material of unknown thickness. The Birds Nest zone is characterized by partially dissolved medium to large nahcolite nodules and abundant nahcolite crystals. The top of the Big Three oil shale beds is at a depth of 417 feet and the top of the Mahogany zone is at a depth of 603 feet, providing interburden interval thicknesses of 79 and 265 feet, respectively.

Skyline 16: The Skyline 16 well was drilled in 2010 through collaboration between the Utah Geological Survey and the University of Utah's Institute for Clean and Secure Energy (plate 17). The main goal of the drilling was to recover core through the entire Parachute Creek Member, including the saline zone and the underlying rich oil shale units. This well is located near the southern boundary of the large saline nodule zone which defines the area of the Birds Nest aquifer possibly suitable for saline water disposal. The Skyline 16 core begins at a depth of 20 feet, near the top of the Green River Formation, and continues down to 1006 feet, within the top of the Douglas Creek Member. The lower Birds Nest zone is thinner in this area and lies between 126 and 182 feet. The volcaniclastic material occurs in two beds: a lower, thinner bed within the top of the saline zone and an upper, thicker bed above the saline zone. The Birds

Nest zone is characterized by partially dissolved medium to large nahcolite nodules and abundant nahcolite crystals. The top of the Big Three oil shale beds is at a depth of 259 feet and the top of the Mahogany zone is at a depth of 430 feet, providing interburden interval thicknesses of 77 and 248 feet, respectively.

Southern Basin Cores

Five cores were examined from south of the defined large-saline-nodule Birds Nest zone: Asphalt Wash 1, Corehole 10, Suicide Canyon 1, CRU-1, and SUB 12 (figure 12, table 2, plates 18-22). The saline zone in this area averages about 130 feet thick, but is composed entirely of small saline mineral crystals or shortite fracture fill, displaying varying amounts of dissolution; no large saline mineral nodules or beds exist. The same transition to small saline crystals presumably exists to the north and west, but no cores or outcrop are available to confirm this suspicion and bulk density logs do not pick up the signature from the smaller saline crystals. Groundwater may still flow through the saline zone in this area, but the saline zone lacks the large void space needed for significant volumes of saline water disposal.

Asphalt Wash 1: The Asphalt Wash 1 well was drilled in 1976 by the USGS to help characterize the oil shale in the area (plate 18). The core starts at a depth of 307 feet, very near the base of the saline zone, and continues down to 1364 feet, well into the Douglas Creek Member of the Green River Formation. The core only captures about 15 feet near the base of the saline zone (which extends to 322 feet) and is characterized by abundant small saline mineral crystals.

Corehole 10: The Corehole 10 well was drilled in 1960 by the National Farmer's Union to help characterize the oil shale in the area (plate 19). The core starts at a depth of 370 feet, about midway through the saline zone, and continues down to 660 feet, at the top of the Mahogany zone. The core only captures about 74 feet near the base of the saline zone (which extends to 444 feet) and is characterized by abundant partially dissolved small saline mineral crystals and shortite fracture fill.

Suicide Canyon 1: The Suicide Canyon 1 well was drilled in 1965 by ARCO to help characterize the oil shale in the area (plate 20). The core starts at a depth of 104 feet, which is within the saline zone, and continues down to 576 feet, near the base of the Mahogany zone. The core captures 84 feet of the base of the saline zone (which extends to 218 feet) and is characterized by abundant partially dissolved small saline mineral crystals.

CRU-1: The CRU-1 well was drilled in 1976 by the USGS to help characterize the oil shale in the area (plate 21) (Keighin, 1982). This is one of two cores near the southern outcrop that capture the entire saline zone. The core starts near the surface at a depth of 14 feet, above the saline zone but below the Uinta Formation, and continues down to 498 feet, near the base of the Mahogany zone. The saline zone is 135 feet thick and extends from 104 feet to 239 feet. The zone is characterized by abundant partially dissolved small saline mineral crystals and zones of shortite fracture fill. In addition, the five to six thin rich oil shale beds seen near the center of the basin above the lower Birds Nest zone are clearly visible in the Fischer assay log from this well.

South Uinta Basin 12 (SUB-12): The SUB-12 well was the last in a series of 12 wells drilled by the U.S. Energy Research and Development Agency – Laramie Energy Research Center (ERDA-LERC) from 1975 to 1977 near the southern oil shale outcrop (plate 22) (Vanden Berg and others, 2006; only the core and Fischer assay data exist, no other information on this drilling program is available). The SUB-12 well cored from 91 feet to 621 feet, capturing the entire saline zone and extending down to the deltaic sands below the R-6 oil shale zone. The saline zone is 138 feet thick and extends from 132 feet to 270 feet. The zone is characterized by abundant partially dissolved small saline mineral crystals and zones of shortite fracture fill. In addition, the five to six thin rich oil shale beds seen near the center of the basin above the lower Birds Nest zone are clearly visible in the Fischer assay log from this well.

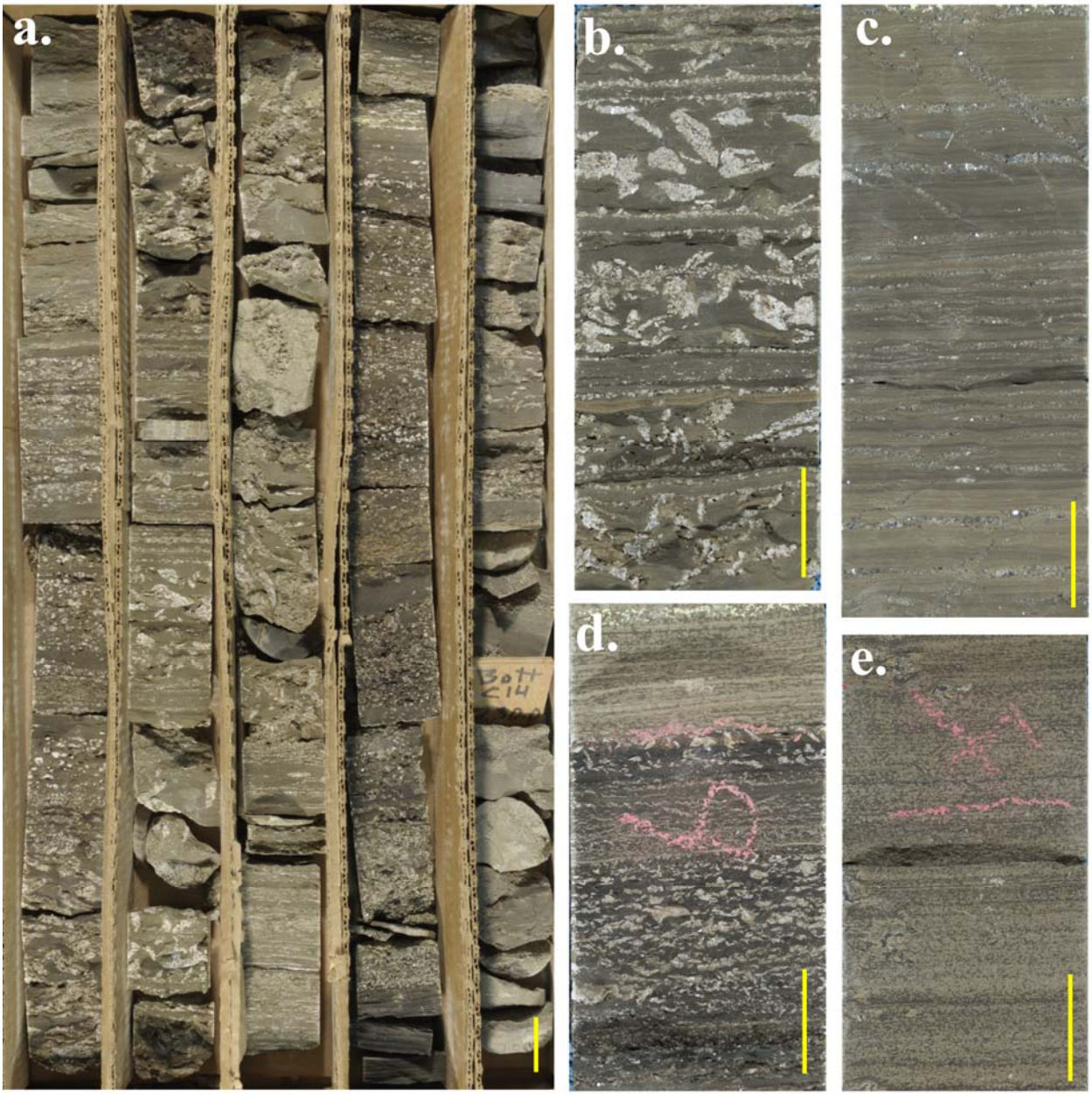

Figure 12. *Photographs of core within the saline zone from the basin's southern margin, yellow bars represent one inch. a. Partially dissolved medium to small saline mineral crystals, SUB 12, 221-231 ft. b. Partially dissolved medium saline mineral crystals, CRU-1, 197 ft. c. Thin saline mineral layers (shortite?), CRU-1, 105 ft. d. Partially dissolved small saline mineral crystals, CRU-1, 177 ft. e. Very small saline mineral crystals, CRU-1, 170 ft.*

Outcrop Evaluation

Rock layers in the southern Uinta Basin generally dip 1 to 4 degrees to the northwest, resulting in extensive upper Green River Formation outcrop exposures along the eastern and southern flanks of the basin (Sprinkel, 2007, 2009). Plate 1 displays the rich Mahogany oil shale zone outcrop as a thin green line and the approximate saline zone outcrop as a thin brown line. The saline zone outcrop was estimated from the mapped "Horsebench sandstone" outcrop exposure (Sprinkel, 2007, 2009). This "sandstone" is not actually the Horsebench, as defined in the southwestern Uinta Basin, but represents the volcaniclastic material discussed in the previous section that sits directly on top of the saline zone. The outcrop line was edited to only include areas with observable saline minerals, mainly on the eastern side of the basin. In most cases, only cavities left behind by total dissolution of nahcolite nodules are present along outcrop, whereas smaller saline mineral crystals show varying degrees of dissolution. Four stratigraphic sections were measured (Cowboy, Watson, Long Draw, and Bitter Creek) and general observations were recorded from several other outcrop locations in order to help define the extent of the saline zone and the Birds Nest aquifer (plates 23-26).

Measured Sections

Cowboy section: The Cowboy section was measured along the White River, just east of Cowboy Canyon (near the termination of the Cowboy gilsonite vein) (figure 13, plate 23). This was the northernmost outcrop section examined in detail as saline zone exposures farther to the north are obscured by sloping topography. The saline zone exposed in this section is about 113 feet thick and dominated by small saline mineral crystals with zones of medium to large saline nodules. The lower Birds Nest zone is estimated at 63 feet thick; however, the tell-tale large nahcolite nodules usually found below the lowest occurrence of volcaniclastic material are often covered in this area. In addition, unlike the other outcrop areas farther south, significant large nahcolite nodules exist above the lowest volcaniclastic flow, providing evidence that the volcaniclastic material may be part of the overall Birds Nest aquifer system.

Watson section: The Watson section was measured from outcrop along the Kings Well road near Evacuation Creek (figure 14, plate 24). This section marks the southernmost extent of the large saline nodules on the eastern side of the basin, before the transition to only small saline mineral crystals a short distance farther to the south. The overall saline zone is estimated to reach about 93 feet thick and is dominated by small saline mineral crystals and shortite fracture fill. The large nahcolite nodules only occur in three distinct layers (about 12 feet thick overall) directly below the lowest occurrence of volcaniclastic material.

Long Draw section: The Long Draw section was measured near the northern end of Long Draw (plate 25). The saline zone is estimated at about 90 feet thick (additional saline minerals might be found in unexposed rocks below the base of the measured section) and is dominated by small saline mineral crystals and shortite fracture fill. In addition, no volcaniclastic material was found exposed at this site, helping to define the southern extent of the debris flows.

Bitter Creek section: The Bitter Creek section was measured along the Kings Well road on the west side of Bitter Creek (figure 15, plate 26). The saline zone is estimated at about 110 feet thick (as with the Long Draw section, additional saline minerals might be found in unexposed rocks below the base of the measured section) and is dominated by small saline mineral crystals and shortite fracture fill. This exposure is believed to be near the southwesternmost extent of the overall saline zone dominated by small saline mineral crystals.

Figure 13. *Photographs from the Cowboy measured section. a. The Cowboy section exposed along the White River. b. Dissolved nahcolite nodule within the Cowboy section. c. Shortite fracture fill within the Cowboy section.*

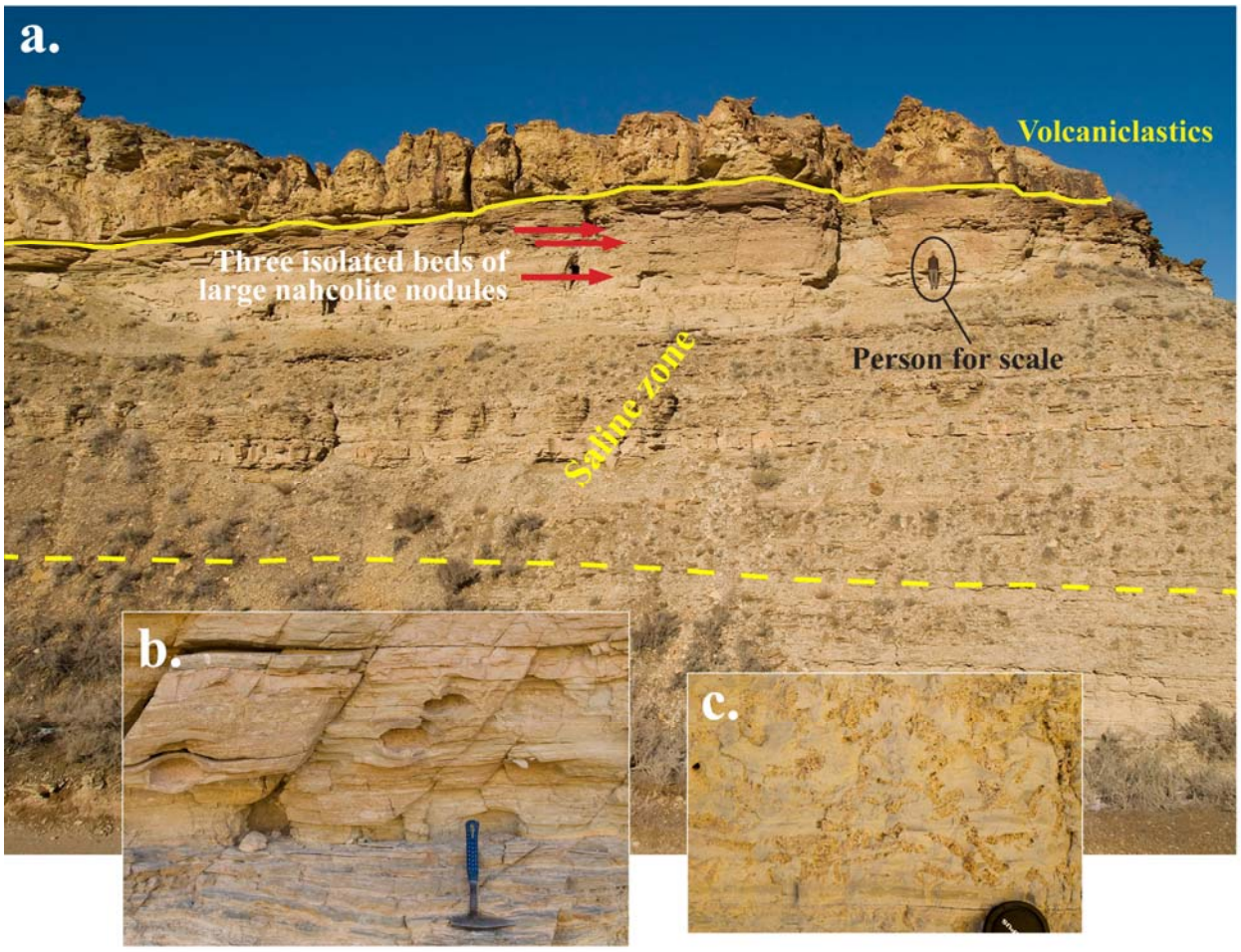

Figure 14. *Photographs from the Watson measured section. a. The Watson section displays the southern extent of the large nahcolite nodules which occur in only three isolated beds. b. Dissolved nahcolite nodules within the Watson section. Note the high-angle fractures. c. Partially dissolved shortite fracture fill within the Watson section.*

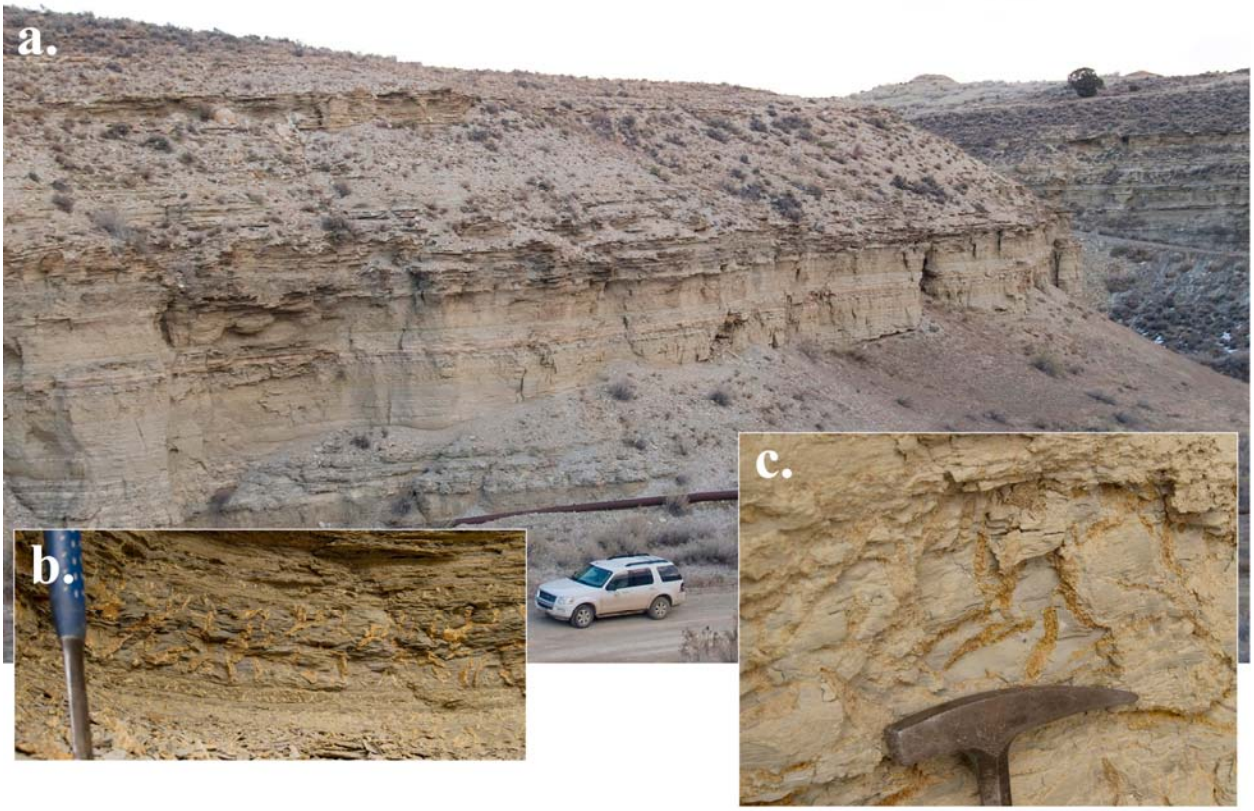

Figure 15. *Photographs from the Bitter Creek measured section. a. The Bitter Creek section was measured through the saline zone on the southern margin of the basin where only small saline mineral crystals are present. b and c. Shortite fracture fill within the Bitter Creek section.*

Additional Outcrop Observations

Despite the lack of good outcrop exposure, the northern extent of the large nahcolite nodule zone appears to be just north of the White River, as observed across the border in Colorado (section 14, T. 1 N., R. 104 W., northern extent observation point on plate 1). The limited outcrop in this area contains sparse, small to medium nahcolite nodules, but the thickness of the overall unit could not be determined (figure 16).

Upper Green River Formation outcrop along the northern portion of Evacuation Creek, near its intersection with the White River, are the type localities for the Birds Nest zone (figure 17). The cliffs along the creek expose numerous cavities left behind from the dissolution of large nahcolite nodules. In fact, the name "Birds Nest" comes from the fact that mud swallows like to nest in the empty nacholite nodule cavities along the edge of the creek (Cashion, 1967). This area is also thought to be one of the main recharge sources for the Birds Nest aquifer (Holmes and Kimball, 1987). As water passes over the exposed Birds Nest aquifer along Evacuation Creek and the White River, it enters the unit and flows northwest, down the dip of the beds. This concept is further discussed in the water chemistry section. A measured section was not completed at this location due to the availability of several cores in the area.

Near the old townsite of Watson, Evacuation Creek once again cuts into the saline zone of the upper Green River Formation. Extensive exposures are present along this transect, which display the decreasing abundance of the large nahcolite cavities from north to south (North Watson observation point south to the Watson measured section).

The final observation point was made in Buck Canyon off the Seep Ridge road in section 36, T. 12 S., R. 21E, SLBLM. The saline zone in this area appears to be essentially not present, possibly the result of being too far from the basin's paleo-depocenter. A few thin beds were found that contain minor small saline mineral crystals, but only negligible occurrences compared to the abundant saline minerals found at sections as close as Bitter Creek. These field observations helped define the extent of the small saline crystal area show in yellow on plate 1.

Regional Cross Sections

With only a limited number of cores capturing the Birds Nest aquifer and saline zone, a method was needed to make use of the thousands of oil and gas wells in the eastern Uinta Basin that have been drilled through this interval. Comparing the detailed core logs to geophysical logs revealed that the presence of large saline mineral nodules and beds were recorded on the bulk density log as low-density spikes (1.7-2.0 g/cm^3 as compared to ~2.5 g/cm^3 for typical organic-lean oil shale). It was also recognized that bulk density logs do not record the presence of small saline mineral crystals or shortite fracture fill. Only one other log seemed to record the presence of the saline minerals – the caliper log, used to measure the diameter of the borehole, often recorded larger hole widths in places where large saline mineral cavities were encountered.

Despite the fact that a bulk density log cannot be used to characterize the entire saline zone (both large nodules and smaller crystals), these logs proved useful in mapping the lateral extent of the area containing large saline nodules and thus the area having enough storage for possible saline water disposal. The first step in the mapping process was to create five regional cross sections, three north-south and two east-west, covering the expected extent of the Birds Nest aquifer (plate 1, plates 27-31). Bulk density, caliper, and gamma ray logs (in some cases Fischer assay oil yield data were plotted when a bulk density log was not available for wells with core) were plotted verses depth for each well and scaled vertically to reflect depth below surface. To make the sections shorter, the horizontal distance between wells was set to a uniform value instead of scaling to the true horizontal distance between the wells. The position of the overall saline zone was estimated from the core data, and the upper and lower Birds Nest zones were picked based on the presence of low-density spikes on bulk density logs. In addition to the saline zone, the underlying rich and lean oil shale units (lower R-8, A-Groove, Mahogany Zone, B-Groove, R-6, L-5,

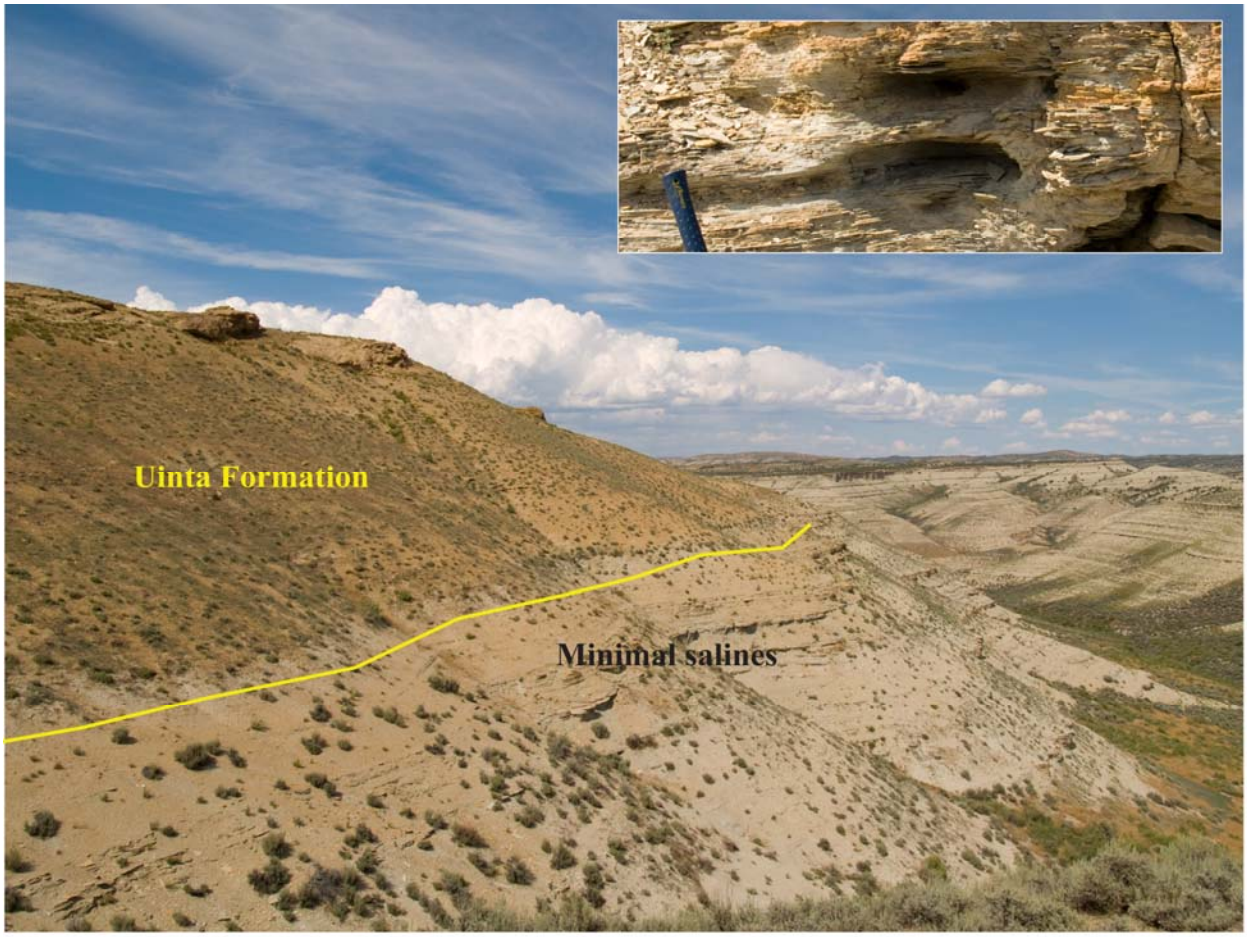

Figure 16. *Photographs of Birds Nest outcrop near its northern extent, characterized by abundant small saline mineral crystals with an occasional larger nodule (inset).*

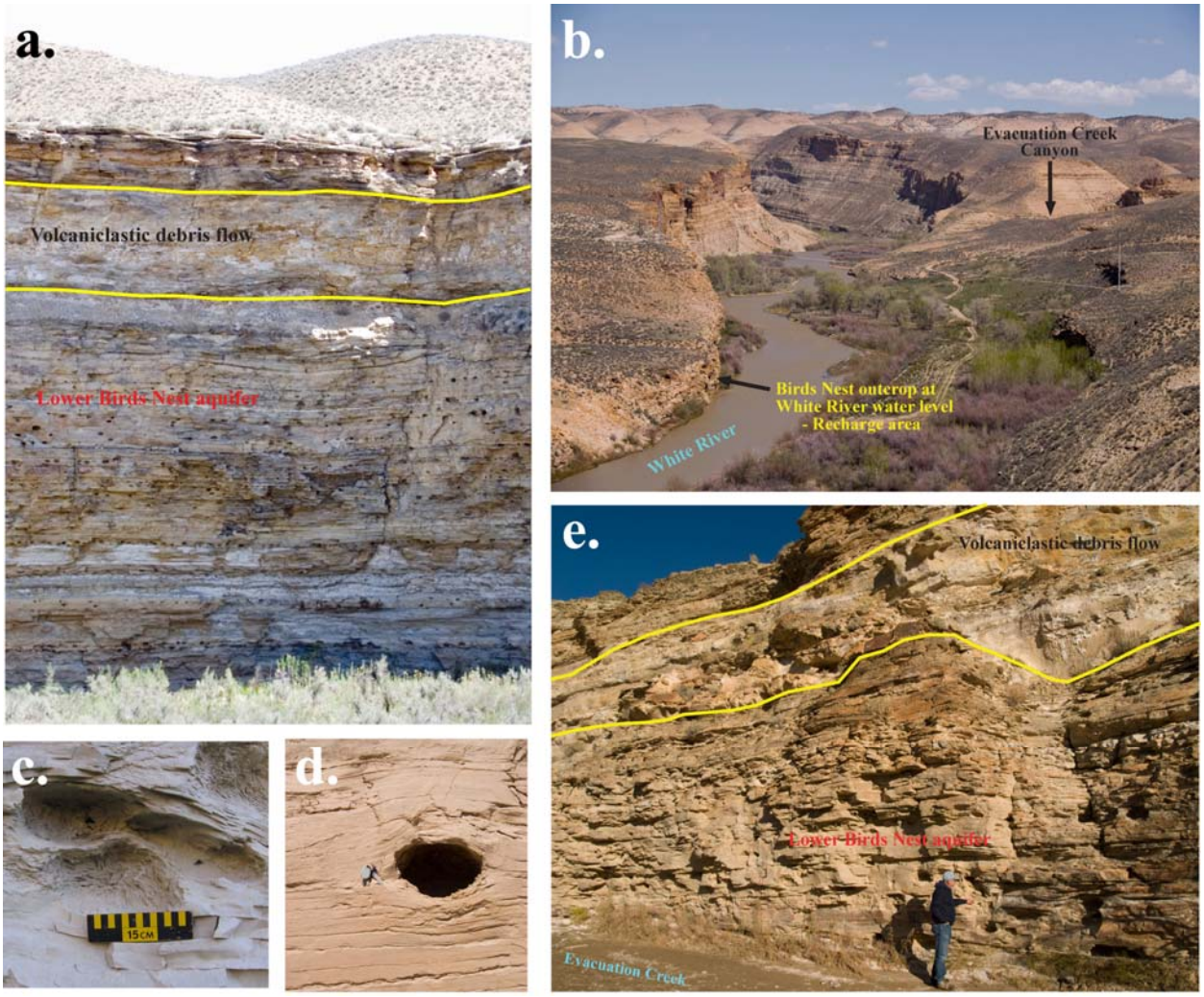

Figure 17. *Photographs of Birds Nest outcrop along Evacuation Creek and the White River. a. Outcrop of the lower Birds Nest aquifer along Evacuation Creek. b. Outcrop of the lower Birds Nest aquifer along the White River. c and d. Dissolved nahcolite nodules; notice how the nodule growth warped and fractured the surrounding sediments. e. Outcrop of the lower Birds Nest aquifer along Evacuation Creek.*

R-5, L-4, and R-4) were highlighted, again using the bulk density log to designate their boundaries (rich oil shale is less dense than lean oil shale). The five to six rich oil shale beds present within the saline zone interburden are also noted on the cross sections.

Cross Section Descriptions

A-A' – North-south: The A-A' north-south cross section is composed of 13 wells and cuts through the middle of the basin's paleo-depocenter, passing near Anadarko's active Birds Nest saline water disposal wells (plate 27). The saline zone in the southern wells is near the surface and dips to nearly 4000 feet below the surface in the northernmost wells. Only the seven middle wells record the presence of large saline nodules within the saline zone, with the bulk density signal disappearing in the southernmost three wells, as well as disappearing in the northernmost three wells. In addition, the signature of the oil shale beds begins to disappear in the northernmost wells.

B-B' – East-west: The B-B' east-west cross section is composed of 13 wells and also cuts through the middle of the basin's paleo-depocenter (plate 28). The saline zone starts near the surface in the eastern wells and dips to about 2700 feet below the surface in the westernmost wells before disappearing. Six wells record the presence of large saline nodules within the saline zone in both an upper and lower zone, while the eastern five wells only record the presence of the lower Birds Nest zone, due to the presence of the volcaniclastic debris flow material (discussed in an earlier section). All oil shale units were mapped through the entire cross section.

C-C' – North-south: The C-C' north-south cross section is composed of nine wells and cuts through the western portion of the basin's paleo-depocenter (plate 29). The saline zone in the southern wells is about 1000 feet below the surface and dips to over 4000 feet in the northernmost wells before disappearing. Only the four center wells record the presence of large saline nodules in both an upper and lower Birds Nest zone, with the bulk density signal disappearing in the southernmost three wells as well as the northernmost two wells. In addition, the usual signature of the oil shale beds begins to disappear in the northernmost wells.

D-D' – East-west: The D-D' east-west cross section is composed of nine wells and cuts through the northern portion of the basin's paleo-depocenter (plate 30). The western four wells record the presence of large saline nodules within the saline zone in both an upper and lower zone, while the central well only records the presence of the lower Birds Nest zone. The saline zone signature, as well as the oil shale signature, is lost in the eastern four wells.

E-E' – North-south: The E-E' north-south cross section is composed of 11 wells and hugs the eastern side of the basin near the outcrop exposure (plate 31). The southern eight wells all have core available from the saline zone, of which the southern three wells contain no large saline mineral nodules. The northern three wells also lack the density log signature of large saline nodules. Also displayed on the cross section is the north-south extent of the volcaniclastic material, which occurs in one or two distinct beds/flows. The typical oil shale log signature again disappears in the northernmost wells, but can be traced easily through the central and southern wells.

Examination of Additional Wells

The creation of the five regional cross sections allowed the overall extent of the Birds Nest aquifer to be roughly defined. To better define the boundaries in areas away from the cross section traces, additional bulk density logs were examined from hundreds of oil and gas wells. While this area has been extensively drilled for natural gas and crude oil, found straigraphically below the Birds Nest, one limiting factor on the utility of this well data is whether the oil and gas operator logged the upper part of the

borehole through the Birds Nest zone. More often than not, the upper ~3000 feet of the well including the Birds Nest zone was cased and not logged. Despite this limitation, logs from 322 wells (including all cores and cross section wells) were examined and tops were picked for the upper and lower Birds Nest zones in the 217 wells which lay within the extent of the aquifer (plate 1, appendix A). Tops for the oil shale horizons were also picked in all examined wells. Well data coverage is fairly uniform across the study area, except in the northwest corner (T. 3 S., R. 1 W., R. 1 E., and R. 2 E.). This area has not seen the extensive oil and gas drilling compared to areas farther south and east, and thus the aquifer boundaries are not as well defined.

Isopach Maps

After defining the areal extent of the Birds Nest aquifer, the tops database could be used to create isopach maps of the upper and lower zones, as well as the interburden between the zones. The upper surface of each zone was also subtracted from a digital elevation model of the area to create overburden contours.

Upper Birds Nest Aquifer Isopach

The upper Birds Nest aquifer, as defined by 150 wells, covers 410 square miles and averages 79 feet thick (figure 18). The aquifer is thickest near its center (between 100 and 110 feet thick) and gradually thins toward its edges (between 33 and 40 feet thick) defining the bowl-like structure of the ancient lake's depocenter. The upper Birds Nest ranges in depth from about 1000 feet in the southeast to about 4000 feet in the northwest.

Lower Birds Nest Aquifer Isopach

The lower Birds Nest aquifer, as defined by 217 wells, covers 719 square miles and averages 84 feet thick (figure 19). The lower aquifer has the shape of an elongated oval and is thickest in the center (between 100 and 110 feet thick) and gradually thins toward the north and south (between 33 and 40 feet thick). The lower Birds Nest is exposed at surface on the eastern side of the basin and deepens northwestward to just over 4000 feet in the northwest.

Aquifer Interburden Isopach

The upper and lower Birds Nest zones are separated by a 100- to 210-foot-thick sequence, thickening to the west, of organic-lean oil shale that contains only limited saline mineral deposition (figure 20). It is unlikely that the upper and lower aquifers are hydraulically connected through this thick package of impermeable oil shale, unless extensive fractures or cross-cutting gilsonite veins are present (see discussion below).

BIRDS NEST WATER CHEMISTRY

Regulations stipulate that underground saline water disposal can only occur within aquifers that already have water averaging more than 10,000 mg/L TDS (U.S. EPA, 2012). Therefore, it is important to define areas within the Birds Nest aquifer that meet this critical criterion to identify areas suitable for large-scale saline water disposal. A database was compiled containing 209 analyses from 162 wells of Birds Nest water chemistry, of which 156 wells were used in the mapping effort (appendix B). Anadarko Petroleum Company has taken a lead in this effort, collecting water samples from 129 wells penetrating the Birds Nest zone. Caution is needed in using 115 of these analyses, since the water was collected from the open borehole after reaching the Birds Nest interval. Consequently, these samples may be diluted

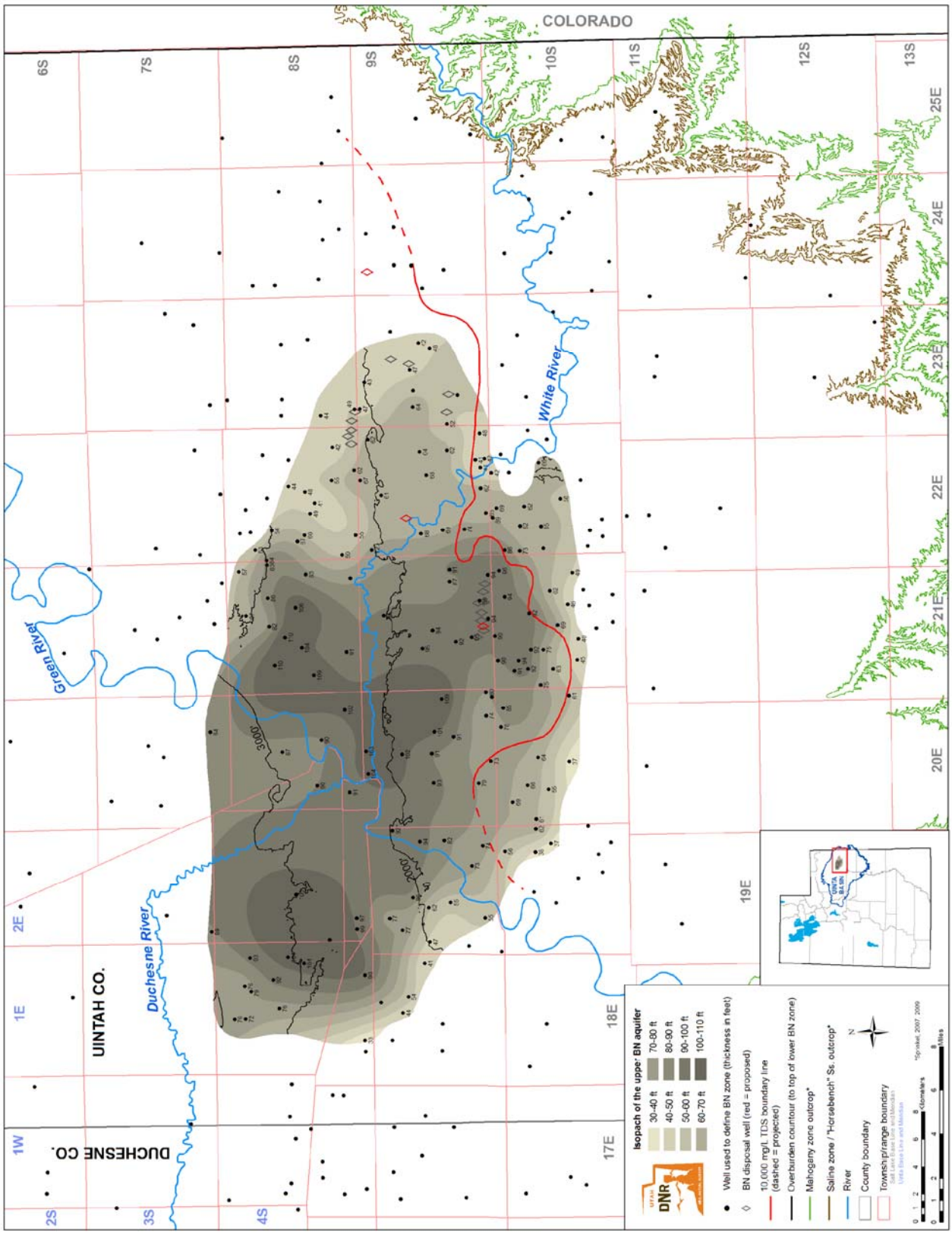

Figure 18. *The upper Birds Nest aquifer thickness.*

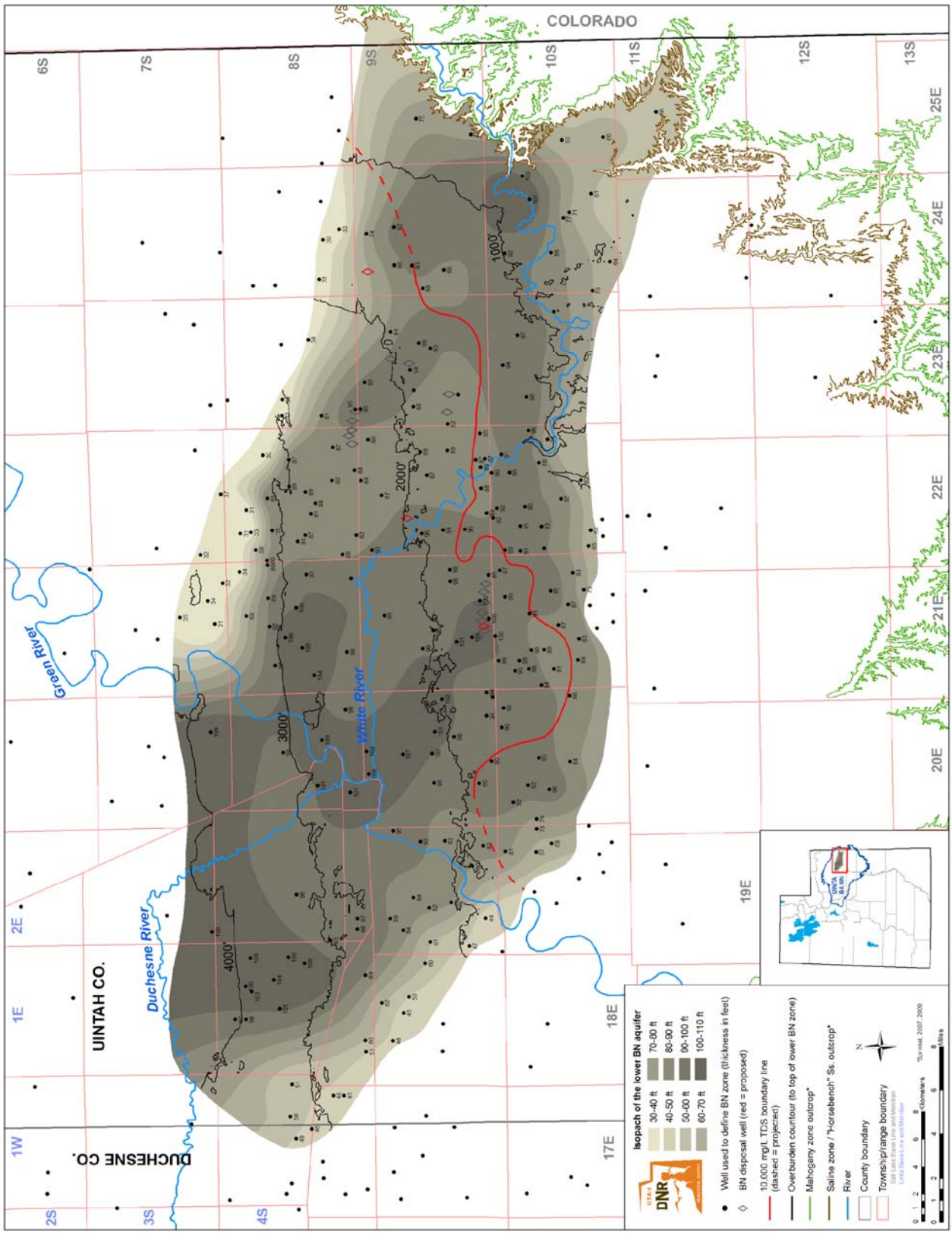

Figure 19. *The lower Birds Nest aquifer thickness.*

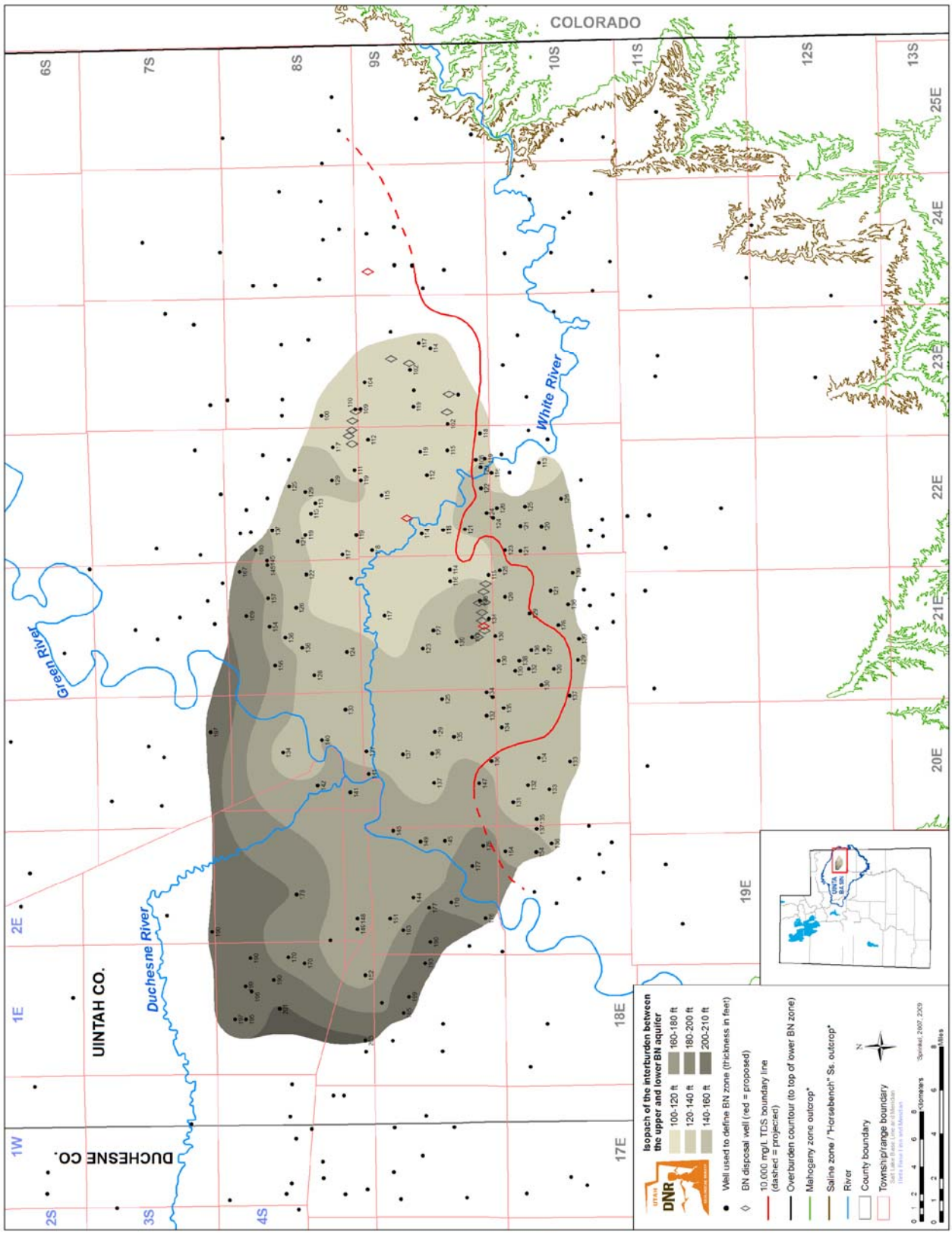

Figure 20. *Thickness of the interburden between the upper and lower Birds Nest aquifer.*

with fresher water from aquifers above the Birds Nest zone (fresher water from the overlying Uinta Formation sands). Because of potential dilution, these data points represent a minimum TDS level for water in the Birds Nest zone. These diluted water samples are still useful in mapping the 10,000 mg/L TDS boundary in the subsurface, as the transition is often very dramatic.

In addition to the 115 Anadarko samples collected from open boreholes, 40 Birds Nest-specific water analyses were compiled from various sources. To prove the existence of saline water near the 19 permitted Birds Nest disposal wells (table 1), Anadarko (14 analyses), EOG Resources (8 analyses), and Questar (1 analyses) were required to collect Birds Nest-specific water samples for TDS analysis. In addition, 17 Birds Nest-specific water analyses were found within old oil shale well files.

Using the above-mentioned water chemistry database, it was possible to draw a line on the map representing the southwest to northeast transition of 10,000 mg/L TDS water within the Birds Nest aquifer (figure 21). Chemistry of water to the northwest of the boundary (averaging >10,000 mg/L TDS and as high as 100,000 mg/L TDS) is distinct from that in the southeast (averaging <10,000 mg/L TDS and down to near 1000 mg/L TDS). This abrupt change in water chemistry is most likely due to the differing amounts of saline mineral dissolution in the two areas. The main area of freshwater recharge for the Birds Nest aquifer is near Evacuation Creek, the White River, and the outcrop to the east and south. With the beds dipping to the northwest, the sub-10,000 mg/L TDS area may have been flushed clean of saline minerals, whereas saline minerals in the northwestern, high-TDS area are still actively dissolving.

As per regulations, saline water disposal may only take place north of the 10,000 mg/L TDS line, eliminating the entire southeast part of the aquifer as a saline water disposal zone. This reduces the possible available area for disposal within the upper Birds Nest zone to 360 square miles and the lower Birds Nest zone to 499 square miles (figures 22-24). This more limited possible disposal area is centered under the Greater Natural Buttes natural gas field, the largest natural gas field in Utah, making the Birds Nest aquifer very attractive as a saline water disposal zone (figure 25).

APPROXIMATE BIRDS NEST PORE VOLUME CALCULATIONS

An attempt was made to calculate the volume of pore space within the upper and lower Birds Nest aquifer that might be available for saline water disposal. The unique pore structure of this aquifer makes a volume calculation very difficult; the best that can be determined is a gross estimation of the available storage space. Examination of a representative outcrop was conducted to approximately estimate the vuggy-porosity of the hollow cavities left behind after saline mineral dissolution, as core often provides too narrow a window (cores often miss nodules giving the appearance of less vuggy-porosity). In addition, operators drilling through this zone commonly report very little water present in the Birds Nest zone, meaning most of the space is available for disposal. In fact, drilling reports indicate that the Birds Nest is a zone of lost circulation where drilling fluids are often lost.

A photograph was taken of the lower Birds Nest aquifer outcrop along Evacuation Creek. Using GIS techniques, each open cavity was “mapped” and the total area of open cavities was calculated and compared to the total area of the rock surface (figure 26). This information was then used to estimate an overall average macro-porosity of 2.5%. In many cases, nodules occur in discreet beds or groups, with estimated macro-porosities as high as 10.5% and 3.5%, respectively.

The upper Birds Nest aquifer, where existing water is >10,000 mg/L TDS, covers 360 square miles and has a mean thickness of 82 feet for a total volume of 820 billion cubic feet. After applying the overall average vuggy-porosity of 2.5%, as calculated from outcrop, the estimated storage volume totals 20 billion cubic feet or 469,000 acre-feet. The lower Birds Nest aquifer, where existing water is >10,000 mg/L TDS, covers 499 square miles and has a mean thickness of 85 feet for a total volume of 1200 billion cubic feet. After applying the overall average vuggy-porosity of 2.5%, the estimated storage volume totals 30 billion cubic feet or 680,000 acre-feet.

Unfortunately, several unknowns complicate the volume estimate provided above: 1) these

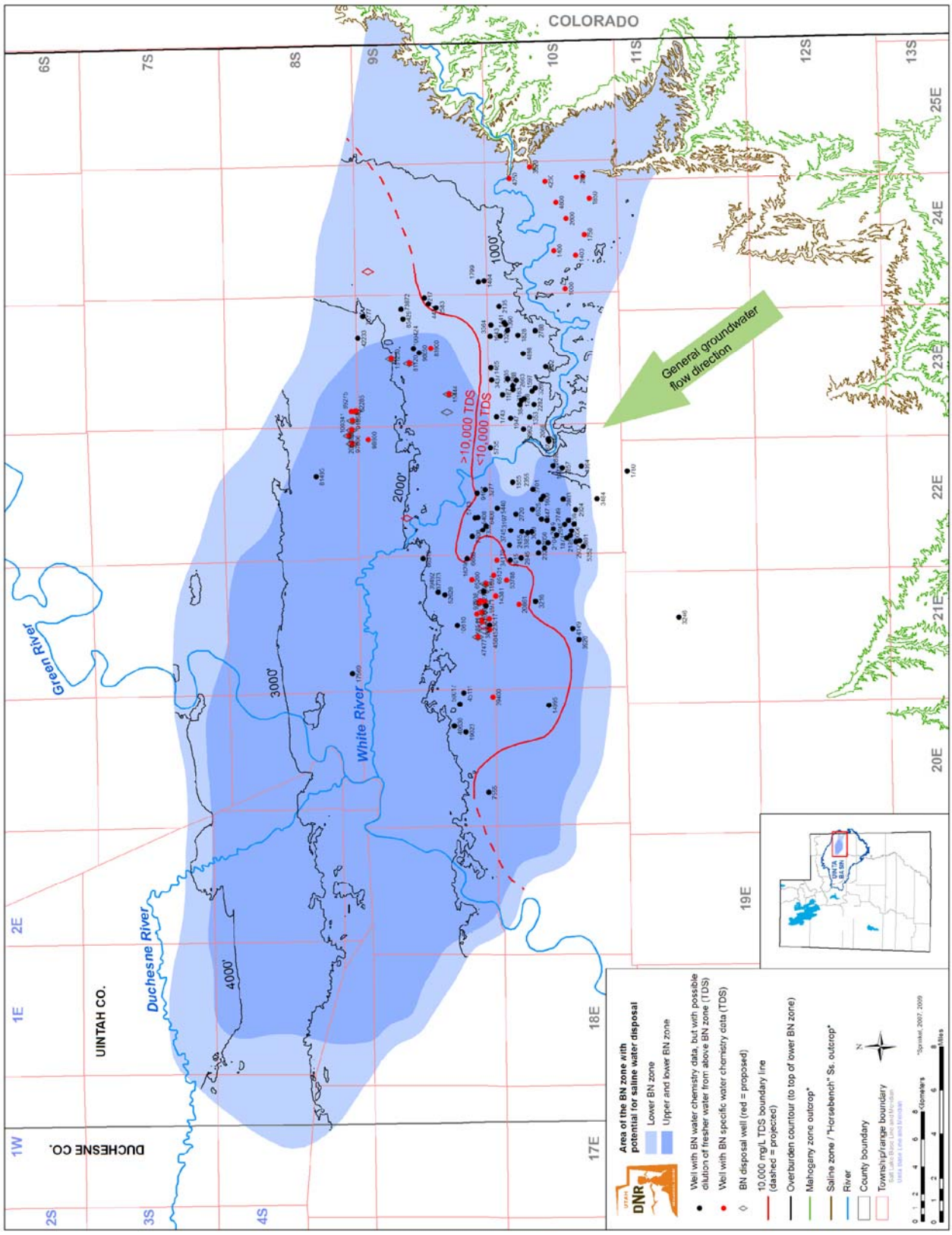

Figure 21. *The Birds Nest aquifer's water chemistry.*

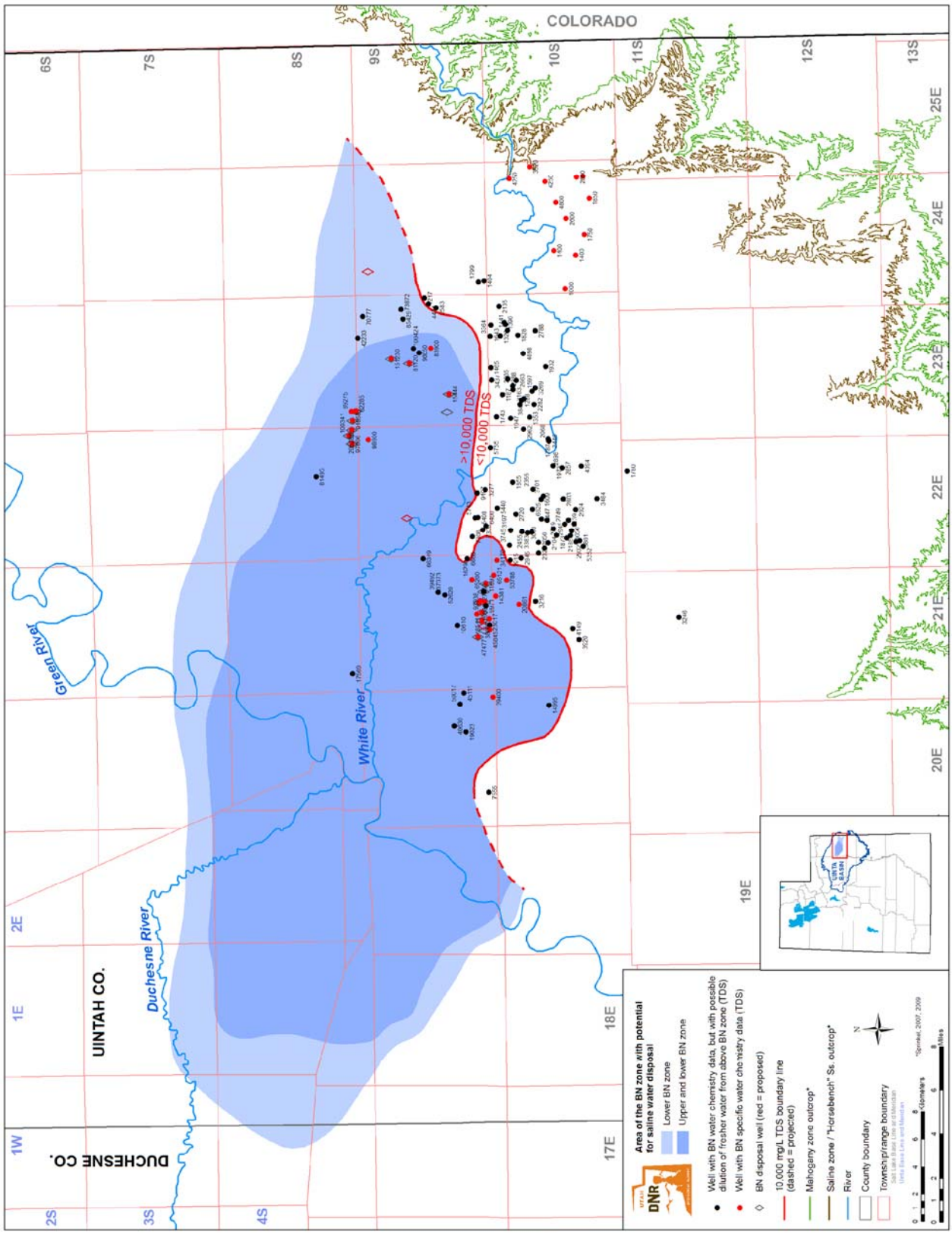

Figure 22. *Area of the Birds Nest aquifer with potential for saline water disposal.*

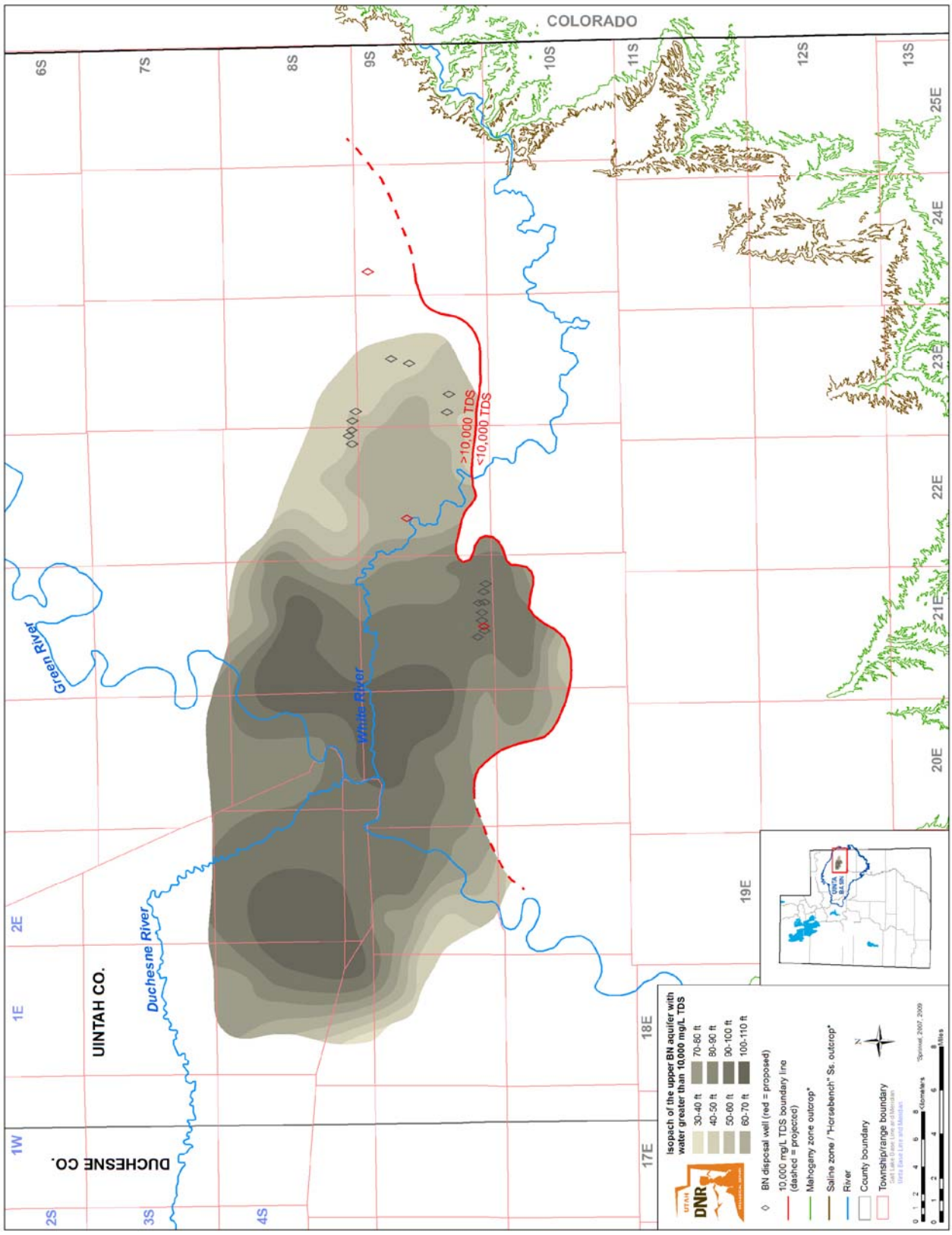

Figure 23. *Thickness of the upper Birds Nest aquifer where there is potential for saline water disposal.*

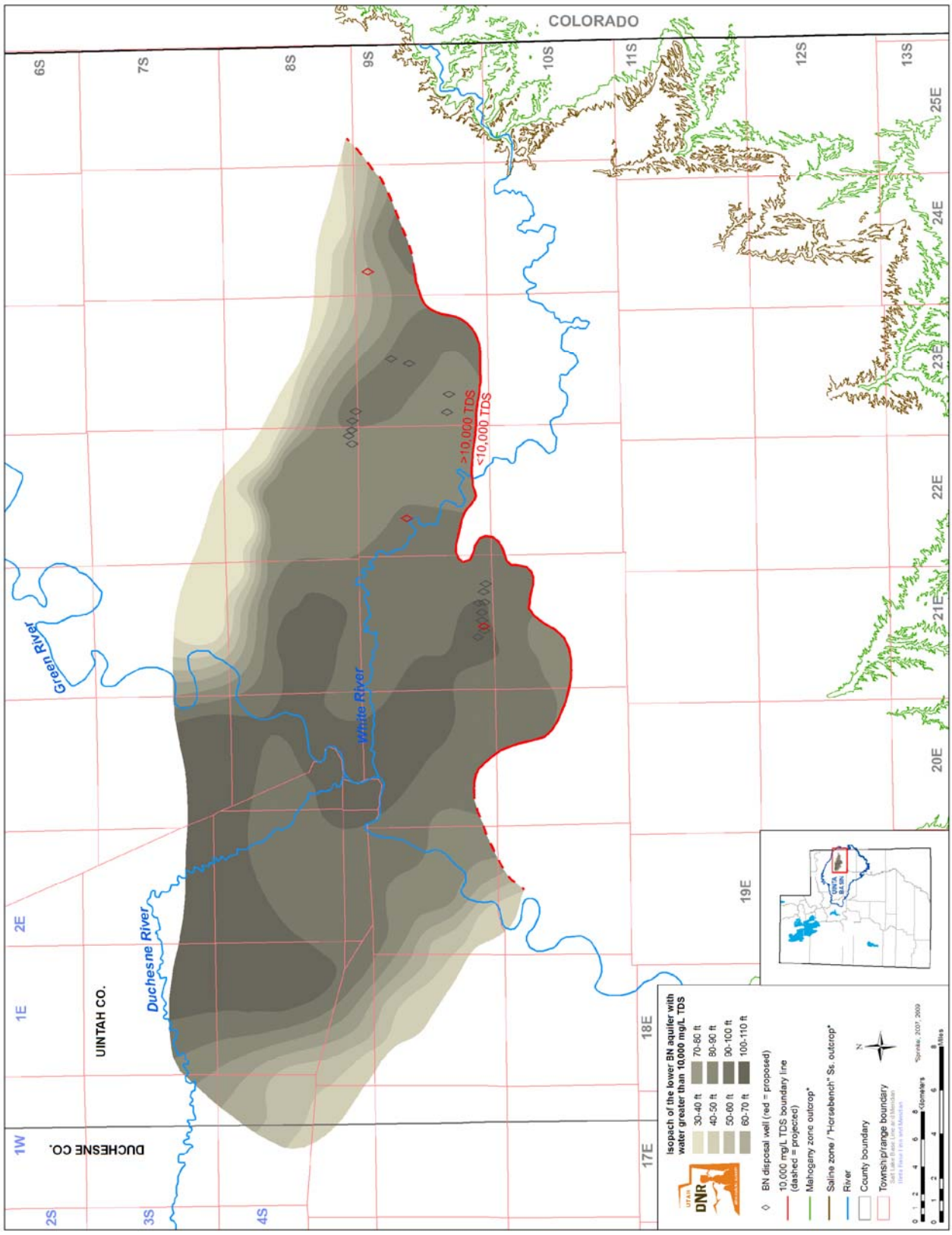

Figure 24. *Thickness of the lower Birds Nest aquifer where there is potential for saline water disposal.*

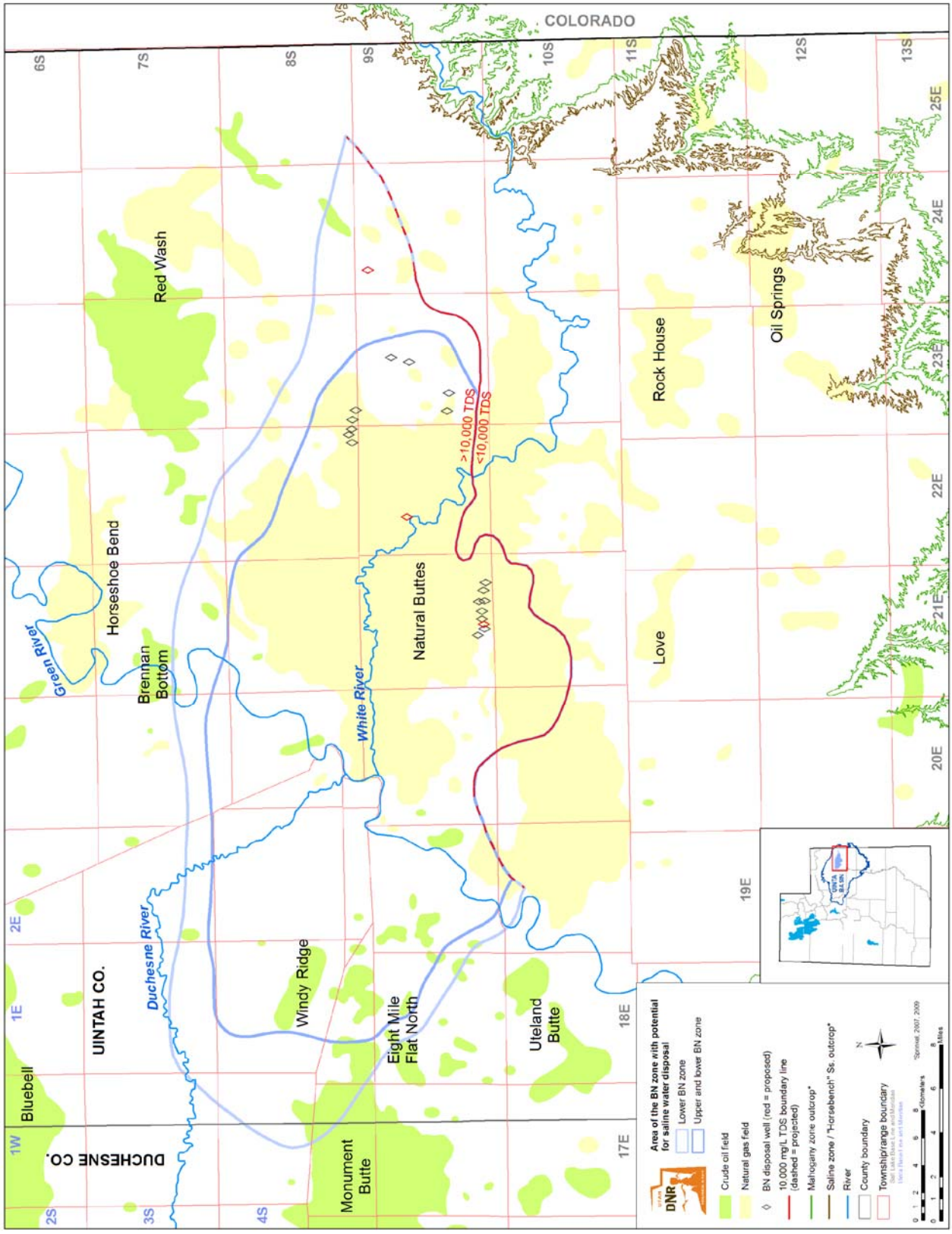

Figure 25. *Area of the Birds Nest aquifer with potential for saline water disposal and its proximity to major producing oil and gas fields.*

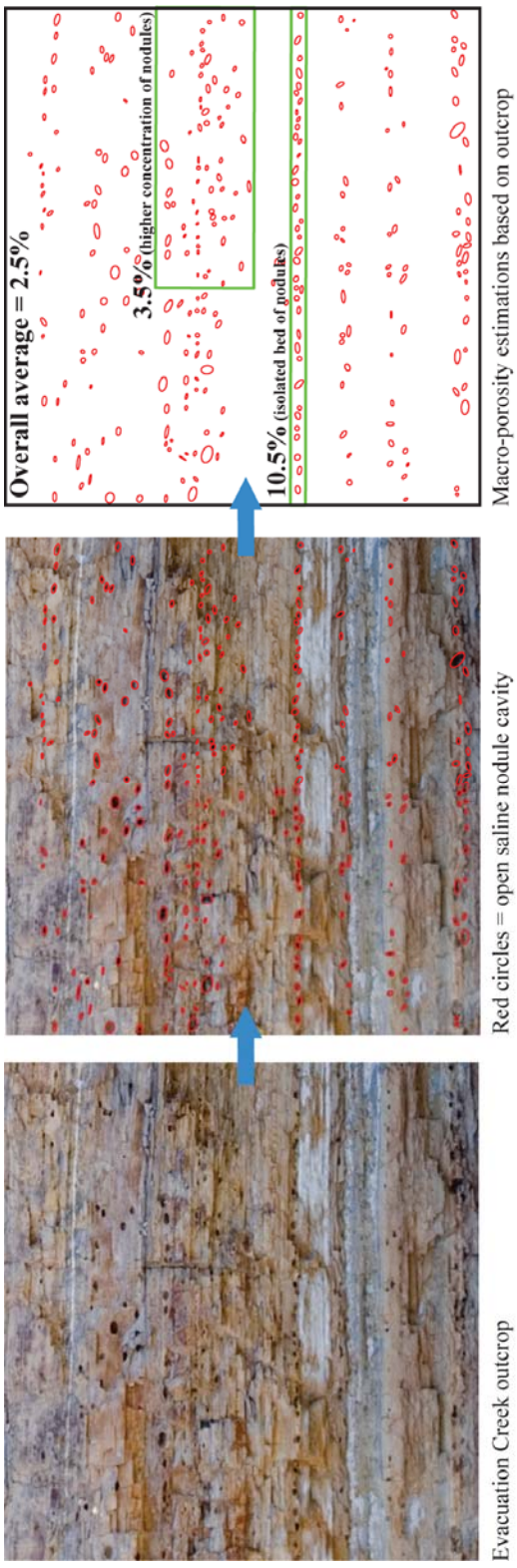

Figure 26. *Method used on Evacuation Creek Birds Nest outcrop to estimate an overall average macro-porosity.*

calculations do not take into account fracture porosity or micro-porosity, which are highly variable and difficult to quantify, and 2) these calculations do not take into account the possible large areas where no or partial saline mineral dissolution has taken place, thus reducing the macro-porosity. Again, these areas are very hard to quantify because a density log reacts similarly to an intact saline nodule or one that has been dissolved away. A caliper log is somewhat more useful, recording widening of the borehole which could be related to saline mineral dissolution, but often, the drilling process causes some dissolution of the saline nodules, giving the false impression of groundwater-induced dissolution. Sometimes drilling reports can be used to determine if the drilling company encountered lost circulation (a sign of natural dissolution), but reading through thousands of drilling reports is cumbersome and beyond the scope of this project.

In many places, the fracture porosity might be more important than the vuggy macro-porosity. Near EOG Resource's disposal wells, TDS measurements from Birds Nest specific water range from 80,000 mg/L up to 200,000 mg/L (figure 21). With the existing water at or near saline saturation, active dissolution of saline minerals might be limited, suggesting that the available space for disposed water could lie within the fracture network. In fact, the Red Wash 1 core (plate 8), near EOG Resource's disposal wells, only shows limited dissolution of the saline minerals.

INFLUENCE OF GILSONITE VEINS ON GROUNDWATER MOVEMENT

Gilsonite is a solid hydrocarbon that forms a swarm of subparallel, northwest-trending, near-vertical, laterally and vertically extensive veins in the Uinta Basin, but mostly on the eastern side in Uintah County (plate 1) (Boden and Tripp, 2012). Gilsonite is thought to be sourced from the rich oil shale units of the upper Green River Formation. Overpressuring from hydrocarbon generation and expulsion deep in the Uinta Basin hydrofractured overlying strata, expelling large quantities of thermal water. Subsequently, thick, liquid gilsonite was expelled forcing open most, but maybe not all, existing fractures. The gilsonite veins can extend up to the surface cross-cutting the Birds Nest aquifer, as seen near the surface on the eastern side of the Cowboy vein (figure 27). Questions remain as to how these veins might affect groundwater movement through the Birds Nest zone – i.e., whether they act as barriers to flow or whether they create vertical and/or horizontal pathways for water transmission. The concern is that disposed saline water might use a gilsonite vein or associated fractures to travel into deeper aquifers that might not contain water >10,000 mg/L TDS, or, if the aquifer becomes overpressured, saline water could travel upward into freshwater aquifers. Also, vertical movement of saline water downward could affect development of underlying oil shale deposits.

Hood and Fields (1978) indicated that gilsonite veins and associated fractures near Roosevelt, Utah, tend to trend through potentiometric-contour anomalies as well as trend through points of abnormally high transmissivity and anomalies in the chemical quality of groundwater. They went on to state that upward leakage of saline waters, which are typically characteristic of the deeper Tertiary section, is possible where fractures are not filled with impermeable material. However, where gilsonite is present, it presumably can act as a barrier to groundwater movement. Similarly, Holmes and Kimball (1987) suggested that fractures related to a gilsonite vein transmit water from the Birds Nest aquifer upward through the Uinta Formation and the overlying alluvial aquifer to a spring emitting in the downstream reaches of Bitter Creek.

The assessment below provides additional anecdotal evidence for both cases, barrier and conduit, depending on the type of gilsonite in the vein, vein thickness, and abundance of associated fractures. Unfortunately, very little is known about the gilsonite veins and fractures at depth in the areas suitable for saline water disposal; only surface expressions of the veins are easily mapped and accessed.

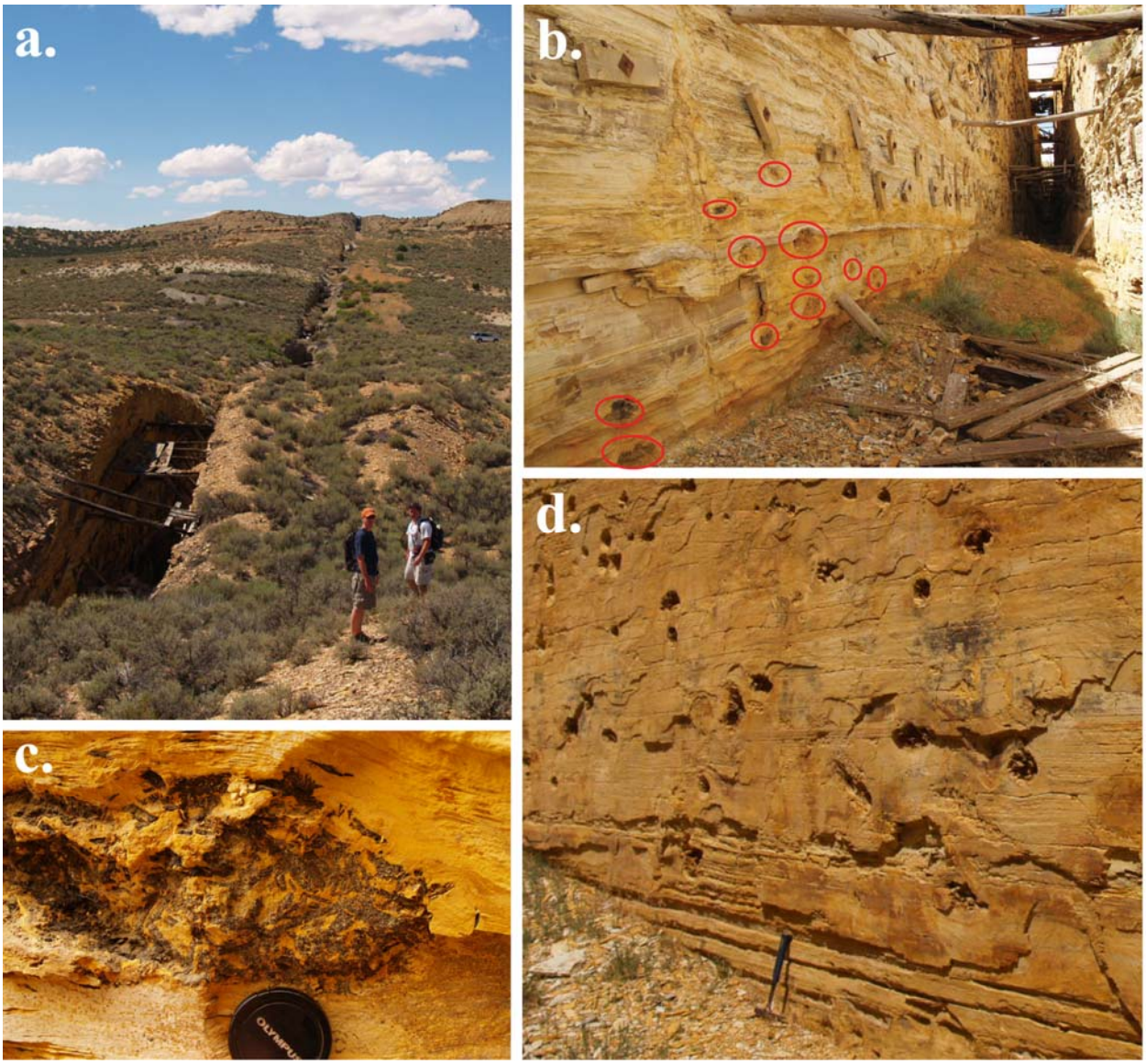

Figure 27. *Photographs of the mined-out Cowboy gilsonite vein cross-cutting the Birds Nest aquifer. a. Cowboy gilsonite vein. b. Wall of mined-out Cowboy vein showing large nahcolite nodules of the lower Birds Nest aquifer (red circles). c. Nahcolite nodule replaced with gilsonite within the wall of the Cowboy vein. d. Wall of mined-out Cowboy vein showing large nahcolite nodules.*

Basin Depocenter Cores - Evidence for Gilsonite as a Barrier to Groundwater Flow

Near the basin's paleo-depocenter, several cores exist that recovered the entire saline zone. Most of these cores show significant saline mineral dissolution (e.g., 13X-2). In fact, Anadarko has begun disposing saline water into the Birds Nest in this area. However, there is one well (Utah State 1) with core slightly to the north, which shows no sign of saline mineral dissolution. This core is separated from the southern cores by a gilsonite vein, as mapped by its surface expression (figure 28). Water within the aquifer generally recharges from areas along outcrop in the east and south, particularly where the White River and Evacuation Creek pass over the outcrop, and travels down-dip to the northwest. Water within the Birds Nest has dissolved the saline minerals to the south of the vein, but the gilsonite vein seems to stop water from reaching the area on its northern side, creating a possible zone of no saline mineral dissolution with unknown extent. Similar areas of no dissolution are assumed to exist, especially on the northern sides of known gilsonite veins, but it is difficult to quantify these areas without core.

Gilsonite Mine Tour – Evidence for Gilsonite as Both a Barrier and Conduit

The senior author toured two mines in different gilsonite veins, each roughly 3 feet thick, to assess how groundwater interacts with the veins. The first mine, within the Bonanza vein and at a mining depth of 630 feet, contained highly fractured gilsonite that easily transmitted water through the vein (figure 29). The second mine, within the Independent vein, and at a mining depth of 230 feet, contained a variety of gilsonite called "select" that is very solid and transmitted no water. These observations suggest that gilsonite veins could act as both barriers or conduits for water depending on the type of gilsonite in the vein. However, gilsonite type at depth is nearly impossible to determine in the absence of a mine.

Kings Well Groundwater Analysis – Evidence for Gilsonite as a Groundwater Conduit

Water from the Kings well, which is completed in a shallow bedrock aquifer, has elevated nitrate levels, as seen in seasonal water chemistry analyses performed by the Utah Geological Survey (figure 30) (Wallace, in prep.). This might be expected from alluvial aquifers in an area with significant agriculture (near Ouray, Utah, in central Uintah County), but not in a bedrock aquifer from an area with no farmland. The Kings well does supply water to grazing stock. Waste (which is high in nitrate) from the stock congregating around the well might be percolating down the gilsonite vein and into the bedrock aquifer.

Course of Evacuation Creek – Evidence for Gilsonite Veins Influencing Water Flow

Near the intersection of State Route 45 and the Dragon road, Evacuation Creek generally flows north before taking an abrupt 90-degree turn to the east. Upon close inspection, it was determined that the path of the creek was influenced by a very thin gilsonite vein (<2 inches thick) and associated fracture zone (figure 31). While this has only indirect relevance to underground conditions, it at least suggests that gilsonite veins can influence water flows. In addition, it demonstrates that in some cases, a specific gilsonite vein might not be as important as the vein's associated vertical fractures, which may or may not contain gilsonite. The case could be made that this fracture system could prove more influential on the movement of groundwater than the gilsonite veins.

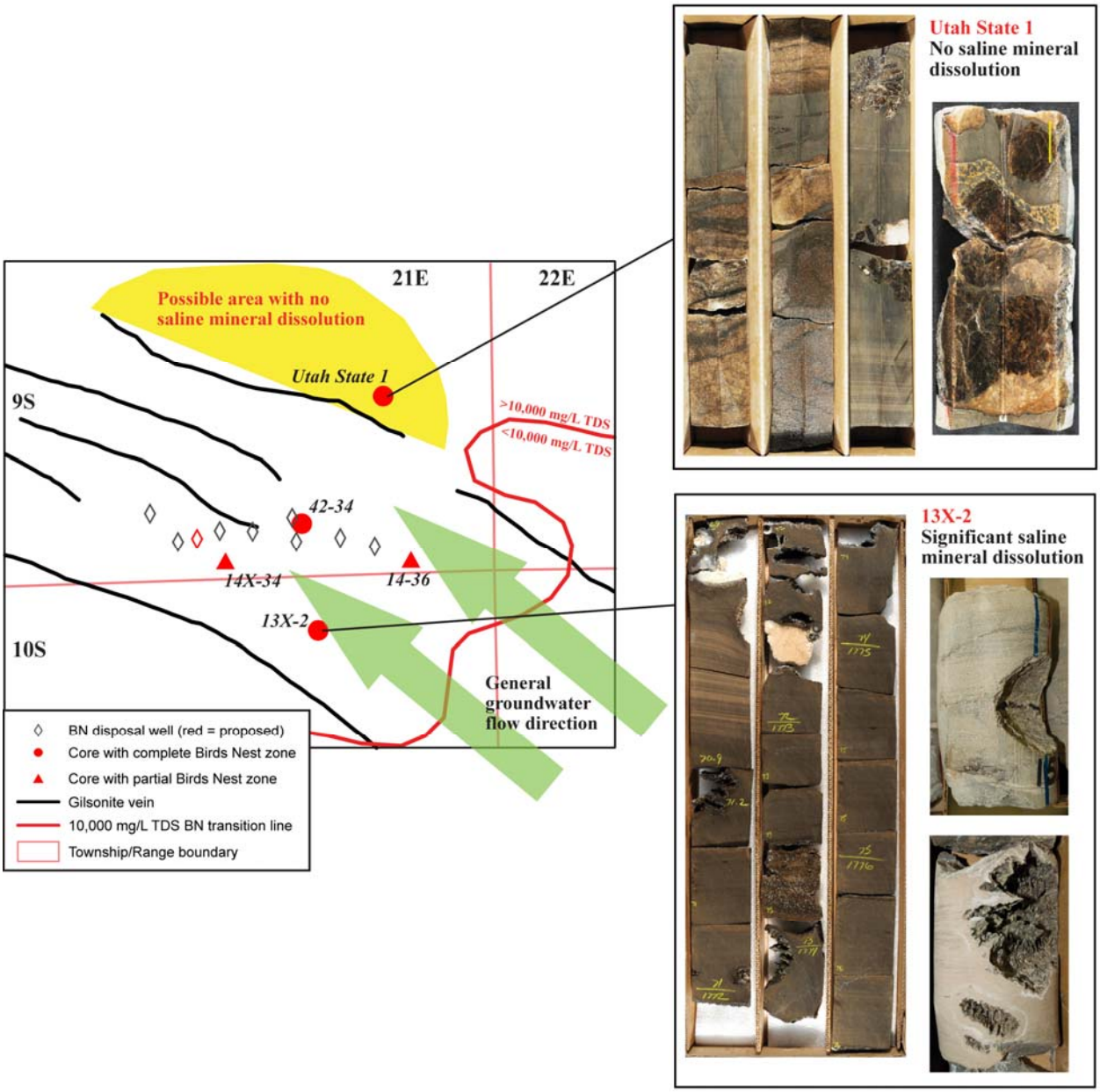

Figure 28. *Evidence for basin-center gilsonite veins acting as barriers to groundwater flow. Saline minerals in the 13X-2 core have experienced significant dissolution and are near Anadarko's Birds Nest saline water disposal wells. Saline minerals in the Utah State 1 core show no signs of dissolution. The two wells are separated by a gilsonite vein which could be preventing groundwater from reaching the area north of the vein.*

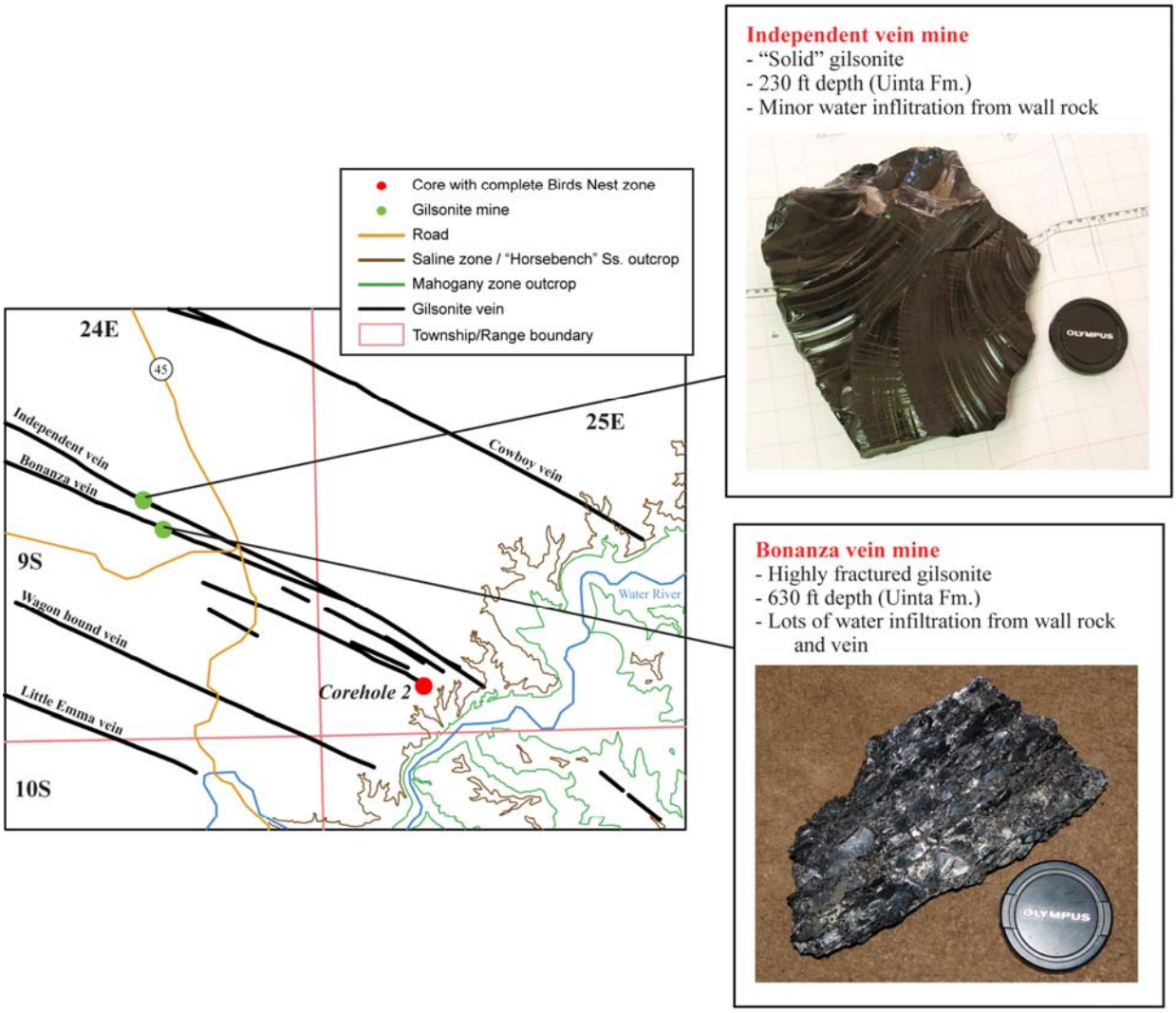

Figure 29. *Examples of gilsonite veins acting as both barriers to groundwater flow and conduits from gilsonite mine tour. Different kinds of gilsonite can be found in two different veins/mines; the solid gilsonite found in the Independent vein mine could act as a significant barrier to groundwater flow, whereas the fractured gilsonite of the Bonanza vein mine easily transmitted water through the vein.*

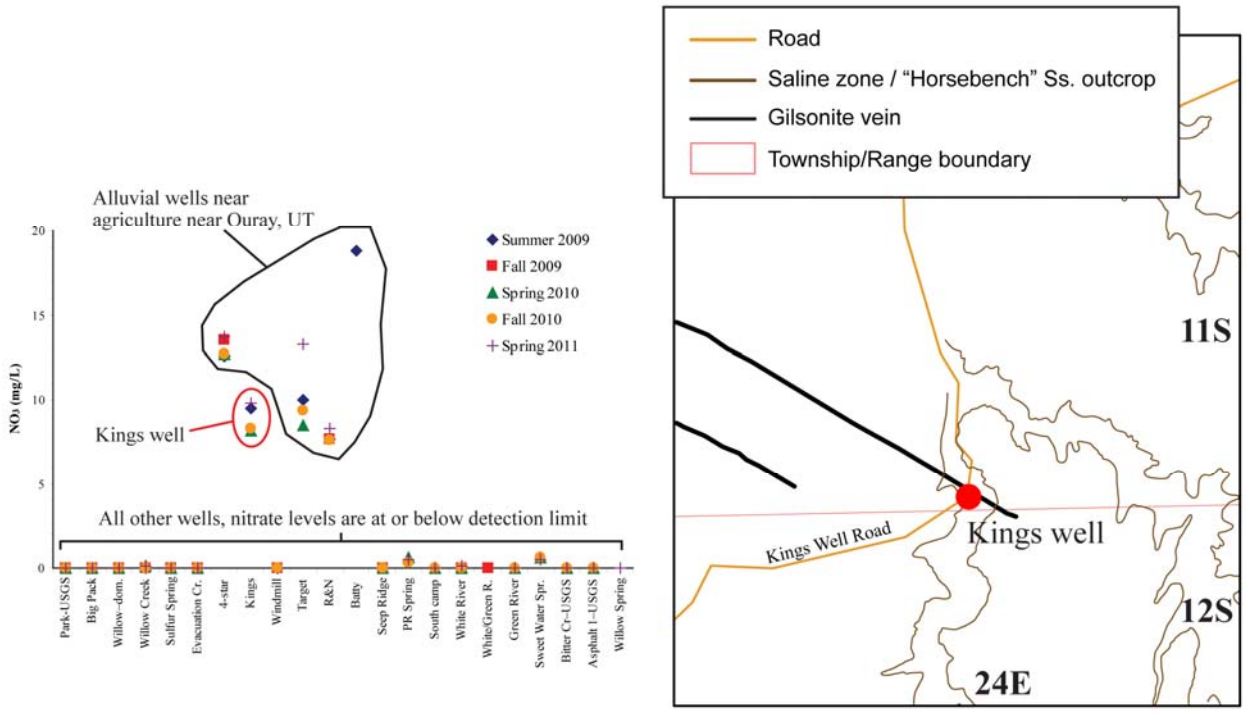

Figure 30. *Possible evidence for water traveling vertically along a gilsonite vein into a shallow bedrock aquifer. Seasonal nitrate levels from surface water and shallow wells in Uintah County mostly record concentrations below the detection limit, except for a cluster of wells near Ouray, Utah, where there is significant nearby agriculture, and the Kings well, which is next to a gilsonite vein. The Kings well is used to water stock; waste from the stock congregating near the well could be percolating down the gilsonite vein into the bedrock aquifer.*

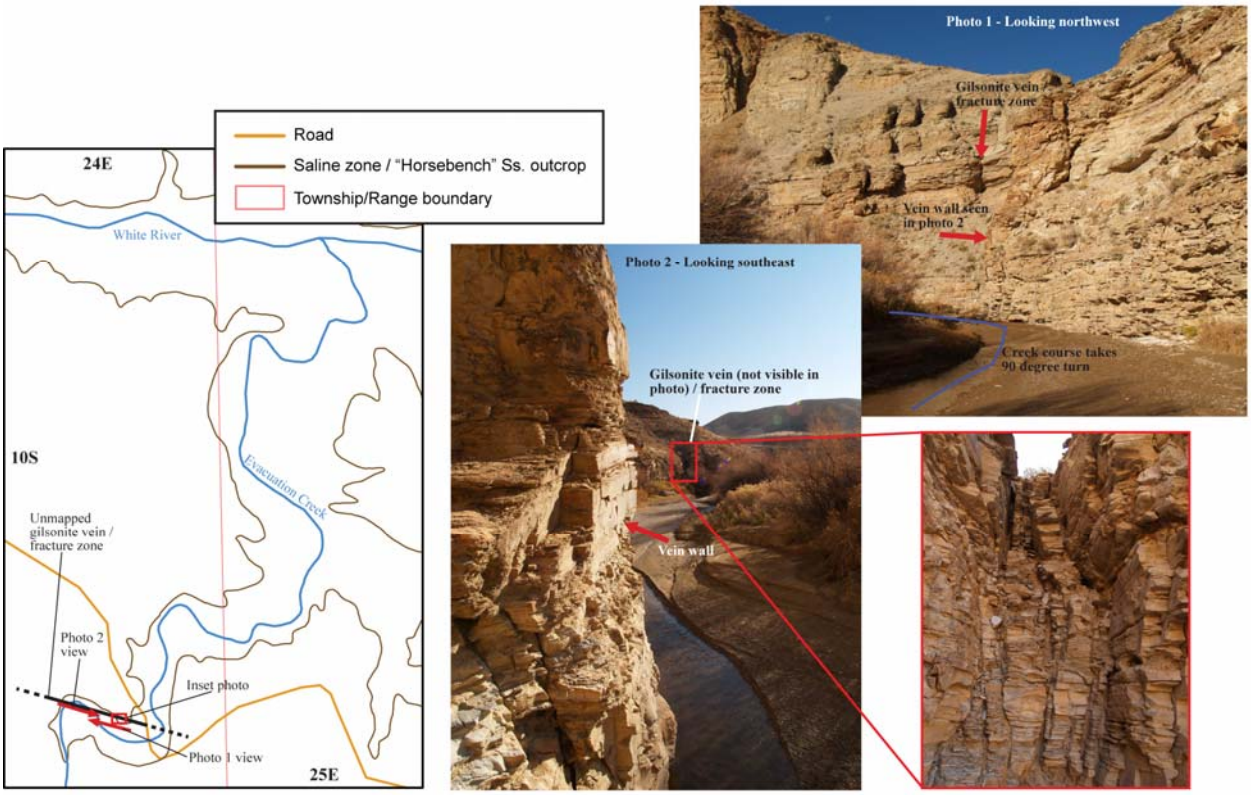

Figure 31. *Evidence along Evacuation Creek that gilsonite veins and their associated fractures influence the course of surface water flow.*

BIRDS NEST AQUIFER AND OIL SHALE

Oil shale is a carbonate mudstone deposited in a large ancient lake system that contains abundant organic matter derived mostly from algae or cyanobacteria. Oil shale is considered a thermogenically immature source rock, meaning it has not experienced temperatures or pressures high enough to geologically convert the organic matter, called kerogen, into conventional oil and/or natural gas (except maybe in the deepest parts of the Uinta Basin to the northwest). However, several companies are working on technologies to artificially convert oil shale's kerogen into petroleum products using two basic methods: 1) surface/underground mining and surface retort (including modified *in-situ* capsule retorts), and 2) *in-situ* heating (heating the oil shale within the ground via wells) and recovery. The Utah oil shale deposit is more conducive to mining and surface retort since the richest oil shale zones are relatively thin (a sequence of oil shale averaging 25 gallons of oil per ton of rock (gpt) is between 70 and 120 feet thick) and accessible along extensive outcrops (figure 32). In contrast, the Colorado oil shale deposit, in the Piceance Basin, is better suited to *in-situ* recovery with a much thicker organic-rich sequence (a 25 gpt zone more than 1000 feet thick) under 1000 to 2000 feet of cover (USGS, 2010b). Detailed descriptions of the various oil shale conversion technologies and the companies looking to employ them can be found in the INTEK, Inc. report "Secure Fuels from Domestic Resources: Profiles of Companies Engaged in Domestic Oil Shale and Tar Sands Resource and Technology Development, 5th Edition," prepared for the U.S. Department of Energy, Office of Petroleum Reserves, Naval Petroleum and Oil Shale Reserves (INTEK, 2011).

The upper Green River Formation in the Uinta Basin hosts one of the largest deposits of oil shale in the world – as stated above, estimated in-place resources total 1.32 trillion barrels of oil (USGS, 2010a) with approximately 77 billion barrels as a potential economic resource (Vanden Berg, 2008) (figure 5). Nearly the entire upper Green River Formation consists of alternating organic-rich and lean oil shale, with the richest and the most prospective horizon being the Mahogany zone (figure 4). This zone represents a time when the ancient lake was at its highest level. After Mahogany-zone time, the lake began to shrink, at times becoming a restricted basin with high-salinity water. It was at this time that saline minerals were deposited in the lake bed sediments along with organic-lean oil shale. The fact that the extent of the Birds Nest aquifer is coincident with and lies a short distance above the Uinta Basin's most prospective oil shale horizon raises questions as to what impacts large-scale saline water disposal into this zone might have on potential future oil shale development (figure 32).

Utah's oil shale deposit is broken up into alternating organic rich and lean zones, with potentially economic oil shale generally limited to deposits averaging at least 15 gpt. The Birds Nest aquifer lies within the relatively lean upper to middle R-8 zones, stratigraphically above the potentially economic oil shale horizons (figure 4). In order to relate the Birds Nest aquifer to potential economic oil shale zones below, two thicknesses of interburden were calculated and mapped using the data in appendix A: the thickness between the base of the lower Birds Nest aquifer and the top of the Mahogany oil shale zone, and the thickness between the base of the lower Birds Nest and the top of the defined economic oil shale, picked at the top of the lower R-8 (defined by Big Three oil shale beds) (figure 4). The top of the economic oil shale was selected at the top of the lower R-8 since this is the stratigraphically highest zone averaging roughly 15 gpt. Above this, in the middle R-8, the oil shale grade drops below 10 gpt, then becomes even leaner in the upper R-8. The interburden between the Mahogany zone and the lower Birds Nest aquifer ranges from 240 feet thick in the south to 430 feet thick in the north (figure 33). The interburden between the lower R-8 and the lower Birds Nest mostly ranges from 70 to 90 feet thick, except in the northeast, where the interburden reaches 180 feet thick (figure 34).

As stated above, the richest oil shale zone in Utah is the Mahogany zone, in which individual oil shale beds have Fischer assay values of up to 80 gallons of oil per ton of rock. The Mahogany zone as a whole averages between 20 and 25 gpt, is between 60 and 120 feet thick, and outcrops along the eastern and southern flanks of the basin. Currently, all companies in Utah looking to develop an oil shale industry are focused on the near-surface extent of the Mahogany zone with plans to develop a surface/underground mine and surface retort or employ surface modified *in-situ* technologies (figure 32). Saline water disposal

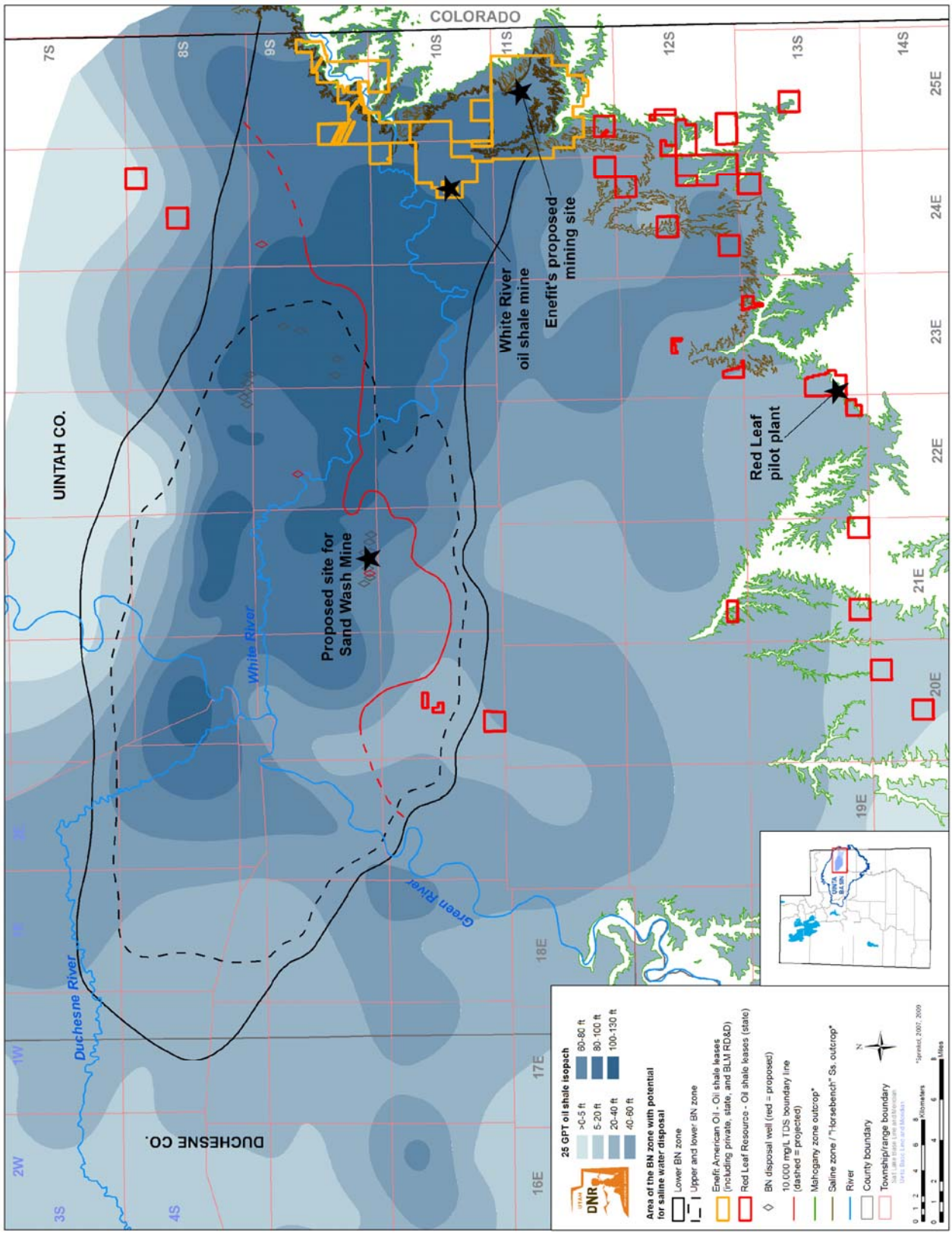

Figure 32. *Area of the Birds Nest aquifer and its coincidence with the 25 GPT oil shale zone.*

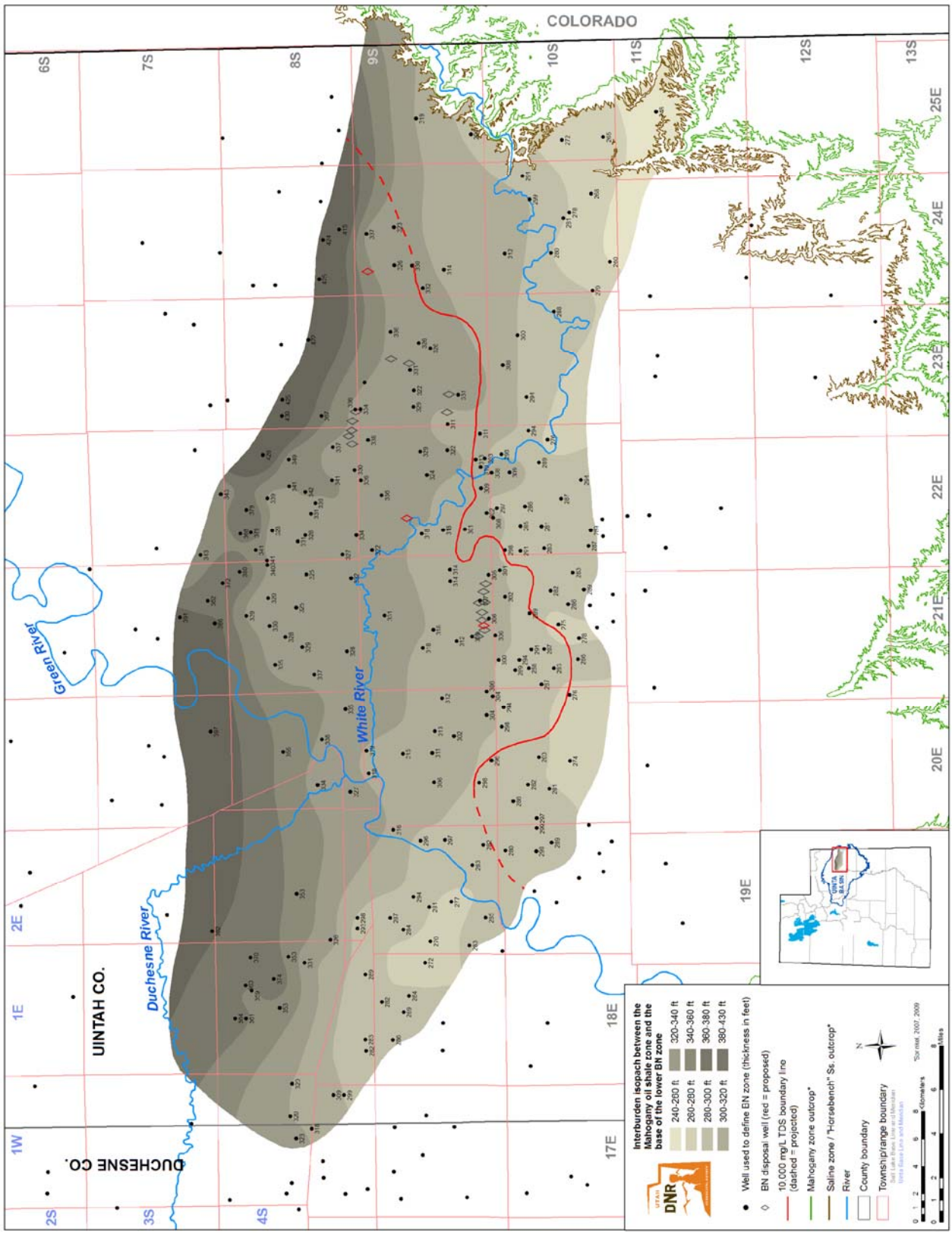

Figure 33. *Thickness of the interburden between the base of the lower Birds Nest aquifer and the top of the Mahogany zone.*

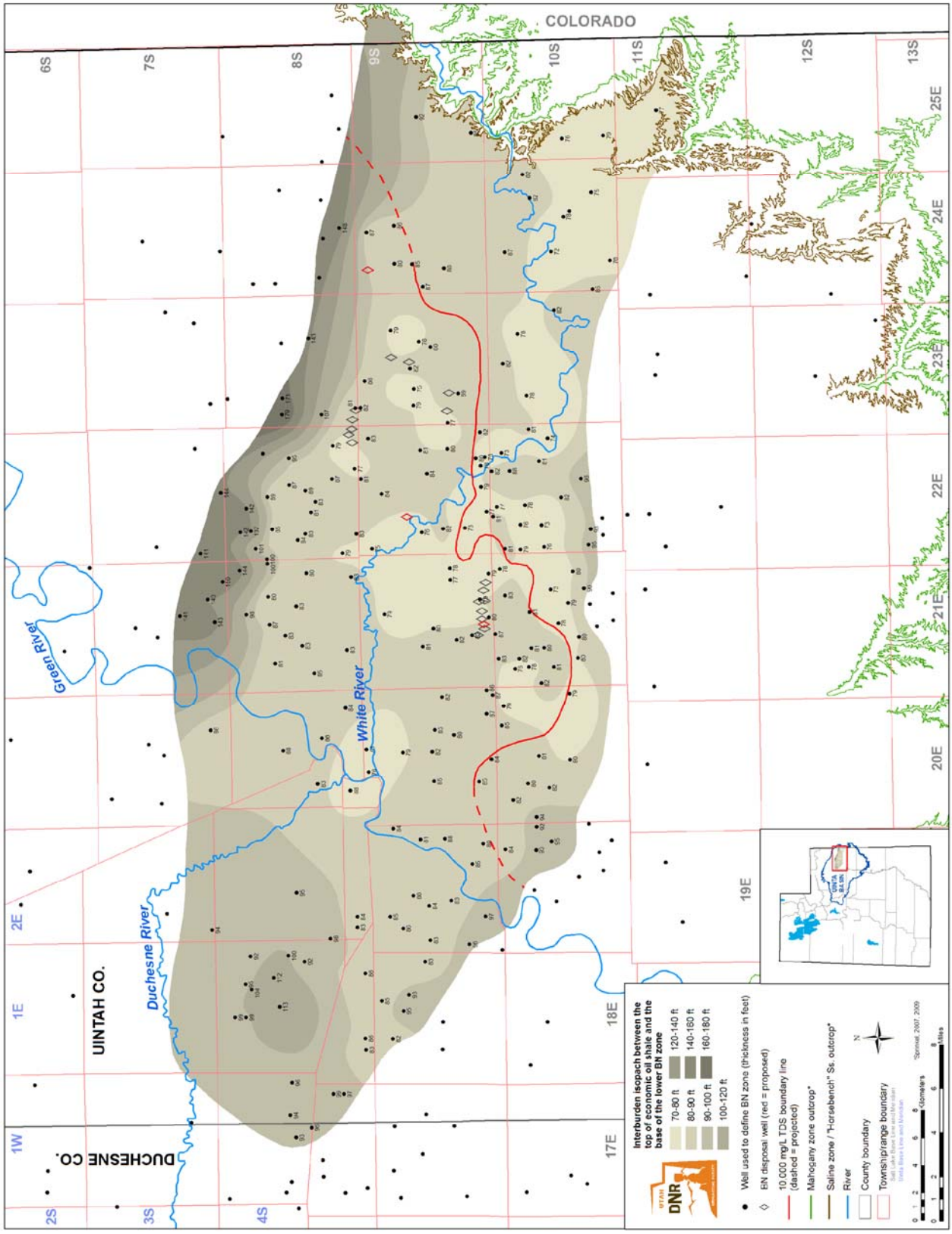

Figure 34. *Thickness of the interburden between the base of the lower Birds Nest aquifer and the top of the economic oil shale.*

into the Birds Nest aquifer should not adversely affect any company looking to develop oil shale near outcrop. Since disposal may only take place north of the 10,000 mg/L TDS boundary (as mapped on plate 1 and figure 21), active disposal will be several miles northwest and down-dip of the near-surface oil shale.

Impacts of saline water disposal into the Birds Nest aquifer on future oil shale development will depend on two main factors: 1) the value of leaner deposits, and 2) the possible vertical connectivity of oil shale deposits. As stated above, the Birds Nest aquifer lies within relatively lean oil shale rocks. Most likely, advances in *in-situ* technologies that might exploit leaner deposits will limit the recovery zone to the lower R-8 and below (leaving 70-90 feet of impermeable oil shale between the retort zone and the aquifer), purposely avoiding the Birds Nest aquifer and problems associated with retorting shale within a zone filled with water and saline minerals. Therefore, the lean oil shale within the Birds Nest has little to no economic value. In addition, if technologies advance to the point where deep underground mines prove economic (oil prices would also need to be favorably high), the mines would still be centered on the Mahogany zone, roughly 1500-3000 feet deep in the area where disposal can take place, with about 300 feet of impermeable oil shale between the mining horizon and the aquifer. In fact, in the early 1980s, substantial research was conducted on a proposed mine within the Mahogany zone, accessed via a proposed ~2000-foot shaft, very near the area where Anadarko currently has active Birds Nest saline water disposal operations (TOSCO Development Corp., 1982) (figure 32). This mine was never developed due to the crash in oil prices in the mid-1980s.

If economics ever did prove favorable for either *in-situ* technologies or deep underground mine development, the most pressing question will be whether water in the Birds Nest aquifer can migrate vertically through thick sequences of impermeable oil shale by way of fractures or gilsonite veins, contaminating operations stratigraphically below the Birds Nest zone. Any kind of water infiltration into the mining horizon could greatly affect the economics of such marginal deposits. The likelihood of such a scenario is remote but plausible, and will only increase as saline water disposal increases. Future research should look to address the issue of vertical migration of water in the upper Green River Formation.

SUMMARY AND CONCLUSIONS

The Birds Nest aquifer has significant potential as a large-scale saline water disposal zone for several reasons:

1) The aquifer currently contains highly saline water, much higher than the required 10,000 mg/L TDS, in areas generally north of T. 10 S., SLBLM.
2) There is a large amount of potential storage space (up to 1.2 million acre-feet) due to the dissolution of saline minerals and natural fracturing.
3) The aquifer is relatively shallow, reducing drilling expense.
4) The aquifer is located close to several producing natural gas fields. In fact, the aquifer overlies the Greater Natural Buttes natural gas field, the largest natural gas field in Utah.
5) Saline water disposal would take place within lean oil shale deposits that have little to no current economic potential.
6) Organic-rich, economic oil shale deposits lie between 70 feet (for *in-situ* recovery) and 300 feet (for deep underground mining) below the aquifer.

Nevertheless, disposal into the Birds Nest aquifer poses several unique challenges and risks:

1) Potentially large areas with no saline mineral dissolution exist, thus reducing overall storage potential.
2) The aquifer is relatively shallow, with non-saline water (<10,000 mg/L TDS) both above and below the unit.

3) It is currently unclear where the water within the Birds Nest aquifer eventually goes; is the water pooling in areas down-dip, or is the water migrating vertically through the section?
4) Cross-cutting gilsonite veins and associated fractures have the potential to transmit water vertically through the section, posing risks to "fresh" water aquifers stratigraphically below (or above if the aquifer becomes pressurized).
5) The extent of the Birds Nest aquifer is coincident with the richest oil shale in the Uinta Basin.
6) Vertical transmission of water from the Birds Nest aquifer could adversely affect development of underlying organic-rich oil shale deposits.
7) Additional monitoring wells would be helpful in gaining a better understanding of the hydrology of the Birds Nest aquifer, while tracer studies might be helpful in understanding the flow direction and rate of groundwater movement.

ACKNOWLEDGMENTS

This project was generously funded by the U.S. Department of Energy, National Energy Technology Laboratory under project code NT0005671. Additional funding was provided by the Utah Geological Survey. Special thanks to our DOE project officers Traci Rodosta, Virginia Weyland, and Skip Pratt.

Special thanks go to Sean Kelly at Anadarko Petroleum Corporation who provided excellent background information on the Birds Nest aquifer and a detailed review of this report, as well as providing water chemistry data, digital well logs, and various maps. In addition, Anadarko paid to have two critical Birds Nest cores slabbed for easier examination. EOG Resources and Questar also provided water chemistry data. Thanks also to David Keighley, from the University of New Brunswick, for his detailed review. Thanks to Chuck Tinsley, Tricia Pfeiffer, and other EPA Region 8 staff for their help with data collection. Thanks to the staff of the U.S. Geological Survey and Utah Geological Survey Core Research Centers for finding and setting out several Birds Nest cores. Acknowledgment also goes to Utah Geological Survey employees David Tabet, Mike Hylland, Kimm Harty, and Rick Allis for their detailed review and insightful comments.

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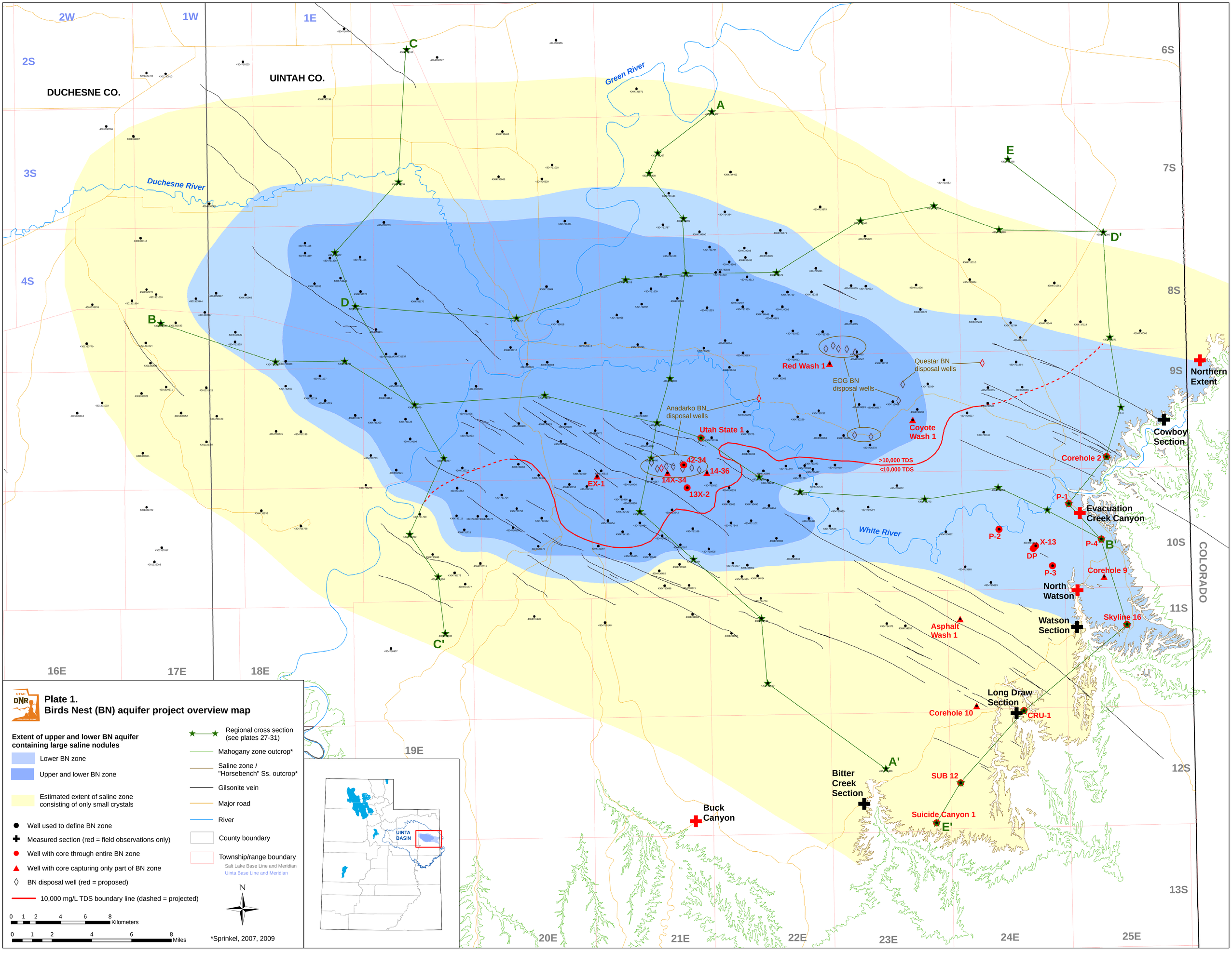


Plate 1.
Birds Nest (BN) aquifer project overview map

Extent of upper and lower BN aquifer containing large saline nodules

- Lower BN zone
- Upper and lower BN zone
- Estimated extent of saline zone consisting of only small crystals

- Well used to define BN zone
- Measured section (red = field observations only)
- Well with core through entire BN zone
- Well with core capturing only part of BN zone
- BN disposal well (red = proposed)
- 10,000 mg/L TDS boundary line (dashed = projected)

- Regional cross section (see plates 27-31)
- Mahogany zone outcrop*
- Saline zone / "Horsebench" Ss. outcrop*
- Gilsonite vein
- Major road
- River
- County boundary
- Township/range boundary

Salt Lake Base Line and Meridian
Uinta Base Line and Meridian

N

0 1 2 4 6 8 Kilometers

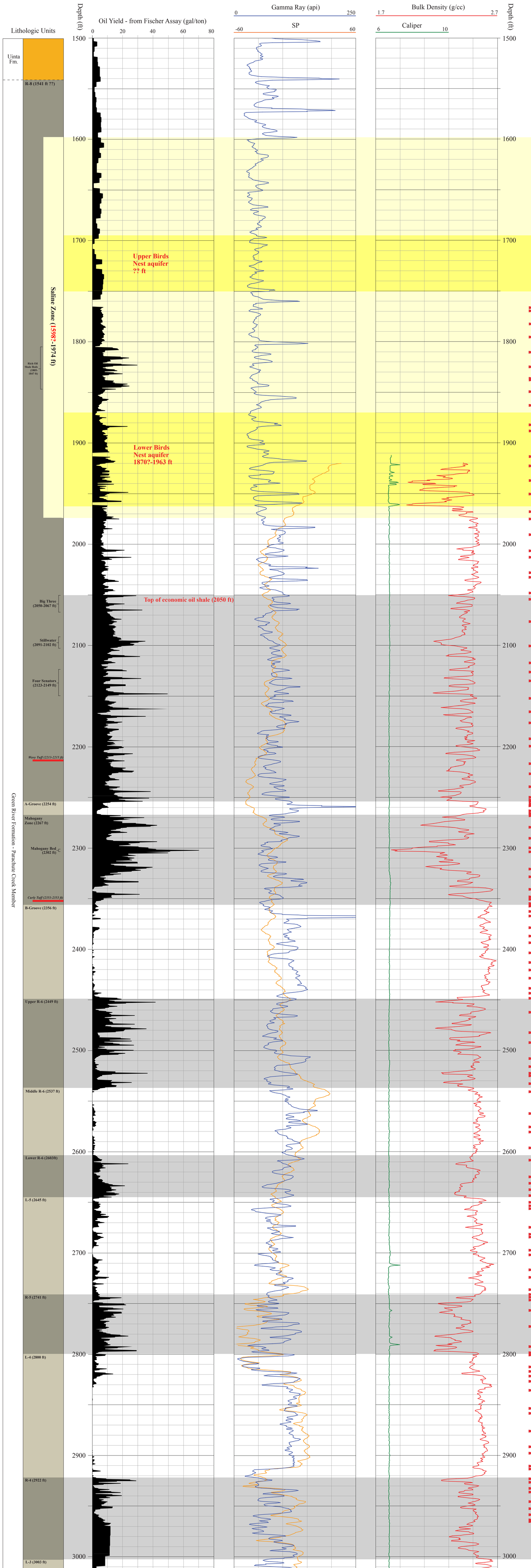
0 1 2 4 6 8 Miles

*Sprinkel, 2007, 2009

Plate 2.

EX-1 core log.

Well name: EX-1 (U043)
Operator: Western Oil Shale Corp.
Location: Section 36, T. 9 S., R. 20 E., SLBLM
UTM E 618562, UTM N 4427091 (NAD 83)
Ground elevation: 4941 ft
Year drilled: 1969
Cored interval: 1764 - 2966 ft (slabbed)
Core location: UGS and USGS Core Research Centers



Core Log Explanation

- Calcareous mudstone - slightly dolomitic
- Siltstone / very fine sandstone - often bitumen stained
- Clay-rich mudstone - slightly calcareous/dolomitic
- Dolomitic mudstone - slightly clay-rich
- Nahcolite bed ($NaHCO_3$)
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Sample analyzed with XRF
- Nahcolite nodule
- Small shortite/nahcolite crystals
- Pyrite/ Marcasite/ Pyrrhotite crystals
- Flat/planar lamination
- Low angle lamination
- Wavy lamination
- Ripples
- Soft sediment deformation/ convolute bedding
- Dewatering structure
- Load casts
- Burrows/bioturbation
- Worm
- Snail
- Scour with massive fill
- Mudrock intraclast
- Organic-rich interval
- Plant material
- Bone fragments
- Lithophypoderma sp. (botfly larvae)
- Gar fish scales
- Shell debris
- Algal influenced lamination
- Stylolites
- Near-vertical fracture - often bitumen filled
- Insects

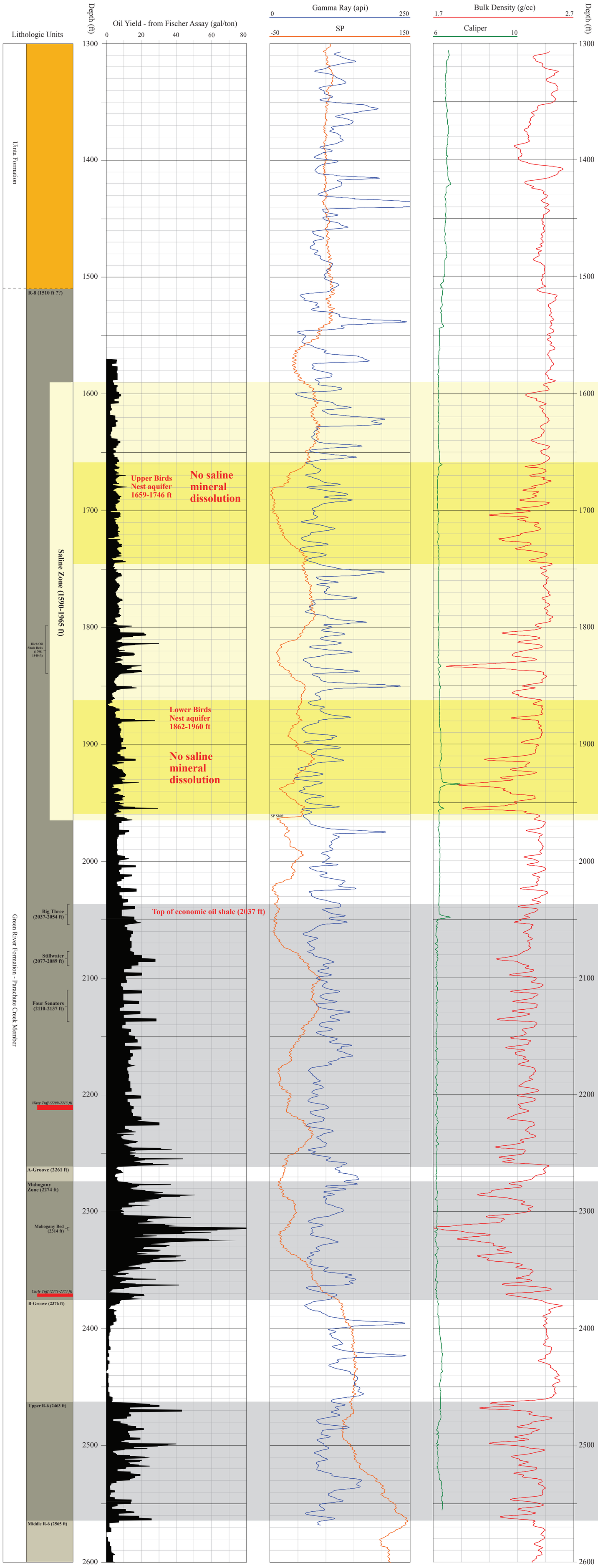
Core Log

clay | silt | sand (vf, f, m, c)

Plate 3.

Utah State 1 core log.

Well name: Utah State 1 (U102)
Operator: Tosco Corp.
Location: Section 26, T. 9 S., R. 21 E., SLBLM
UTM E 626967, UTM N 4430197 (NAD 83)
Ground elevation: 4911 ft
Year drilled: 1974
Cored interval: 1570 - 2600 ft (slabbed)
Core location: Utah Core Research Center



Core Log Explanation

- Calcareous mudstone - slightly dolomitic
- Siltstone / very fine sandstone - often bitumen stained
- Clay-rich mudrock - slightly calcareous/dolomitic
- Dolomitic mud/siltstone - slightly calcareous
- Nahcolite bed ($NaHCO_3$)
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Sample analyzed with XRF
- Nahcolite nodule
- Small shortite/nahcolite crystals
- Thin nahcolite/shortite layers
- Pyrite/ Marcasite/ Pyrrhotite crystals
- Flat/planar lamination
- Low angle lamination
- Wavy lamination
- Ripples
- Soft sediment deformation/ convolute bedding
- Dewatering structure
- Load casts
- Synaeresis cracks
- Mudcracks
- Burrows/bioturbation
- Worm
- Snail
- Scour with massive fill
- Bitumen concentrations
- Mudrock intraclast
- Organic detritus
- Organic-rich interval
- Plant material
- Bone fragments
- Lithophypoderma sp. (botfly larvae)
- Gar fish scales
- Shell debris
- Algal influenced lamination
- Insects
- Stylolites
- Near-vertical fracture - often bitumen filled
- Microfaulting

Core Log

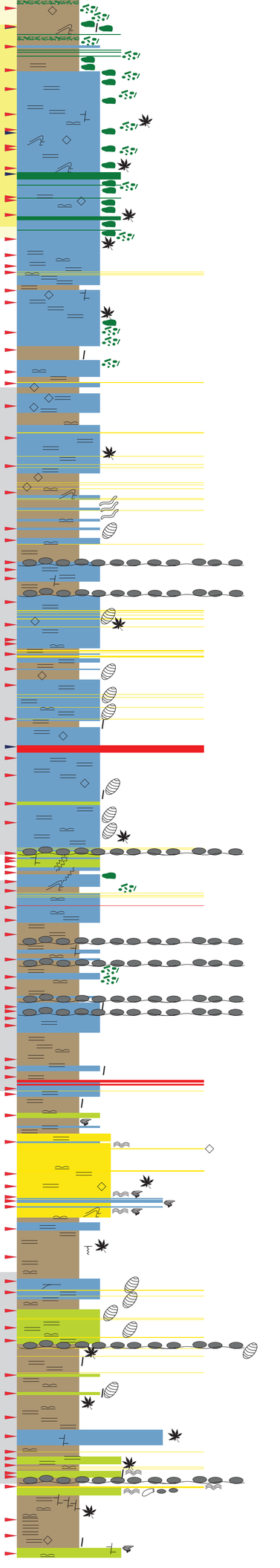


Plate 4.
Utah State 42-34 core log.

Well name: Utah State 42-34 (U113)
Operator: Tosco Corp.
Location: Section 34, T. 9 S., R. 21 E., SLBLM
UTM E 625568, UTM N 4428012 (NAD 83)
Ground elevation: 5030 ft
Year drilled: 1981
Cored interval: 14-2683 ft (1550-1900 ft slabbed)
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

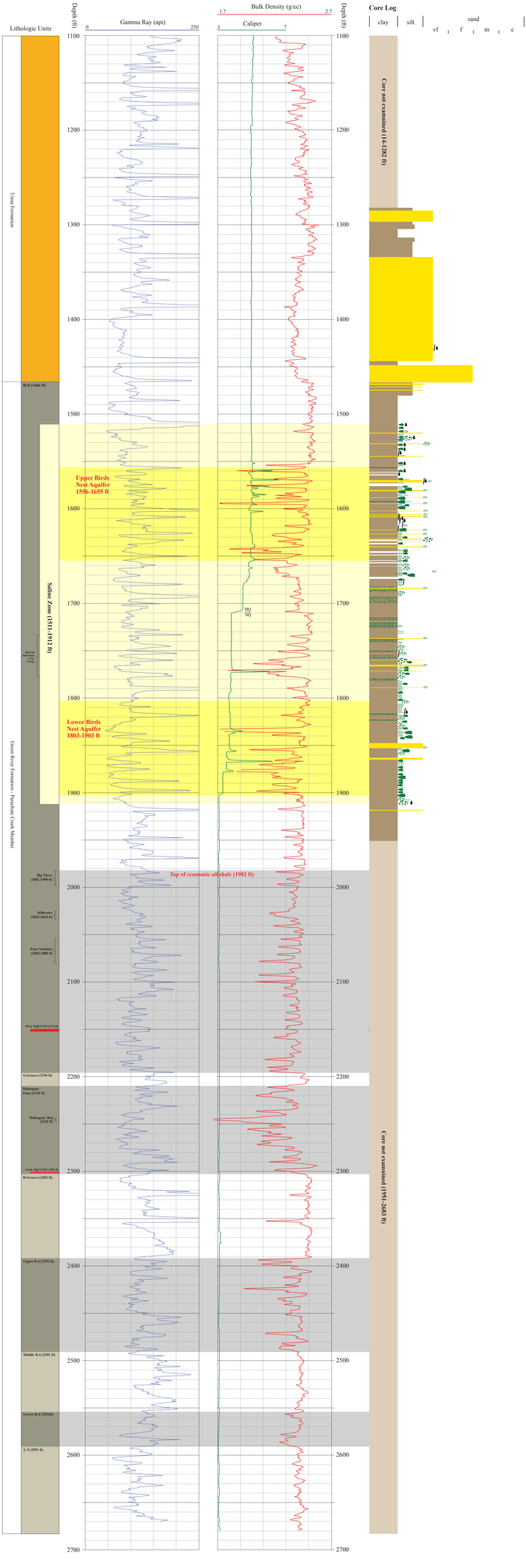


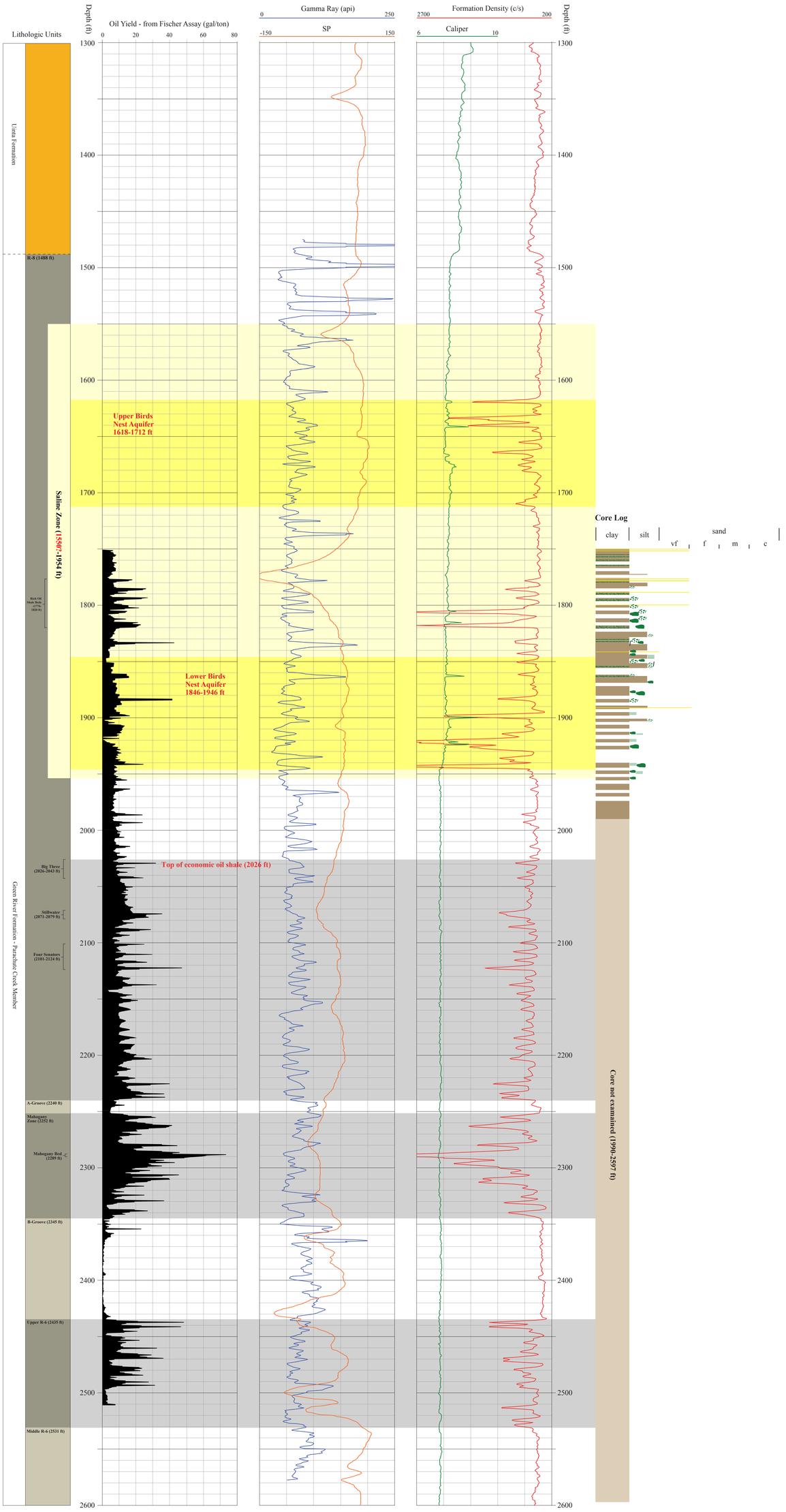
Plate 5.

14X-34 core log.

Well name: 14X-34 (U110)
Operator: Shell Oil Co.
Location: Section 34, T. 9 S., R. 21 E., SLBLM
UTM E 624255, UTM N 4427363 (NAD 83)
Ground elevation: 5047 ft
Year drilled: 1964
Cored interval: 1750-2597 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture



Core Log

Plate 6.
14-36 core log.

Well name: 14-36 (U108)
Operator: Shell Oil Co.
Location: Section 36, T. 9 S., R. 21 E., SLBLM
UTM E 627444, UTM N 4427386 (NAD 83)
Ground elevation: 5100 ft
Year drilled: 1964
Cored interval: 1850-2508 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

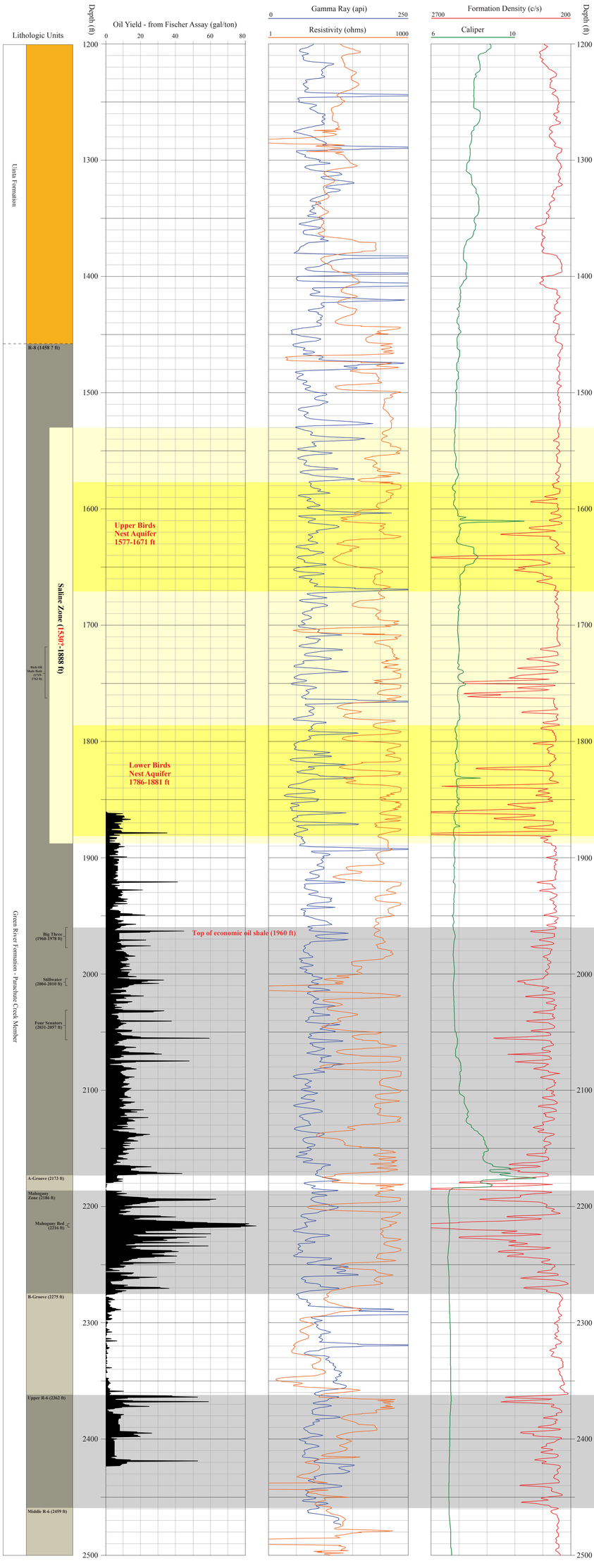


Plate 7.
Utah State 13X-2 core log.

Well name: Utah State 13X-2 (U112)
Operator: Tosco Corp.
Location: Section 2, T. 10 S., R. 21 E., SLBLM
UTM E 625850, UTM N 4426165 (NAD 83)
Ground elevation: 5064 ft
Year drilled: 1977
Cored interval: 120-2191 ft (1200-2191 ft slabbed)
Core location: UGS and USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

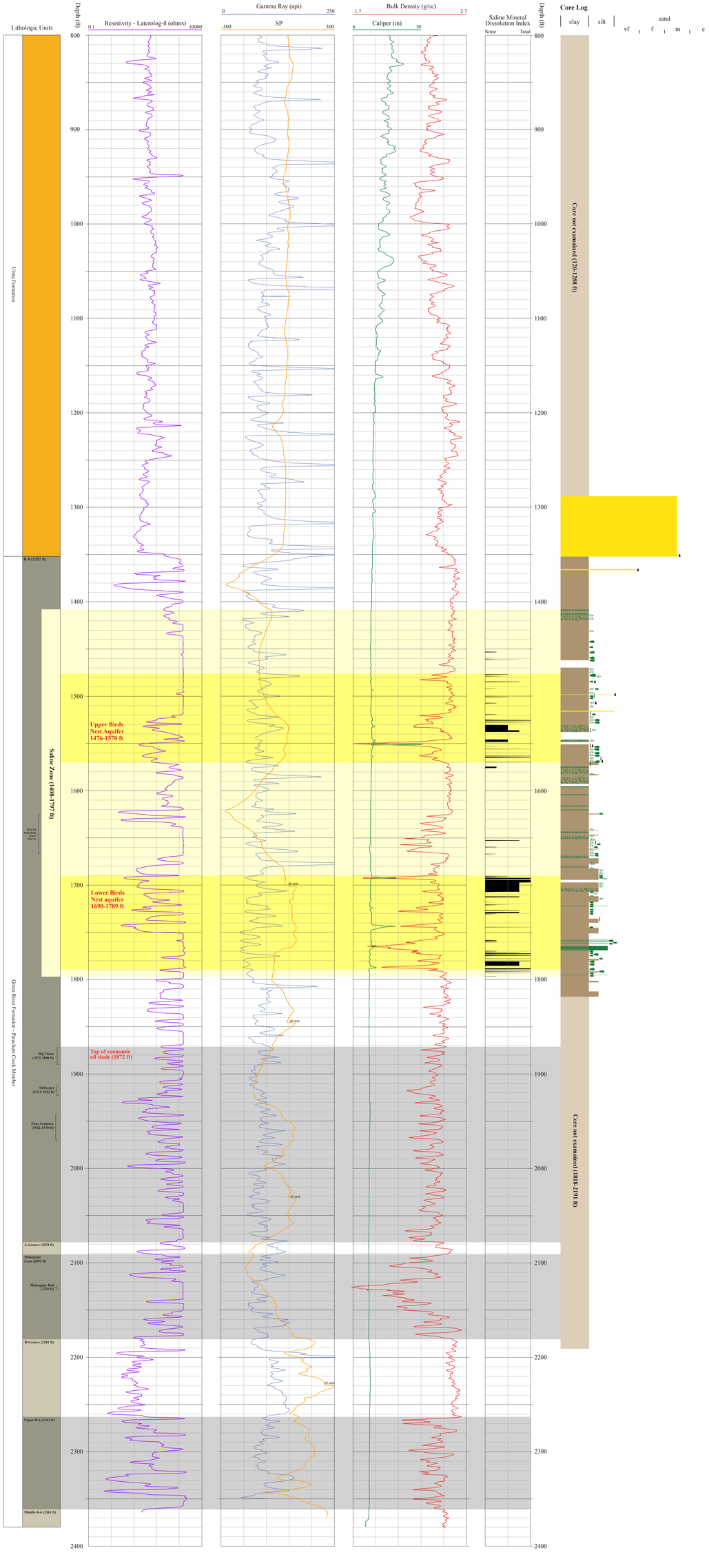


Plate 8.

Red Wash 1 core log.

Well name: Red Wash 1 (U045)
Operator: USGS
Location: Section 1, T. 9 S., R. 22 E., SLBLM
UTM E 637362, UTM N 4436212 (NAD 83)
Ground elevation: 4810 ft
Year drilled: 1981
Cored interval: 2160-2970 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

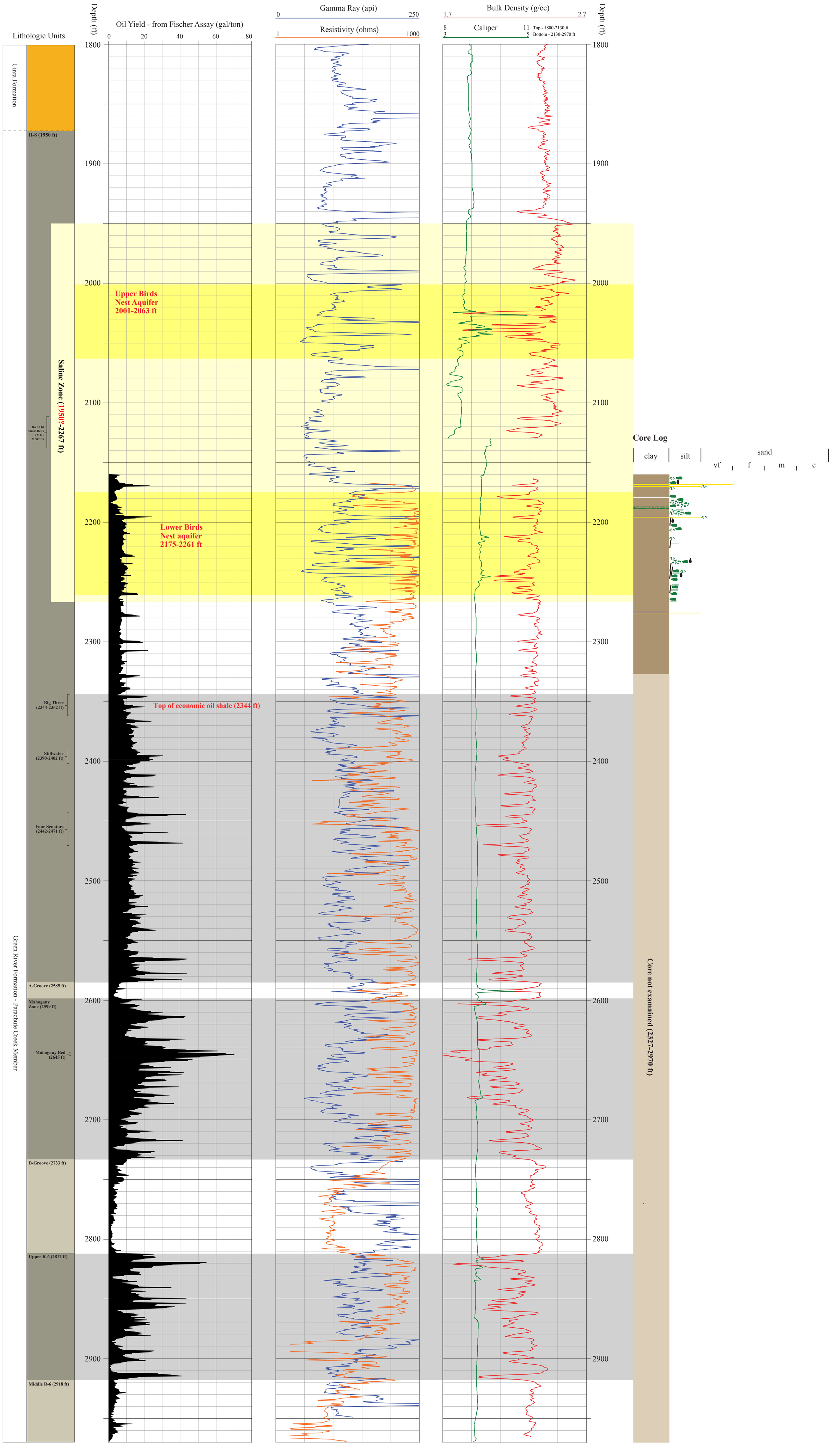
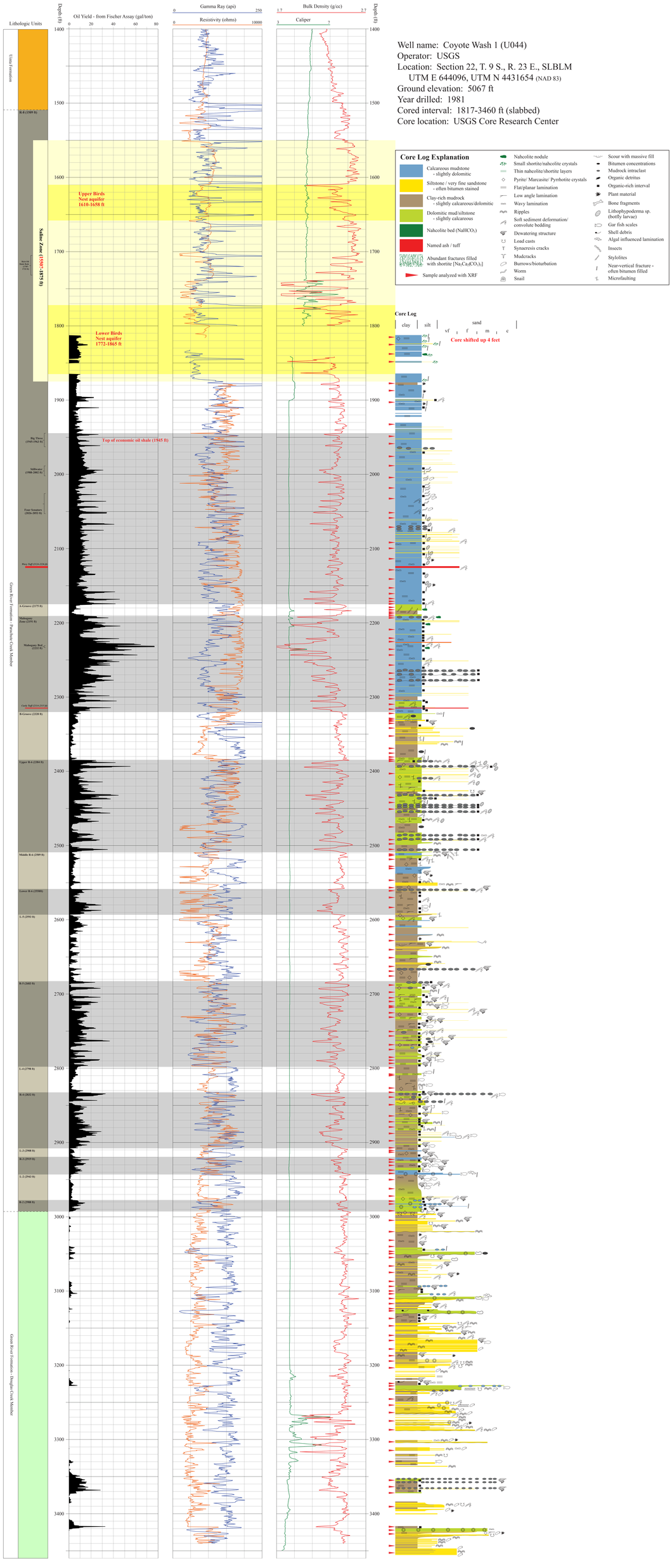


Plate 9.
Coyote Wash 1 core log.



Well name: Coyote Wash 1 (U044)
Operator: USGS
Location: Section 22, T. 9 S., R. 23 E., SLBLM
UTM E 644096, UTM N 4431654 (NAD 83)
Ground elevation: 5067 ft
Year drilled: 1981
Cored interval: 1817-3460 ft (slabbed)
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous mudstone - slightly dolomitic
- Siltstone / very fine sandstone - often bitumen stained
- Clay-rich mudrock - slightly calcareous/dolomitic
- Dolomitic mud/siltstone - slightly calcareous
- Nahcolite bed ($NaHCO_3$)
- Named ash / tuff
- Abundant fractures filled with shortite ($Na_2Ca_2(CO_3)_3$)
- Sample analyzed with XRF

- Nahcolite nodule
- Small shortite/nahcolite crystals
- Thin nahcolite/shortite layers
- Pyrite/ Marcasite/ Pyrrhotite crystals
- Flat/planar lamination
- Low angle lamination
- Wavy lamination
- Ripples
- Soft sediment deformation/ convolute bedding
- Dewatering structure
- Load casts
- Synaeresis cracks
- Mudcracks
- Burrows/bioturbation
- Worm
- Snail
- Scour with massive fill
- Bitumen concentrations
- Mudrock intraclast
- Organic detritus
- Organic-rich interval
- Plant material
- Bone fragments
- Lithophypoderma sp. (bottly larvae)
- Gar fish scales
- Shell debris
- Algal influenced lamination
- Insects
- Stylolites
- Near-vertical fracture - often bitumen filled
- Microfaulting

Plate 10.
Corehole 2 core log.

Well name: Corehole 2 (U028)
Operator: National Farmer's Union
Location: Section 32, T. 9 S., R. 25 E., SLBLM
UTM E 659784, UTM N 4428684 (NAD 83)
Ground elevation: 5507 ft
Year drilled: 1958
Cored interval: 30-560 ft (slabbed)
Core location: Utah Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

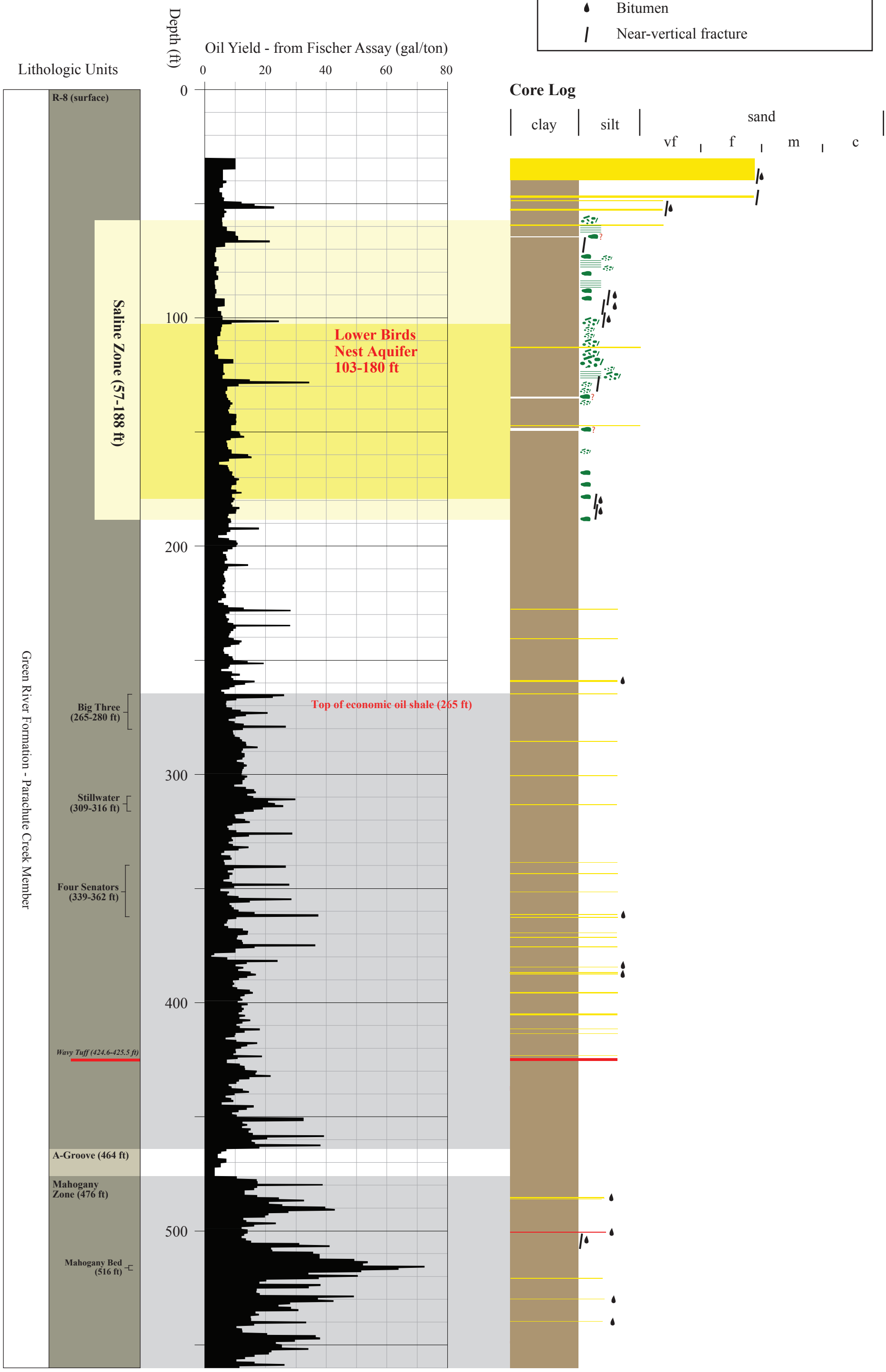


Plate 11.
P-1 core log.

Well name: P-1 (U056)
Operator: White River Shale Co.
Location: Section 12, T. 10 S., R. 24 E., SLBLM
UTM E 656732, UTM N 4424894 (NAD 83)
Ground elevation: 5284 ft
Year drilled: 1974
Cored interval: 74-1240 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

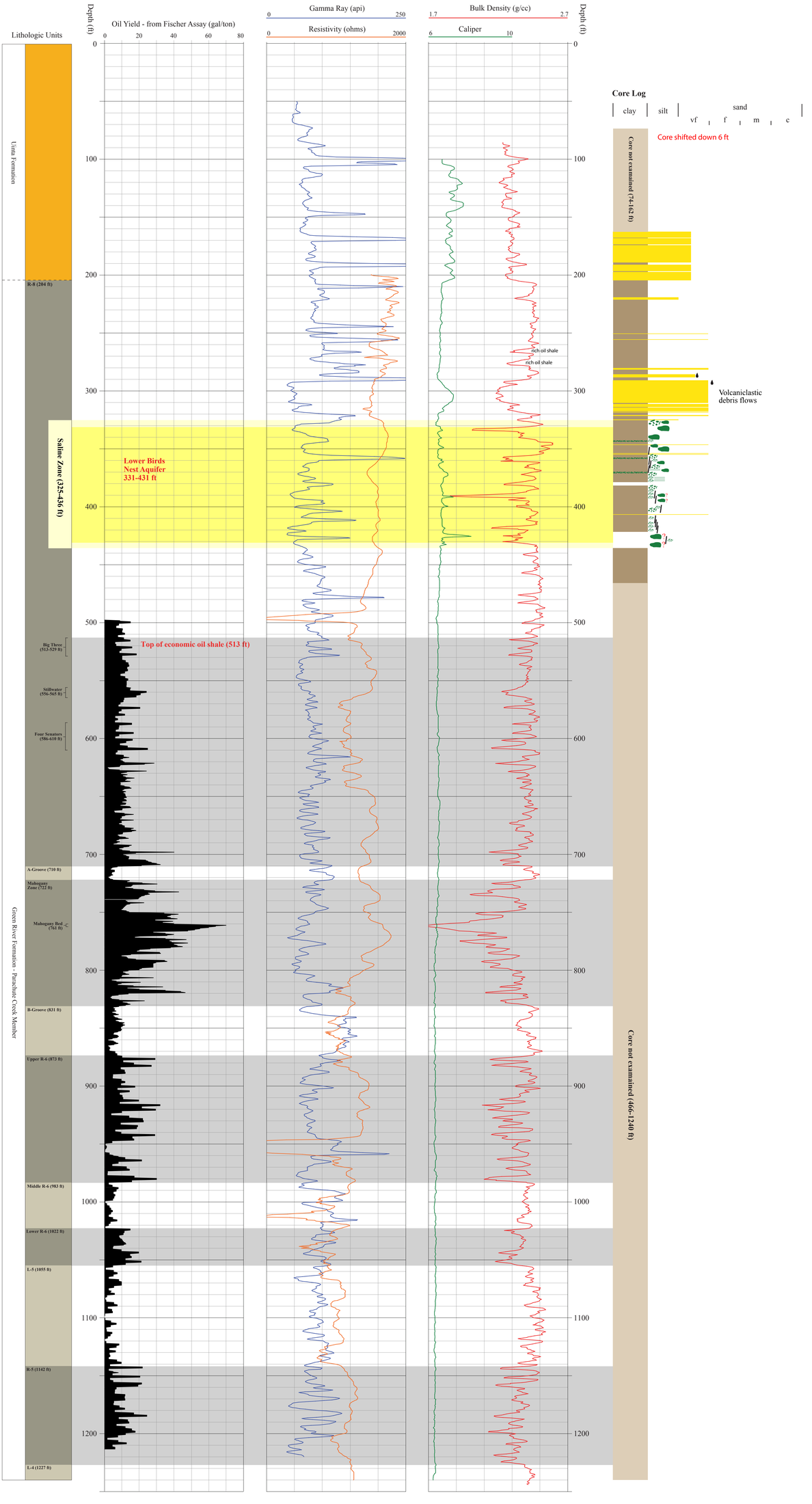


Plate 12.
P-2 core log.

Well name: P-2 (U057)
Operator: White River Shale Co.
Location: Section 17, T. 10 S., R. 24 E., SLBLM
UTM E 651084, UTM N 4422804 (NAD 83)
Ground elevation: 4991 ft
Year drilled: 1974
Cored interval: 94-1292 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

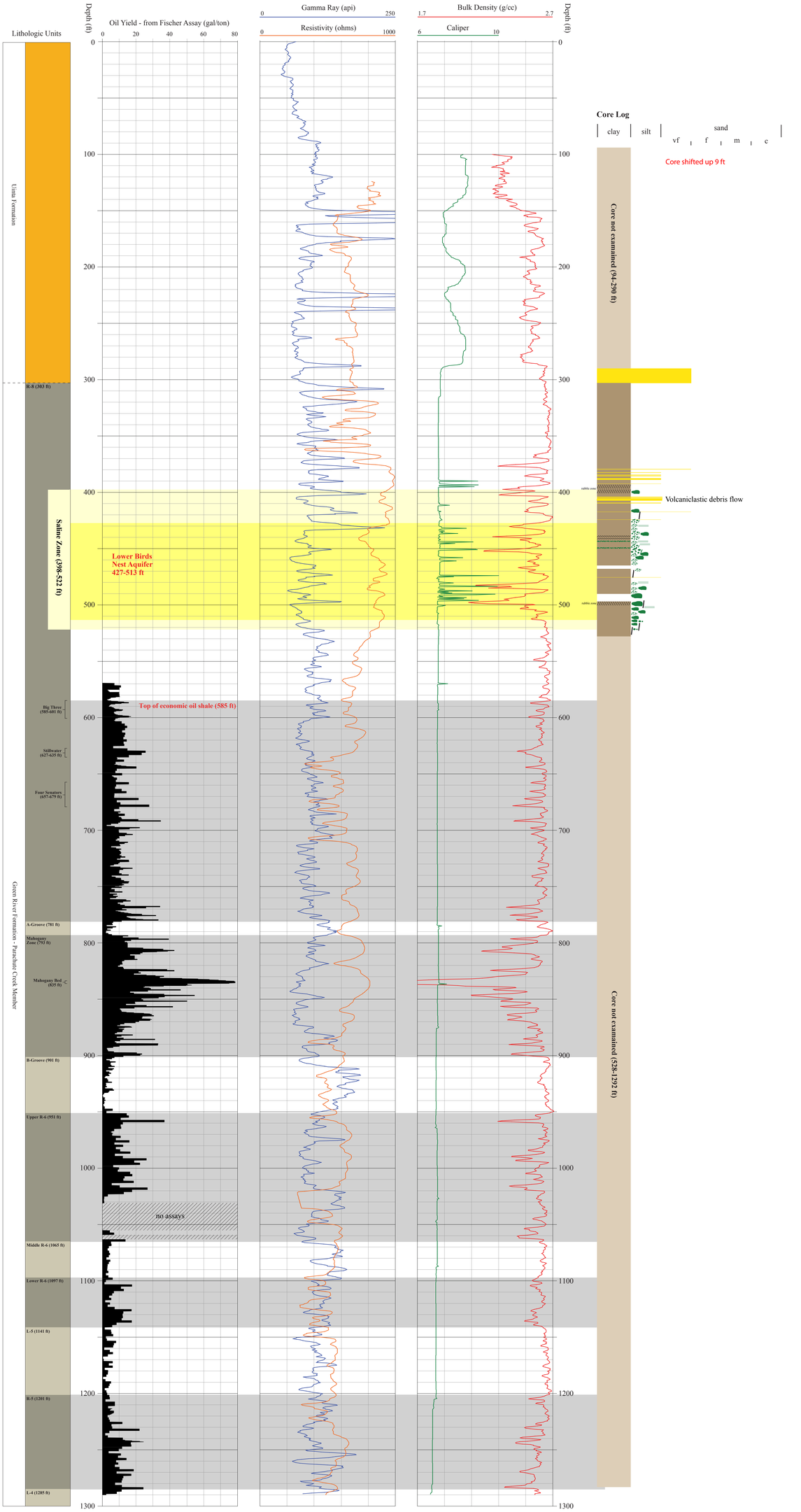


Plate 13.
X-13 core log.

Well name: X-13 (U130)
Operator: White River Shale Co.
Location: Section 22, T. 10 S., R. 24 E., SLBLM
UTM E 654044, UTM N 4421465 (NAD 83)
Ground elevation: 5484 ft
Year drilled: 1976
Cored interval: 13-1125 ft
Core location: USGS Core Research Center

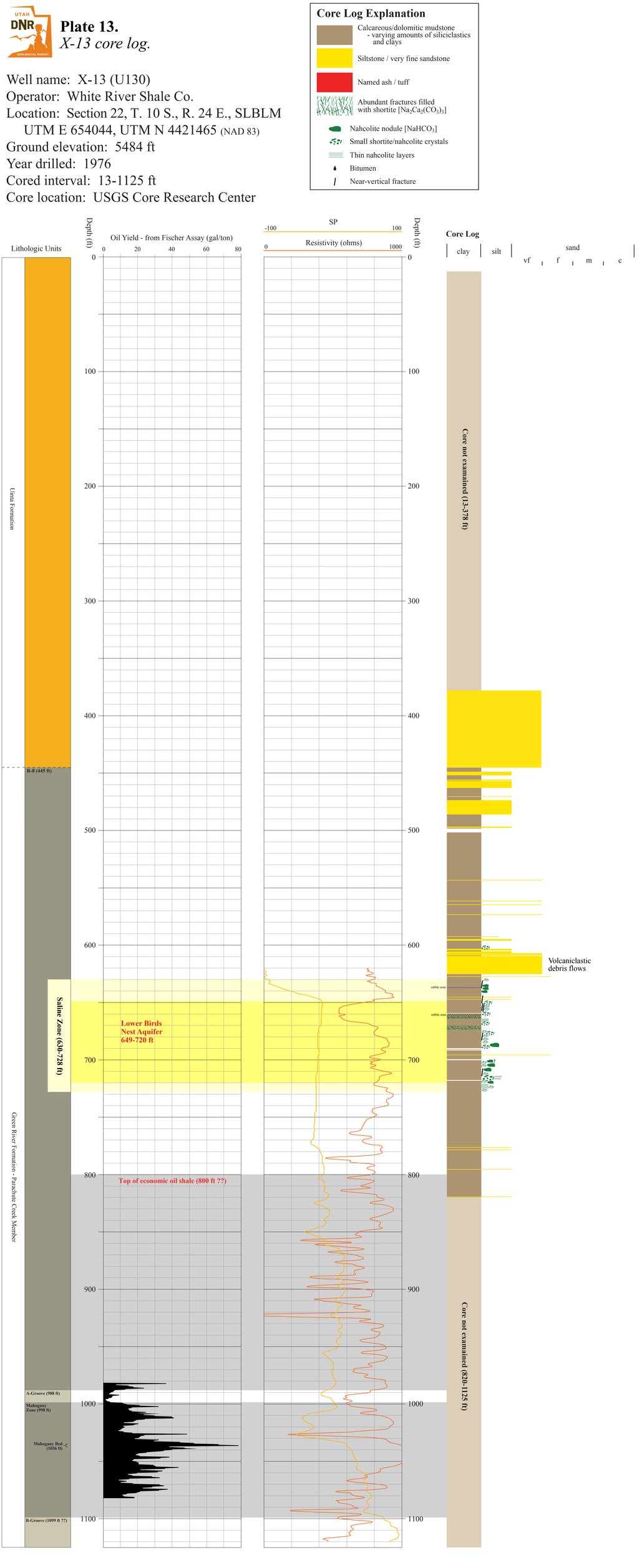


Plate 14.
P-3 core log.

Well name: P-3 (U058)
Operator: White River Shale Co.
Location: Section 26, T. 10 S., R. 24 E., SLBLM
UTM E 655414, UTM N 4421465 (NAD 83)
Ground elevation: 5490 ft
Year drilled: 1974
Cored interval: 70-1220 ft
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

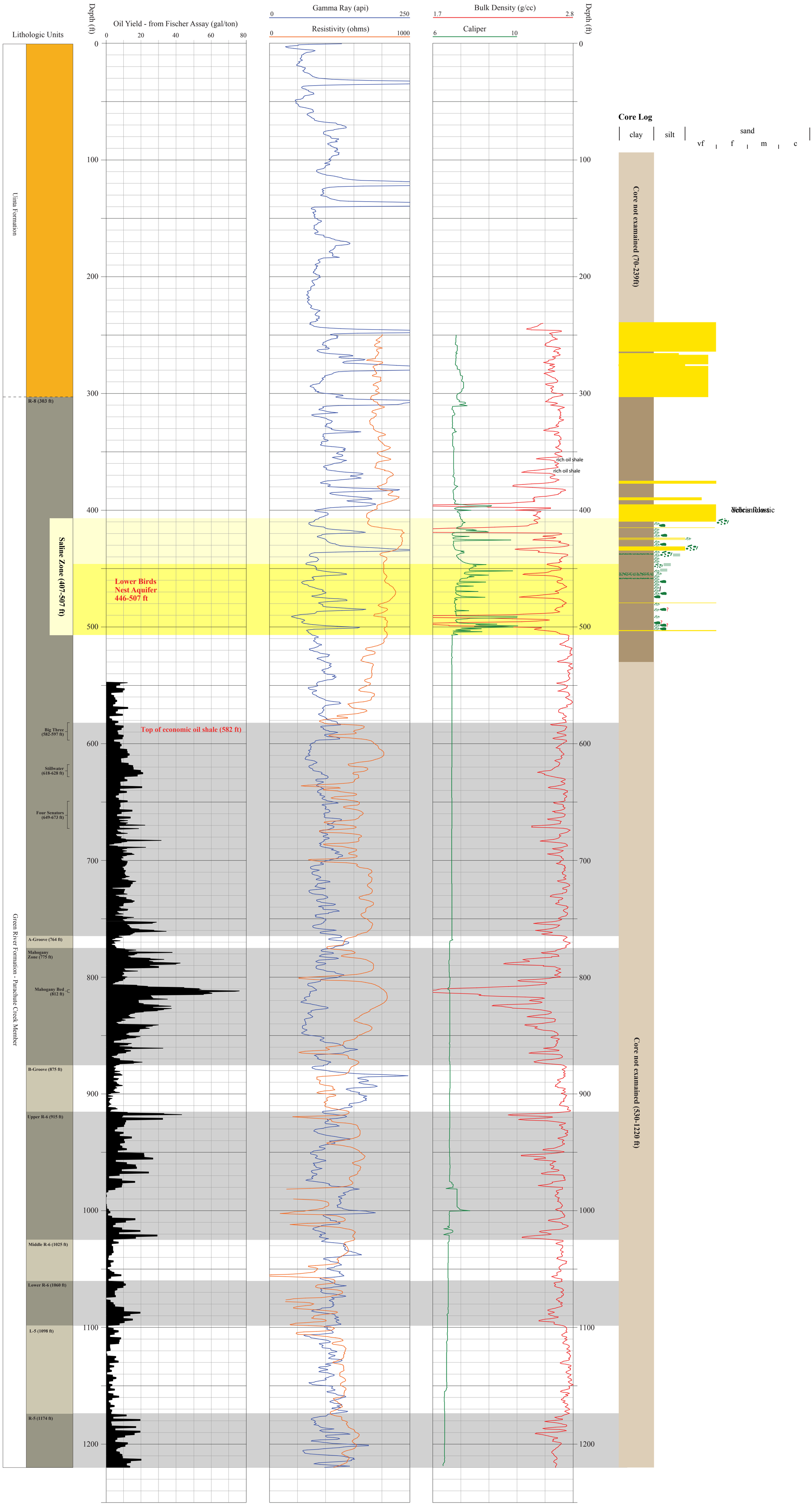
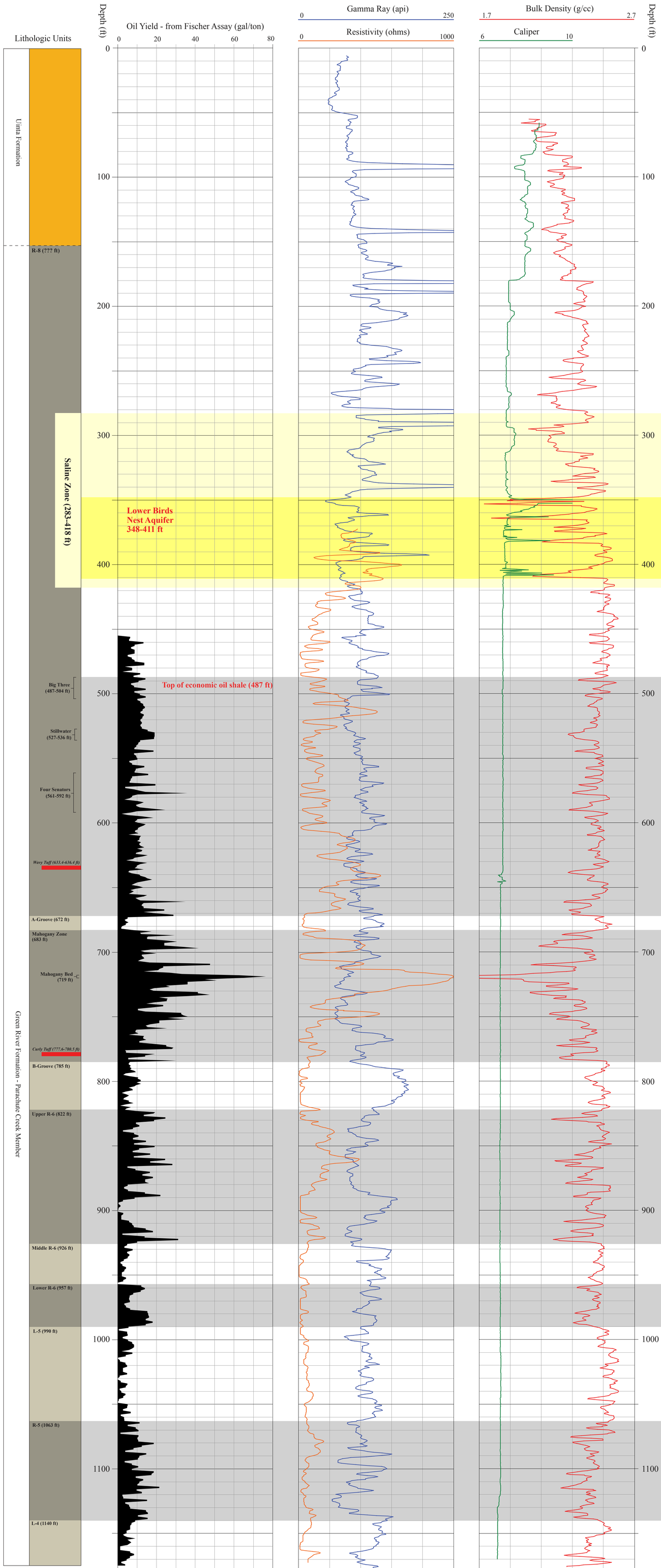


Plate 15.
P-4 core log.

Well name: P-4 (U059)
Operator: White River Shale Project
Location: Section 19, T. 10 S., R. 25 E., SLBLM
UTM E 659365, UTM N 4418979 (NAD 83)

Ground elevation: 5719 ft
Year drilled: 1974
Core location: Utah Core Research Center



Core Log Explanation

- Calcareous mudstone - slightly dolomitic
- Siltstone / very fine sandstone - often bitumen stained
- Clay-rich mudrock - slightly calcareous/dolomitic
- Dolomitic mud/siltstone - slightly calcareous
- Nahcolite bed ($NaHCO_3$)
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Sample analyzed with XRF

- Nahcolite nodule
- Small shortite/nahcolite crystals
- Thin nahcolite/shortite layers
- Pyrite/ Marcasite/ Pyrrhotite crystals
- Flat/planar lamination
- Low angle lamination
- Wavy lamination
- Ripples
- Soft sediment deformation/ convolute bedding
- Dewatering structure
- Load casts
- Synaeresis cracks
- Mudcracks
- Burrows/bioturbation
- Worm
- Snail

- Scour with massive fill
- Bitumen concentrations
- Mudrock intraclast
- Organic detritus
- Organic-rich interval
- Plant material
- Bone fragments
- Lithophypoderma sp. (botfly larvae)
- Gar fish scales
- Shell debris
- Algal influenced lamination
- Insects
- Stylolites
- Near-vertical fracture - often bitumen filled
- Microfaulting

Core Log

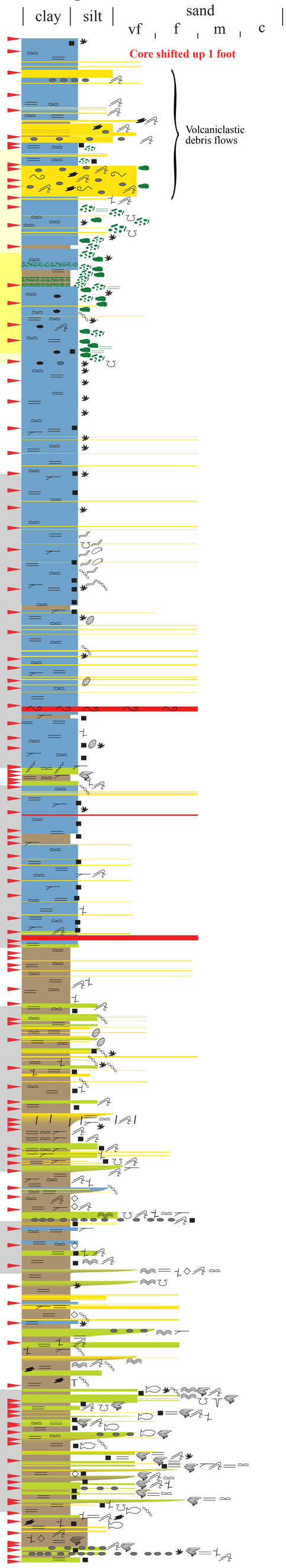


Plate 16.
Corehole 9 core log.

Well name: Corehole 9 (U029)
Operator: National Farmer's Union
Location: Section 32, T. 10 S., R. 25 E., SLBLM
UTM E 659586, UTM N 4418979 (NAD 83)
Ground elevation: 5746 ft
Year drilled: 1959
Cored interval: 240-1123 ft (slabbed)
Core location: Utah Core Research Center

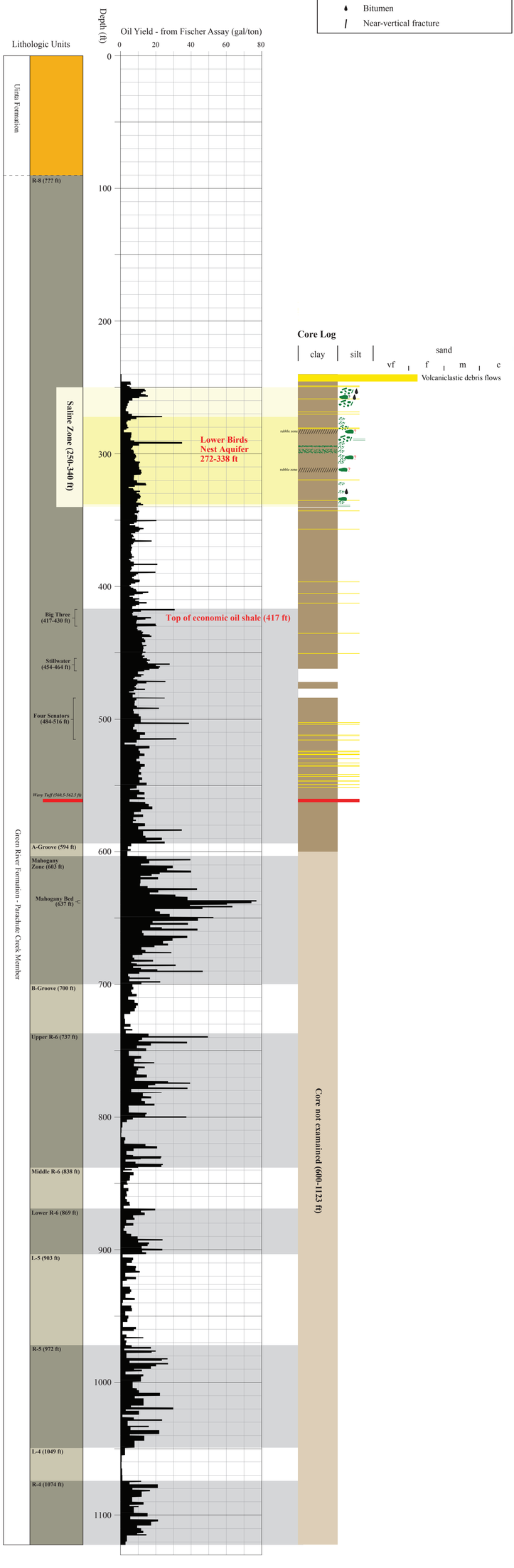


Plate 17.
Skyline 16 core log.

Well name: Skyline 16
Operator: UGS - University of Utah
Location: Section 10, T. 11 S., R. 25 E., SLBLM
UTM E 661445, UTM N 4415109 (NAD 83)
Ground elevation: 6014 ft
Year drilled: 2010
Cored interval: 20-1006 ft (slabbed)
Core location: Utah Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

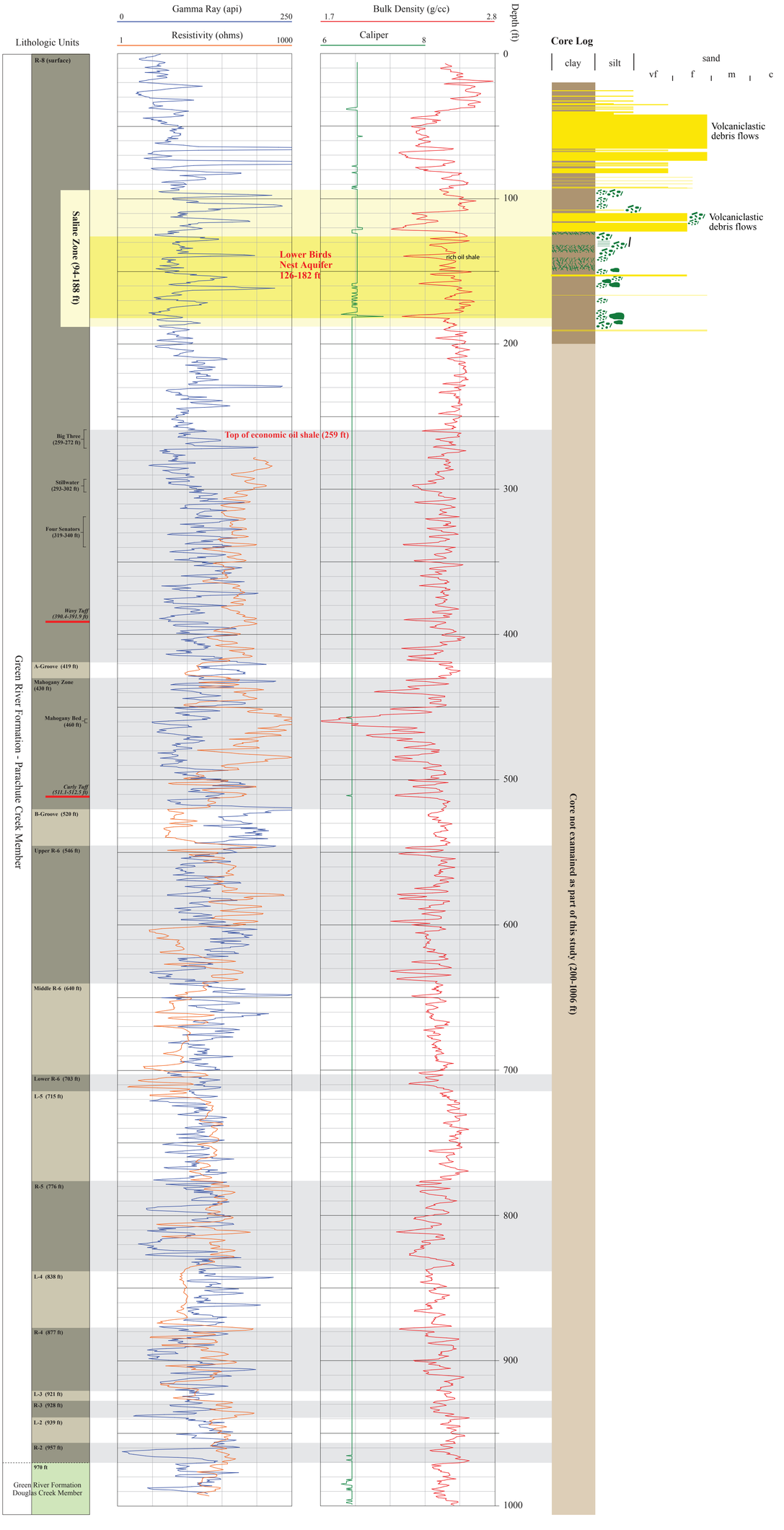


Plate 18.
Asphalt Wash 1 core log.

Well name: Asphalt Wash 1 (U086)
Operator: USGS
Location: Section 7, T. 11 S., R. 24 E., SLBLM
UTM E 647934, UTM N 4415544 (NAD 83)
Ground elevation: 5250 ft
Year drilled: 1976
Cored interval: 307-1364, 2007-2088 ft (slabbed)
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

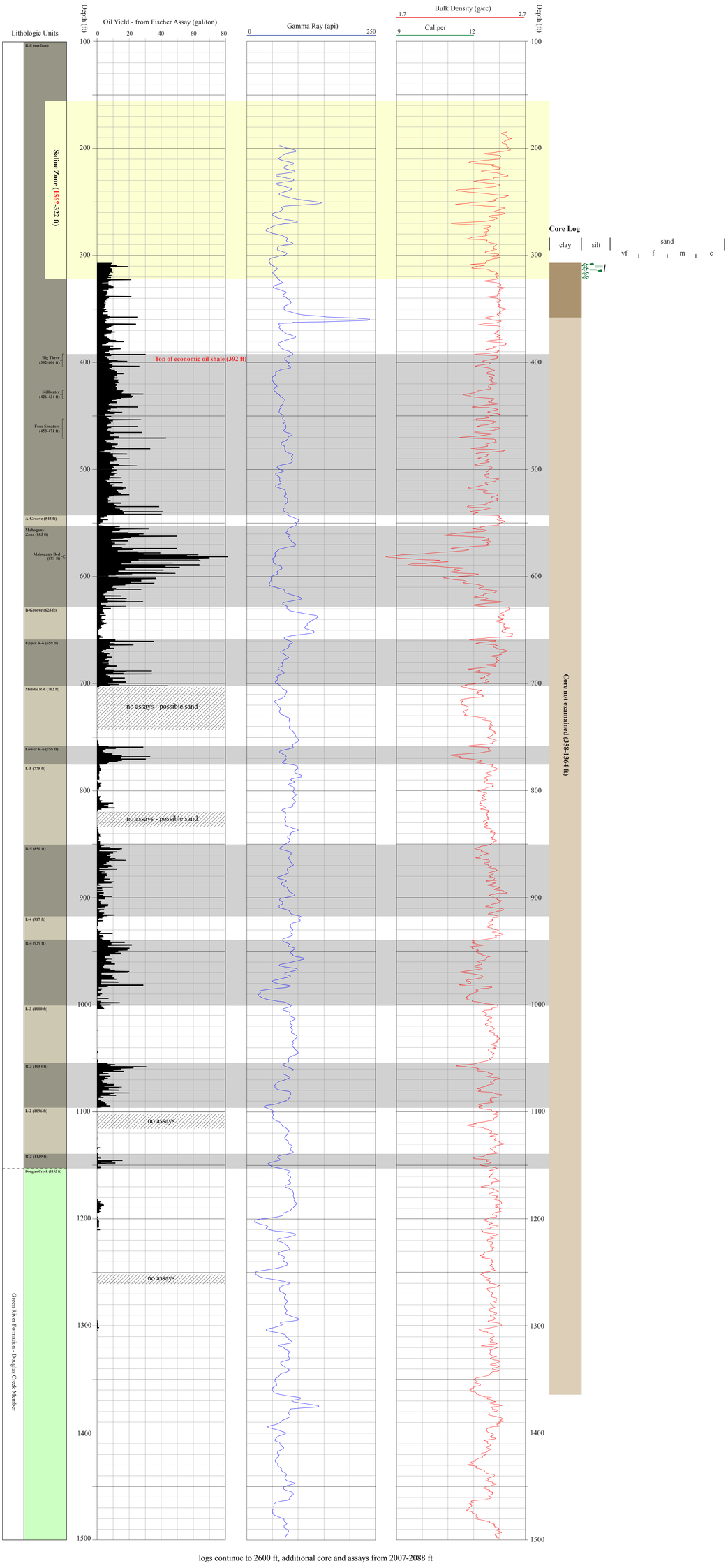
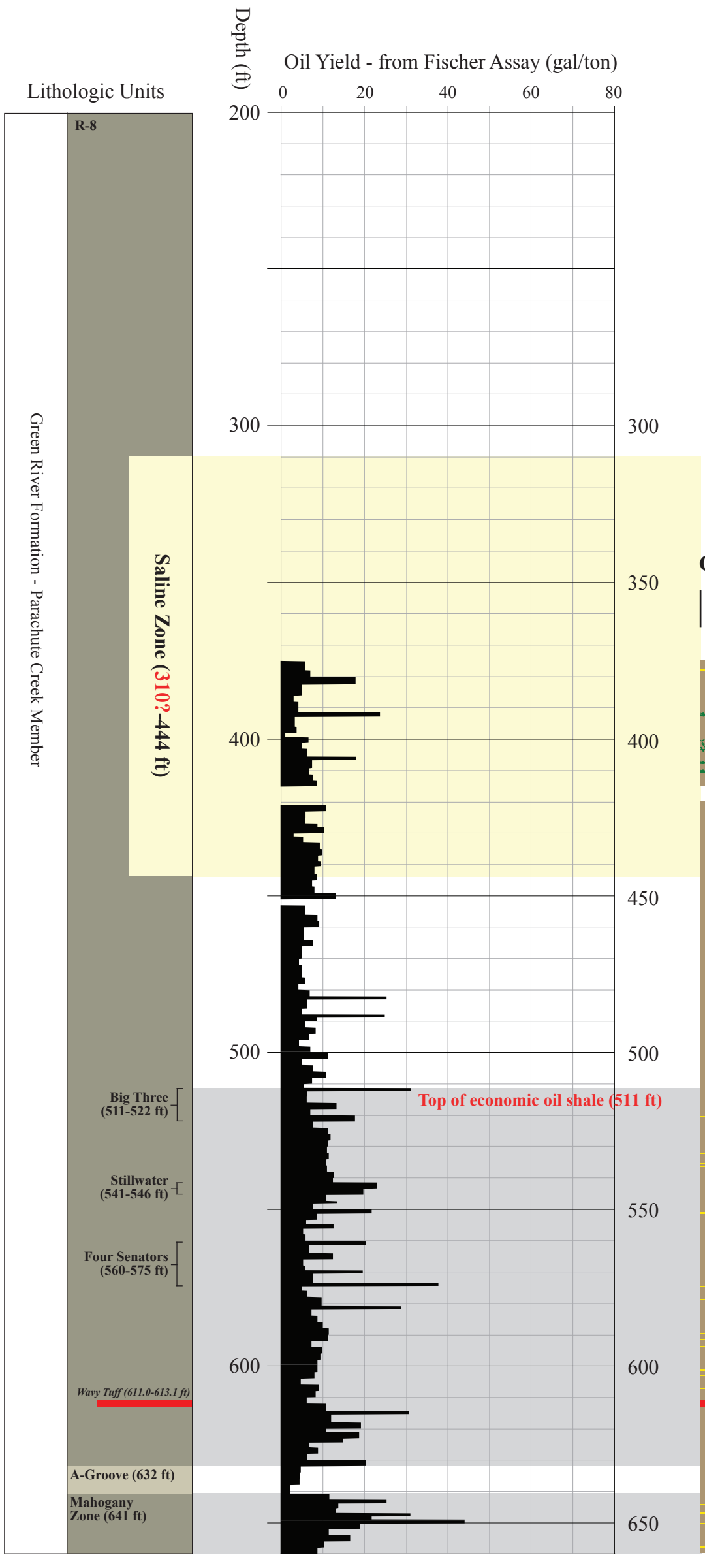


Plate 19.
Corehole 10 core log.

Well name: Corehole 10 (U124)
Operator: National Farmer's Union
Location: Section 32, T. 11 S., R. 24 E., SLBLM
UTM E 649269, UTM N 4408511 (NAD 83)
Ground elevation: 6215 ft
Year drilled: 1960
Cored interval: 375-660 ft (slabbed)
Core location: Utah Core Research Center



Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

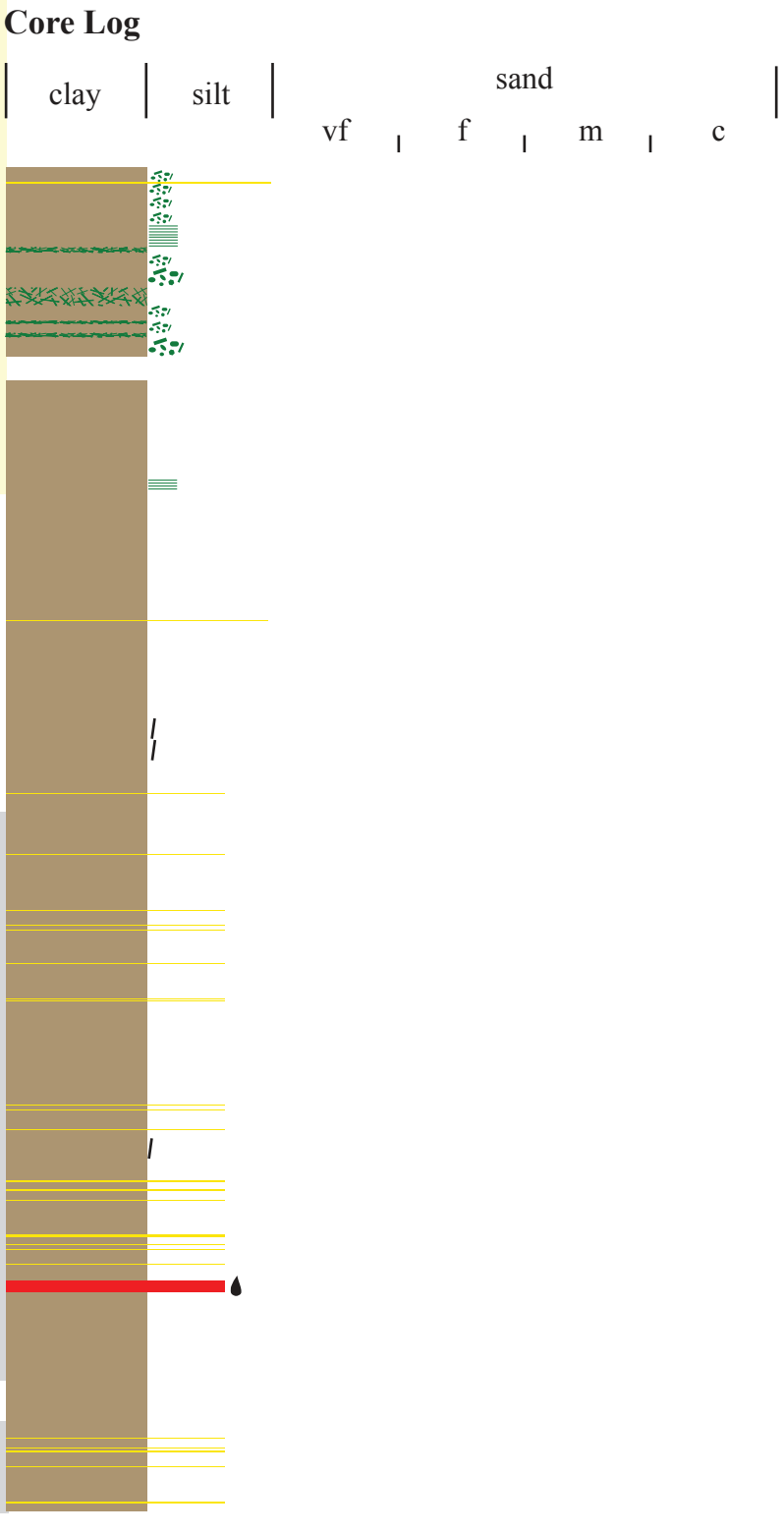


Plate 20.

Suicide Canyon 1 core log.

Well name: Suicide Canyon 1 (U087)
Operator: Arco
Location: Section 36, T. 12 S., R. 23 E., SLBLM
UTM E 646039, UTM N 4399044 (NAD 83)
Ground Elevation: 6362 ft
Year drilled: 1965
Cored interval: 104-576 ft (slabbed)
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

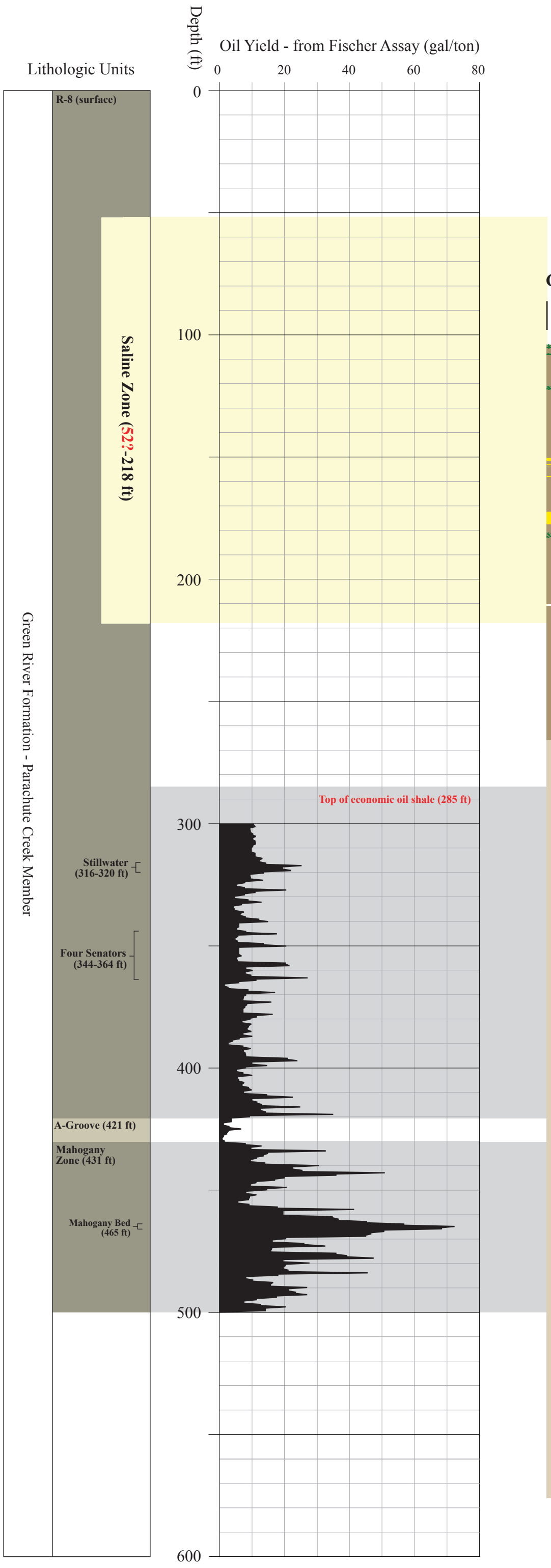


Plate 21.
CRU-1 core log.

Well name: CRU-1 (U055)
Operator: USGS
Location: Section 3, T. 12 S., R. 24 E., SLBLM
UTM E 653097, UTM N 4408125 (NAD 83)
Ground Elevation: 6137 ft
Year drilled: 1976
Cored interval: 14-498 ft (slabbed)
Core location: USGS Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

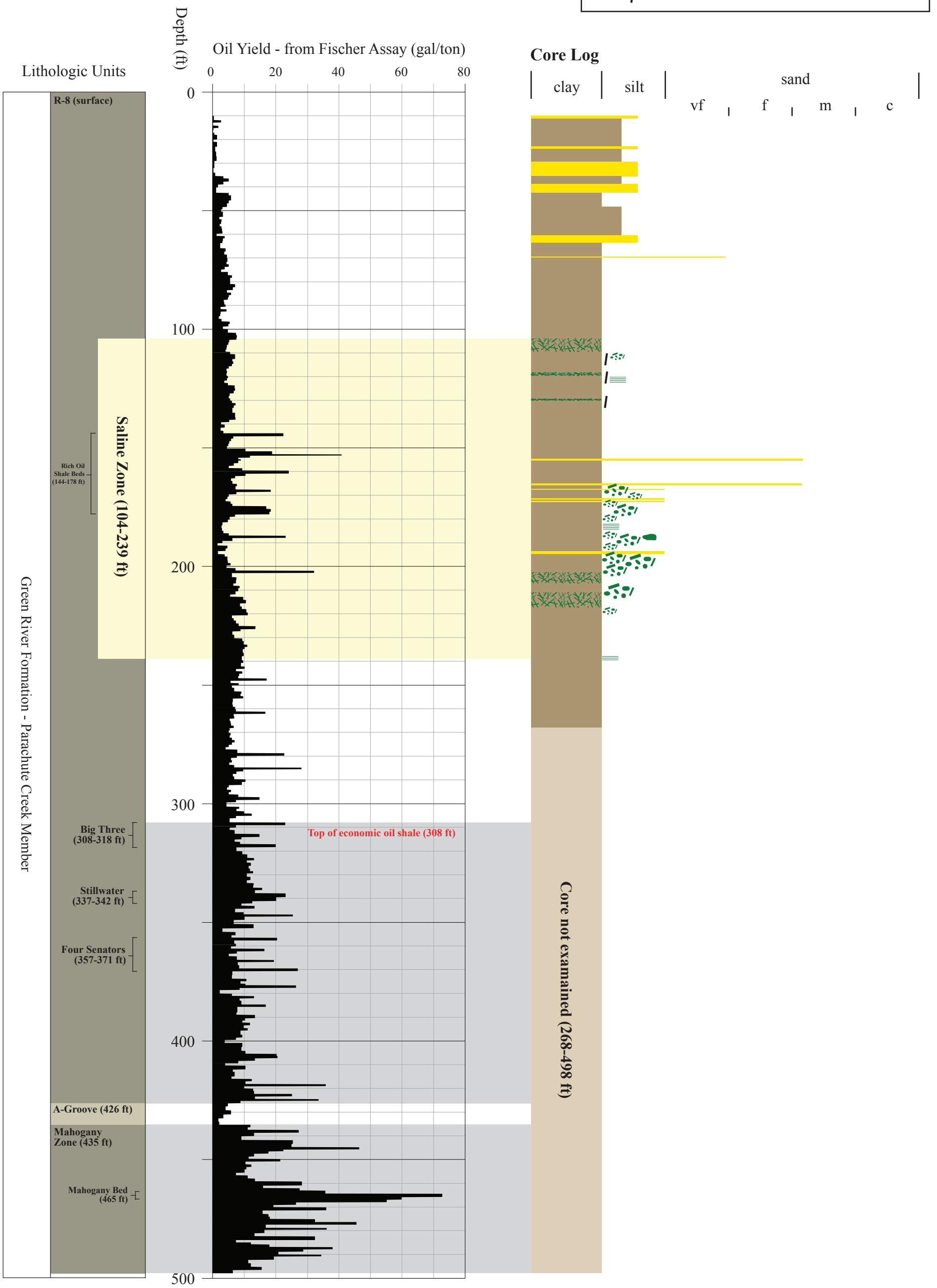


Plate 22.

South Uinta Basin 12 core log.

Well name: S. Uinta Basin 12 (U080)
Operator: U.S. ERDA-LERC
Location: Section 19, T. 12 S., R. 24 E., SLBLM
UTM E 647985, UTM N 4402283 (NAD 83)
Ground elevation: 6261 ft
Year drilled: 1977
Cored interval: 91-621 ft (slabbed)
Core location: Utah Core Research Center

Core Log Explanation

- Calcareous/dolomitic mudstone - varying amounts of siliciclastics and clays
- Siltstone / very fine sandstone
- Named ash / tuff
- Abundant fractures filled with shortite [$Na_2Ca_2(CO_3)_3$]
- Nahcolite nodule [$NaHCO_3$]
- Small shortite/nahcolite crystals
- Thin nahcolite layers
- Bitumen
- Near-vertical fracture

Lithologic Units

R-8 (surface)

Rich Oil Shale Beds (178-205 ft)

Saline Zone (132-270 ft)

Big Three (332-343 ft)

Stillwater (362-366 ft)

Four Senators (382-398 ft)

Wavy Tuff (436.7-438.5 ft)

A-Groove (460 ft)

Mahogany Zone (470 ft)

Mahogany Bed (504 ft)

Curly Tuff ? (548.1-549.3 ft)

B-Groove (551 ft)

Upper R-6 (559 ft)

Deltaic Sands (577 ft)

Green River Formation - Parachute Creek Member

Depth (ft)

Oil Yield - from Fischer Assay (gal/ton)

0 20 40 60 80

0 100 200 300 400 500 600

Top of economic oil shale (332 ft)

Core Log

clay | silt | sand (vf | f | m | c)

Plate 23.
Cowboy measured outcrop section.

Section name: Cowboy
Location: Section 23, T. 9 S., R. 25 E., SLBLM
UTM E 664369, UTM N 4431738 (NAD 83)

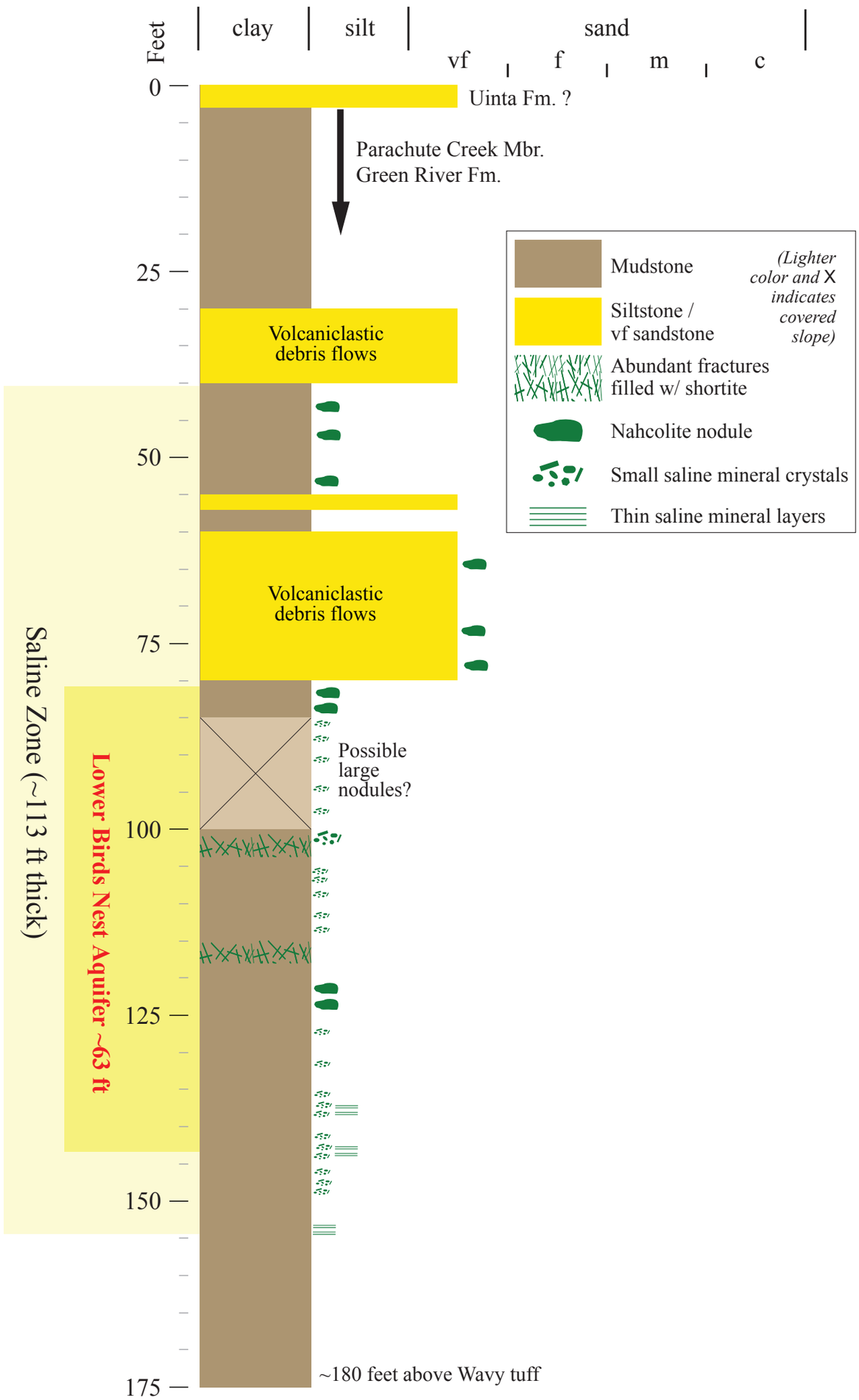


Plate 24.

Watson measured outcrop section.

Section name: Watson

Location: Section 7, T. 11 S., R. 25 E., SLBLM

UTM E 657393, UTM N 4414955 (NAD 83)

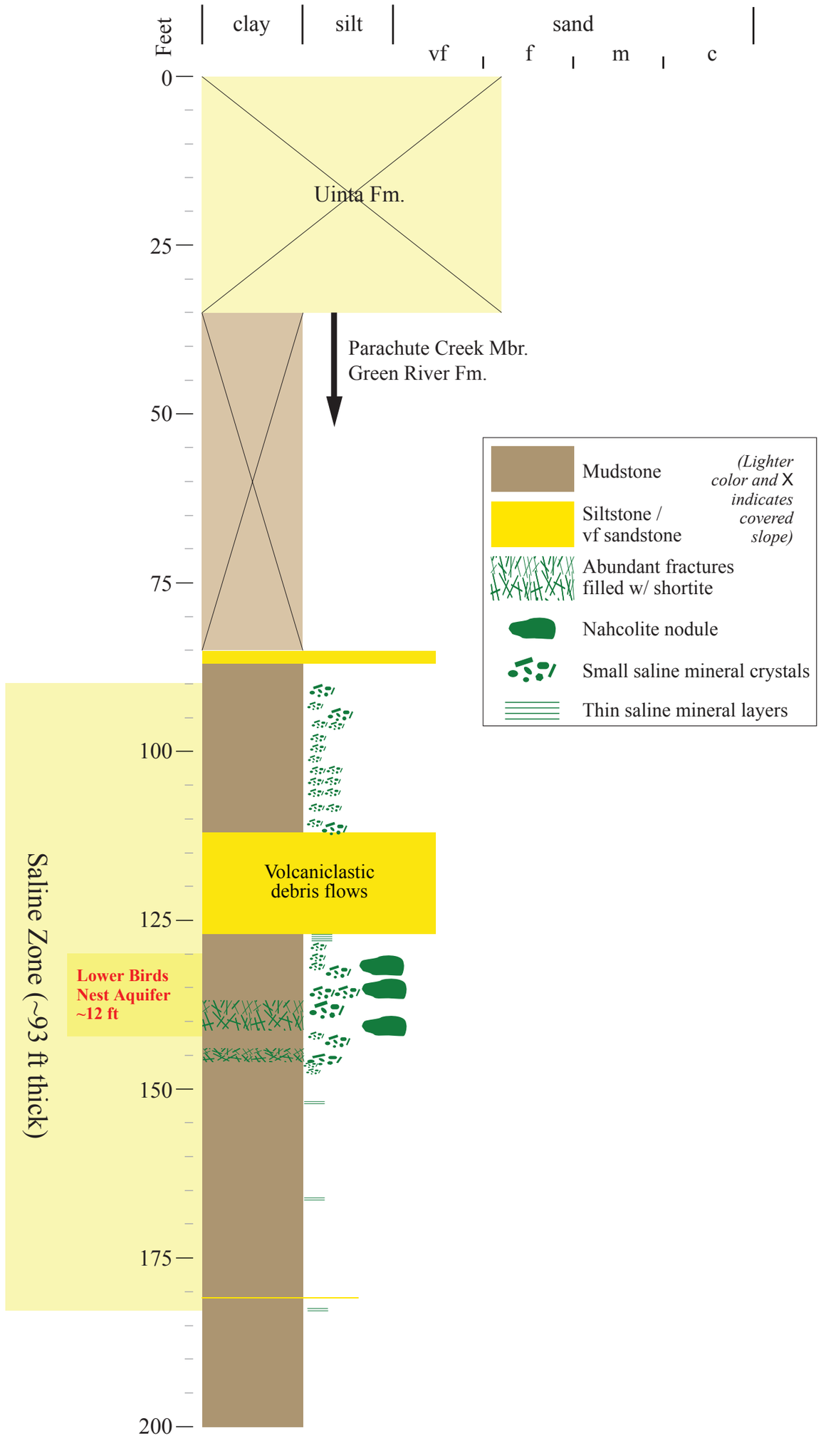


Plate 25.

Long Draw measured outcrop section.

Section name: Long Draw

Location: Section 3, T. 12 S., R. 24 E., SLBLM
UTM E 652475, UTM N 4407951 (NAD 83)

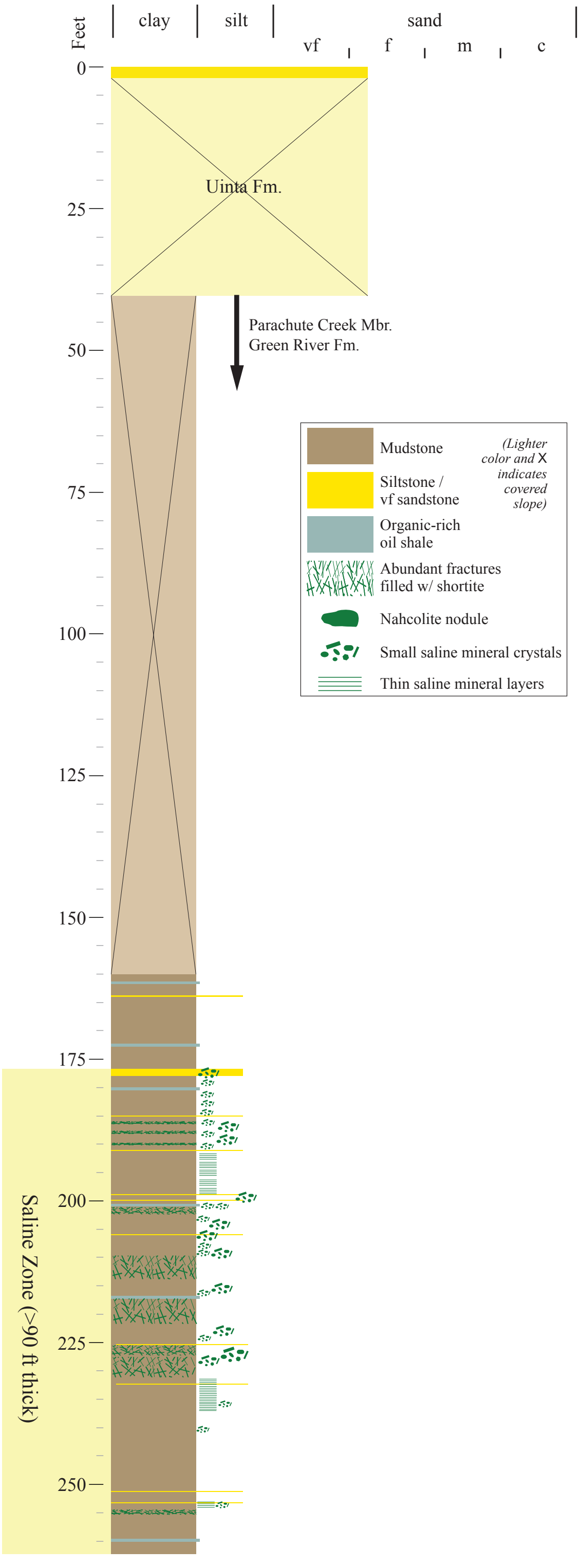


Plate 26.

Bitter Creek measured outcrop section.

Section name: Bitter Creek

Location: Section 29, T. 12 S., R. 23 E., SLBLM
UTM E 640194, UTM N 4400583 (NAD 83)

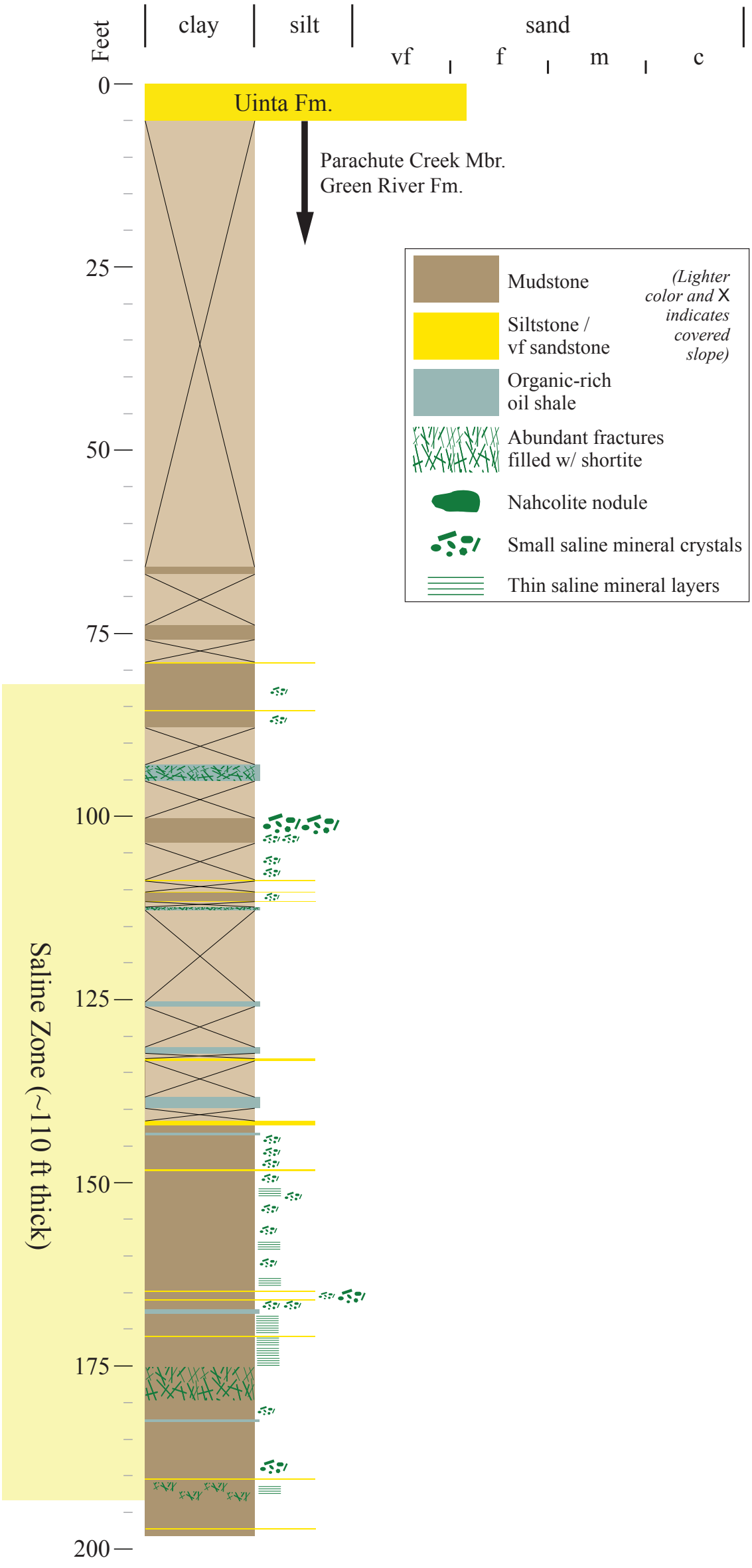


Plate 27.
A-A' north-south cross section.

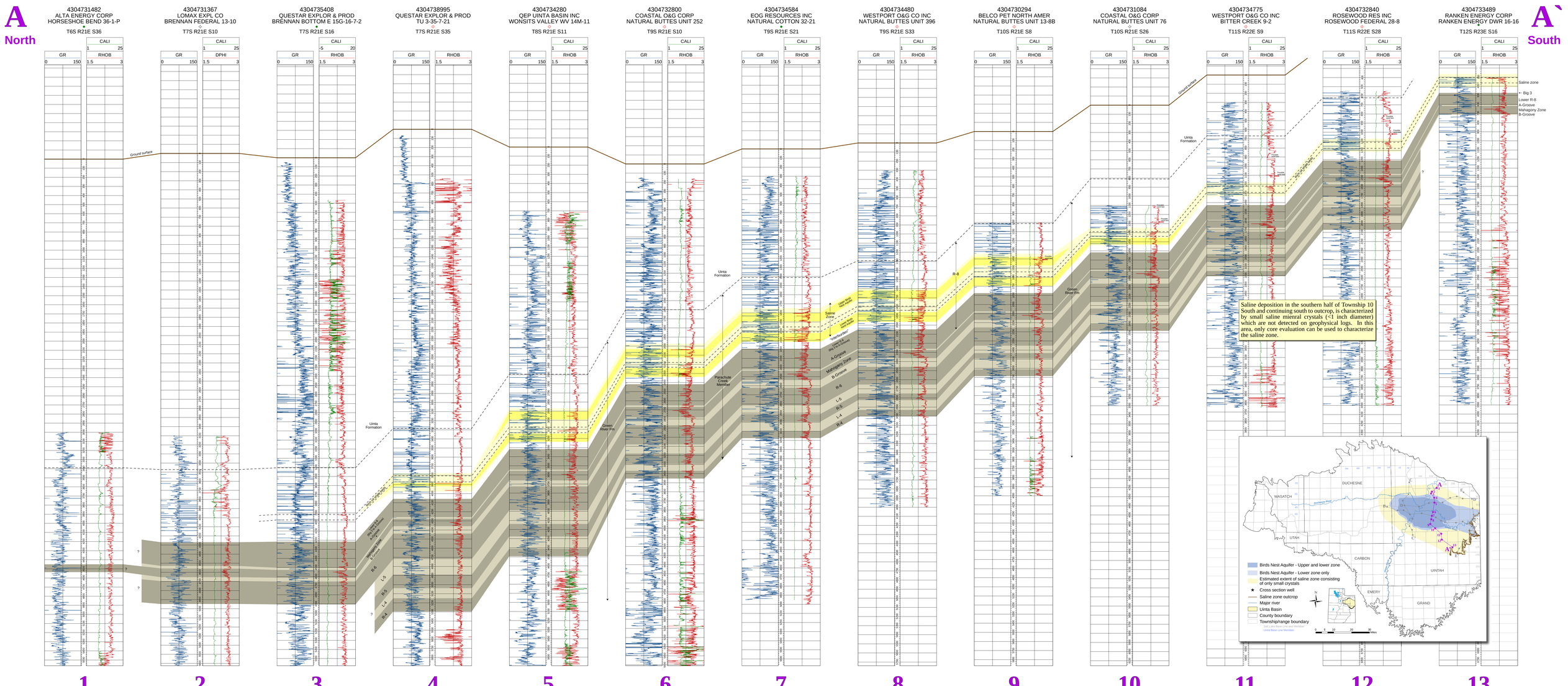


Plate 28.
B-B' east-west cross section.

B
West

B`
East

1	2	3	4	5	6	7	8	9	10	11	12	13
4301330690 LOMAX EXPL CO FEDERAL 9-20 T8S R17E S20	4304731116 NAT GAS CORP OF CALI NGC 33-32 T8S R18E S32	4304731345 GULF ENERGY CORP GULF STATE 36-13 T8S R18E S36	4304730070 DIAMOND SHAMROCK CORP FEDERAL CHORNEY 1-9 T9S R19E S9	4304730434 BELCO PET NORTH AMER DUCK CREEK 2-10 T9S R20E S10	4304734584 EOG RESOURCES INC NATURAL COTTON 32-21 T9S R21E S21	U102 TOSCO Corp Utah State 1 T9S R21E S26	4304720268 TENNECO OIL CO NATURAL BUTTES UNIT 1 T10S R22E S5	4304730724 COASTAL O&G CORP NATURAL BUTTES UNIT 37X T10S R22E S3	4304734773 WESTPORT O&G CO LP BONANZA 11-2 T10S R23E S11	4304730280 PACIFIC TRNSMSN SPLY PTS-FEDERAL 44-5 T10S R24E S5	U061 White River Shale Project X-2 T10S R24E S14	U059 White River Shale Project P-4 T10S R25E S19

GR 0 150 | CALI 1 25 | RHOB 1.5 3

Ground surface

Uinta Formation

Green River Fm

Parachute Creek Member

Saline zone

Big 3

Lower R-8

A-Groove

Mahogany Zone

B-Groove

R-6

L-5

R-5

L-4

R-4

Core available/examined

The most economic oil shale zones are the lower R-8 (top defined by the Big 3), the Mahogany zone, and the upper R-6. These intervals are separated from the Birds Nest by roughly 70-90 ft of lean oil shale "interburden".

Only the lower Birds Nest aquifer is present on the eastern side of the basin. An influx of freshwater, represented by volcaniclastic debris flows, created a localized freshening of the lake, shutting down saline mineral deposition in the area.

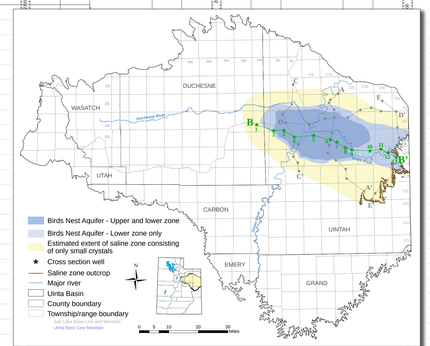


Plate 29.

C-C' north-south cross section.

C North — **C'** South

1	2	3	4	5	6	7	8	9
4304730186 SHELL OIL CO MEAGHER TRUST 1-20-B2E T2S R2E S20	4304730254 GULF OIL CORP RANDLETT 3 T3S R2E S20	4304750532 NEWFIELD EXPL CO UTE TRIBAL 5-11-4-1E T4S R1E S11	4304733541 COASTAL O&G CORP UTE TRIBAL 4-25 T4S R1E S25	4304730070 DIAMOND SHMROCK CORP FEDERAL-CHORNEY 1-9 T9S R19E S9	4304732237 PG&E RESOURCES CO FEDERAL 13-26B T9S R19E S26	4304730260 MAPCO INCORPORATED RBU 11-16E T10S R19E S16	4304731898 ENRON OIL & GAS CO OLD SQUAWS CROSSING 2-27 T10S R19E S27	4304731108 COTTON PETROLEUM KINGS CANYON-UNIT 1-11 T11S R19E S11

GR 0–150 · CALI 1–25 · RHOB 1.5–3

Ground surface

Uinta Formation

Parachute Creek Member

Green River Fm

Wash-out (lithology unknown)

Tails of sinuses

Saline Zone

"Interburden" (Lower R-8 to A-Groove)

A-Groove

Mahogany Zone

B-Groove

R-6

L-5

R-5

L-4

R-4

R-8

Saline deposition in the southern half of Township 10 South and continuing south to outcrop, is characterized by small saline mineral crystals (<1 inch diamter) which are not detected on geophysical logs. In this area, only core and outcrop evaluation can be used to characterize the saline zone.

Saline Zone

"Interburden"

Lower R-8 (Big 3 to A-Groove)

A-Groove

Mahogany Zone

B-Groove

R-6

L-5

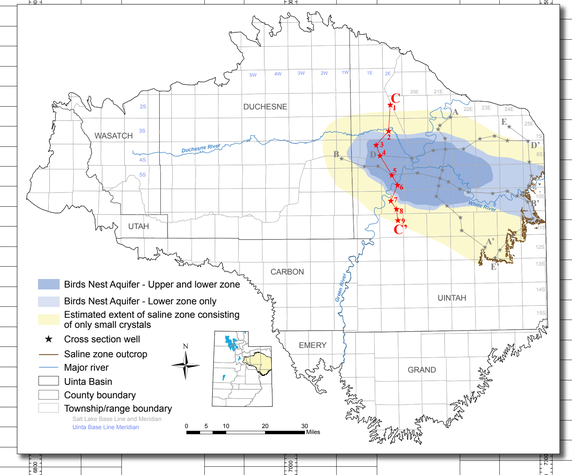


Plate 30.

D-D' east-west cross section.

D **West** — **D'** **East**

1	2	3	4	5	6	7	8	9
4304733541 COASTAL O&G CORP UTE TRIBAL 4-25 T4S R1E S25	4304733017 SEGO RES CORP UTE TRIBAL 29-13D3E T4S R3E S29	4304735318 QEP UINTA BASIN INC WONSITS VALLEY EXTE 3MU-17-8-2 T8S R21E S17	4304734280 QEP UINTA BASIN INC WONSITS VALLEY WV 14M-11 T8S R21E S11	4304734679 QEP UINTA BASIN INC OVER & UNDER GLEN BE 16W-9-8-22 T8S R22E S9	4304737946 QEP UINTA BASIN INC RED WASH UNIT RW 12-32BG T7S R23E S32	4304730259 CHEVRON U S A INC RED WASH UNIT 229 43-26B T7S R23E S26	4304730390 CHEVRON U S A INC RED WASH UNIT 249 14-33C T7S R24E S33	4304732260 EQUITABLE RES ENERGY BALCRON COYOTE FEDE 21-5 T8S R25E S5

GR 0–150 · CALI 1–25 · RHOB 1.5–3 (CALI -5–20 on well 3)

Ground surface

Uinta Formation

Saline Zone

Rich oil shale beds

Parachute Creek Member

Upper Birds Nest Aquifer

Lower Birds Nest Aquifer

"Interburden"

Lower R-8 (Big 3 to A-Groove)

A-Groove

Mahogany Zone

B-Groove

R-8

R-6

L-5

R-5

L-4

R-4

Green River Fm

Possible base of R-4

Caliper

Wash-out (lithology unknown)

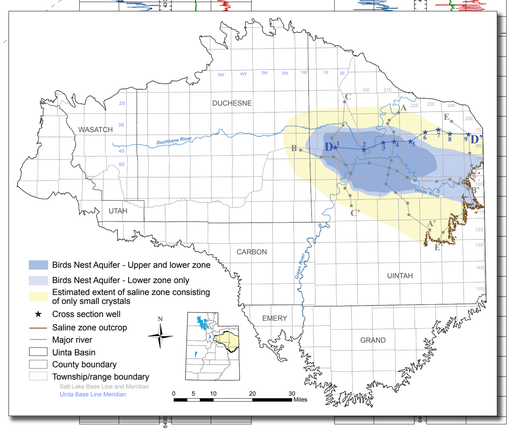


Plate 31.

E-E' north-south cross section.

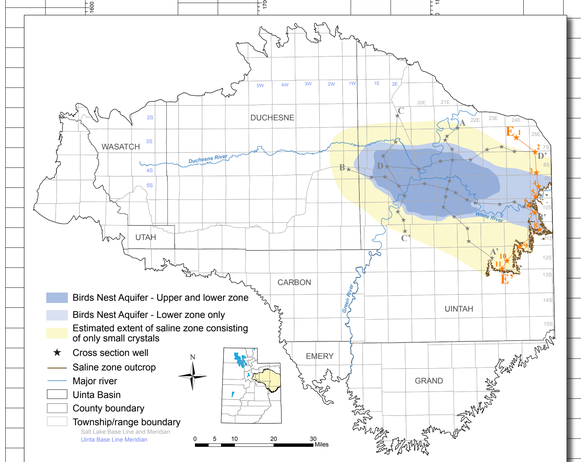
E — North

E` — South

1	2	3	4	5	6	7	8	9	10	11
4304735238 QEP UINTA BASIN INC RED WASH RW 32G-16C T7S R24E S16	4304732260 EQUITABLE RES ENERGY BALCRON COYOTE FEDE 21-5 T8S R25E S5	4304737571 HOUSTON EXP CO THE HACKING RESERVOIR 7-32-8-25 T8S R25E S32	U092 Western Oil Shale Corp. EX-3 T9S R25E S16	U028 National Farmer's Union Corehole 2 T9S R25E S32	U056 White River Shale Co. P-1 T10S R24E S12	U059 White River Shale Co. P-4 T10S R25E S19	Utah Geological Survey Skyline 16 T11S R25E S10	U055 USGS CRU-1 T12S R24E S3	U080 U.S. ERDA-LERC South Uinta Basin 12 T12S R24E S19	U087 Arco Suicide Canyon 1 T12S R23E S36
GR 0–150	GR 0–150	GR 0–150	GR 0–150	Oil Yield 0–80	GR 0–150	GR 0–150	RHOB 1.5–3	Oil Yield 0–80	Oil Yield 0–80	Oil Yield 0–80
CALI 1–25 RHOB 1.5–3	CALI 1–25 RHOB 1.5–3	CALI 1–25 RHOB 1.5–3	CALI 1–25 RHOB 1.5–3		CALI 1–25 RHOB 1.5–3	CALI 1–25 RHOB 1.5–3	CALI 1–25			
Ground surface	Ground surface	Uinta Formation	Volcaniclastic debris	Lower Birds Nest Aquifer	"Interburden"	Lower R-8 (fig.3 to A-Groove)	A-Groove	Mahogany Zone	B-Groove	R-6
L-5	R-5	L-4	R-4	R-8	Parachute Creek Member	Green River Fm	Possible base of R-4	Core available/examined		

Only the lower Birds Nest aquifer is present on the eastern side of the basin. An influx of freshwater, represented by volcaniclastic debris flows, created a localized freshening of the lake, shutting down saline mineral deposition in the area.

Saline deposition in the southern half of Township 10 South and continuing south to outcrop, is characterized by small saline mineral crystals (<1 inch diameter) which are not detected on geophysical logs. In this area, only core and outcrop evaluation can be used to characterize the saline zone.



Appendix A. *Birds Nest aquifer and oil shale tops database.*

*From Vanden Berg, 2008
na=no log or core coverage; x=pick unknown or not present

API	USGS #	Core examined	Cross-section well	Picks from…	Twn	Rng	Sec	Mrd	UTM E	UTM N	Elevation	Upper and/or lower BN	Upper BN			BN Interburden	Lower BN			Saline Zone		Big 3	Still-water	A-Groove	Mahogany Zone	Mahogany Bed	B-Groove	Upper R-6	Upper R-6	L-5	R-5	L-4	R-4	R-4	50 GPT Zone*			35 GPT Zone*			25 GPT Zone*			15 GPT Zone*		
									NAD 83	NAD 83	GL in ft	0=no BN, 1=lower only, 2=upper and lower	Top (ft)	Base (ft)	Thickness (ft)	Thickness (ft)	Top (ft)	Base (ft)	Thickness (ft)	Top (ft)	Base (ft)	Top (ft)	Peak (ft)	Top (ft)	Top (ft)	Peak (ft)	Top (ft)	Top (ft)	Base (ft)	Top (ft)	Top (ft)	Top (ft)	Top (ft)	Base (ft)	Top (ft)	Base (ft)	Thickness (ft)	Top (ft)	Base (ft)	Thickness (ft)	Top (ft)	Base (ft)	Thickness (ft)	Top (ft)	Base (ft)	Thickness (ft)
4301330722				bulk density	10S	17E	5	SL	582110	4424584	5866	0										na	na	x	2330	2352	2403	2482	2542	2709	x	x	x	x	2345.5	2355.5	10.0	2344.5	2368.0	23.5	2341.5	2382.5	41.0	2322.0	2403.0	81.0
4301332057				bulk density	10S	17E	17	SL	583336	4421320	5950	0										na	na	1991	2005	2033	2075	2204	2264	2425	x	x	x	x	2029.5	2034.5	5.0	2028.5	2042.5	14.0	2024.5	2056.0	31.5	2002.5	2064.0	61.5
4301332088				bulk density	10S	17E	20	SL	582740	4420159	6098	0										x	x	x	2038	2065	2112	2186	2248	x	x	x	x	x													
4304735932				bulk density	10S	18E	7	SL	591407	4424310	5318	0										na	na	x	2087	2120	2165	2259	2334	2488	2578	2641	x	x	2116.0	2125.5	9.5	2113.0	2143.5	30.5	2088.5	2145.0	56.5	2067.5	2173.5	106.0
4304735798				bulk density	10S	18E	9	SL	594590	4423073	5078	0										1566	1606	1773	1791	1823	1865	1953	2029	2183	2276	2344	x	x	1820.0	1828.0	8.0	1816.5	1834.5	18.0	1799.0	1834.0	35.0	1757.5	1864.0	106.5
4304731752				bulk density	10S	19E	2	SL	607241	4426136	4987	2	1634	1690	56	154	1844	1925	81			2009	2054	2192	2205	2234	2282	x	2458	2606	2698	2761	2908	2990	2231.0	2237.5	6.5	2227.5	2247.5	20.0	2209.5	2254.5	45.0	2160.0	2279.0	119.0
4304731739				bulk density	10S	19E	9	SL	604223	4424016	5047	0										1748	1785	1922	1934	1965	2008	2106	2183	2339	2418	2484	2630	2711												
4304733111				bulk density	10S	19E	11	SL	607186	4423893	5035	2	1433	1471	38	154	1625	1692	67			1785	1830	1976	1990	2022	2069	2177	2259	2421	2510	2586	2729	2822												
4304733107				bulk density	10S	19E	12	SL	608900	4423862	5095	2	1490	1552	62	137	1689	1767	78			1859	1908	2054	2066	2099	2145	2248	2328	2490	2586	x	2844	2936	2095.5	2101.0	5.5	2093.0	2110.5	17.5	2074.5	2118.0	43.5	2035.0	2141.0	106.0
4304731715				bulk density	10S	19E	13	SL	607822	4422762	5104	2	1409	1446	37	136	1582	1650	68			1745	1790	1927	1939	1968	2012	2100	2182	2323	2396	2485	2606	2686												
4304730260			C-C' - 7	bulk density	10S	19E	16	SL	603407	4422399	5057	0										1597	1638	1769	1782	1812	1854	1942	2018	2176	2251	2340	2461	2546	1808.0	1815.0	7.0	1805.5	1823.5	18.0	1790.0	1830.5	40.5	1735.0	1853.5	118.5
4304730698				sonic	10S	19E	22	SL	605251	4420763	5239	0										1614	1657	1789	1801	1831	1875	1954	2033	2177	2243	2324	2450	2537												
4304732515				bulk density	10S	19E	25	SL	609114	4420035	5220	0										1590	1635	1768	1780	1809	1852	1926	2010	2151	2215	2295	2409	2486												
4304731179				bulk density	10S	19E	26	SL	607030	4419278	5317	0										1550	1593	1736	1748	1768	1812	1885	1967	2103	2166	2248	2374	2459												
4304731898			C-C' - 8	bulk density	10S	19E	27	SL	605701	4418974	5263	0										1449	1492	1624	1638	1668	1710	1784	1863	1998	2065	2150	x	x	1664.5	1673.0	8.5	1660.0	1686.5	26.5	1639.0	1691.5	52.5	1568.0	1710.0	142.0
4304731777				bulk density	10S	19E	36	SL	607896	4418363	5362	0										1509	1552	1684	1696	1726	1769	1841	1920	2056	2120	2205	x	2411	1724.0	1728.0	4.0	1719.0	1735.0	16.0	1715.5	1749.0	33.5	1668.0	1768.0	100.0
4304732114				bulk density	10S	20E	1	SL	617732	4426269	4979	2	1620	1705	85	135	1840	1933	93			2012	2059	2216	2227	2261	2308	2403	2488	2608	2701	2758	2883	2956												
4304730153				bulk density	10S	20E	2	SL	616316	4426432	4961	2	1672	1750	78	134	1884	1974	90			2059	2106	2260	2272	2304	2352	2448	2530	2654	2742	2800	2932	3015												
4304731704				bulk density	10S	20E	6	SL	610854	4425574	4868	2	1473	1542	69	131	1673	1765	92			1847	1893	2038	2051	2082	2126	2224	2302	2437	2526	2596	2732	2815	2079.0	2083.5	4.5	2076.0	2090.0	14.0	2072.5	2104.0	31.5	2021.0	2124.5	103.5
4304733477				bulk density	10S	20E	7	SL	609606	4423850	5087	2	1415	1476	61	135	1611	1690	79			1784	1830	1974	1987	2021	2067	2170	2256	2414	2510	2593	2748	2830												
4304731751				bulk density	10S	20E	8	SL	612055	4424483	4925	2	1406	1472	66	132	1604	1696	92			1776	1822	1966	1978	2009	2055	2149	2227	2363	2448	2536	2660	2739												
4304731632				bulk density	10S	20E	9	SL	614087	4423699	4913	2	1294	1358	64	134	1492	1587	95			1668	1715	1859	1870	1900	1946	2039	2118	2250	2336	2424	2538	2617												
4304720308				bulk density	10S	20E	17	SL	611764	4422929	5093	2	1416	1471	55	133	1604	1700	96			1782	1828	1968	1981	2010	2054	2141	2218	2356	2438	2509	2630	2706	2009.5	2011.5	2.0	2007.5	2015.5	8.0	2004.0	2028.5	24.5	1980.5	2044.0	63.5
4304730376				bulk density	10S	20E	21	SL	613801	4421425	5101	2	1292	1329	37	133	1462	1546	84			1626	1663	1809	1820	1851	1894	1970	2050	2190	2267	2338	2450	2529												
4304731087				bulk density	10S	20E	24	SL	618667	4421447	5199	2	1312	1373	61	137	1510	1596	86			1675	1720	1860	1872	1904	1947	2018	2096	2227	2302	2376	2483	2562												
4304730512				bulk density	10S	21E	1	SL	627765	4426561	5060	2	1466	1562	96	125	1687	1784	97			1862	1908	2070	2085	2119	2175	2263	2359	2460	2555	2610	2720	2786												
	U112	13X-2		core	10S	21E	2	SL	625850	4426165	5064	2	1476	1570	94	120	1690	1789	99	1408	1797	1872	1918	2078	2091	2126	2181	2263	2361	na	na	na	na	na											
4304730367				bulk density	10S	21E	4	SL	623018	4426880	4961	2	1540	1630	90	130	1760	1860	100			1947	1990	2153	2166	2200	2254	2346	2437	2540	2634	2688	2810	2874												
4304730426				bulk density	10S	21E	5	SL	621231	4426643	5022	2	1620	1710	90	130	1840	1939	99			2022	2068	2226	2239	2273	2324	2414	2505	2610	2702	2757	2883	2959												
4304730316				bulk density	10S	21E	6	SL	620484	4425438	5036	2	1526	1617	91	130	1747	1843	96			1919	1964	2120	2132	2166	2215	2304	2389	2504	2592	2649	2768	2843												
4304730420				bulk density	10S	21E	7	SL	620616	4424447	5131	2	1494	1586	92	132	1718	1816	98			1894	1941	2092	2104	2135	2184	2270	2353	2474	2558	2615	2731	2810												
4304730294			A-A' - 9	bulk density	10S	21E	8	SL	622013	4424242	5067	2	1378	1470	92	136	1606	1696	90			1777	1823	1976	1987	2019	2068	2151	2233	2353	2436	2495	2614	2686	2016.0	2022.5	6.5	2012.5	2032.0	19.5	1994.0	2041.5	47.5	1936.0	2066.5	130.5
4304730358				bulk density	10S	21E	8	SL	621232	4425128	5095	2	1510	1604	94	138	1742	1841	99			1923	1971	2124	2135	2169	2216	2303	2392	2503	2592	2646	2771	2848												
4304732942				sonic	10S	21E	10	SL	624634	4424371	5113	2	1402	1494	92	129	1623	1714	91			1795	1839	1993	2003	2038	2089	2165	2255	2372	2453	2508	2625	2691												
4304731166				bulk density	10S	21E	14	SL	626305	4422855	5252	2	1388	1450	62	121	1571	1666	95			1739	1787	1936	1948	1980	2032	2106	2190	2308	2388	2440	2554	2617												
4304730532				bulk density	10S	21E	16	SL	623821	4422274	5237	2	1176	1245	69	128	1373	1460	87			1538	1583	1724	1735	1766	1812	1876	1957	2082	2154	2210	2321	2399												
4304730054				sonic	10S	21E	17	SL	622023	4423323	5135	2	1361	1436	75	127	1563	1652	89			1732	1779	1927	1939	1970	2018	2094	2176	2300	2379	2445	2559	2629												
4304734195				bulk density	10S	21E	18	SL	620628	4422602	5164	2	1375	1438	63	120	1558	1639	81			1720	1765	1910	1922	1954	1999	2074	2154	2280	2360	2422	2537	2610												
4304730504				bulk density	10S	21E	18	SL	619437	4423509	5077	2	1364	1439	75	130	1569	1663	94			1745	1791	1937	1950	1980	2024	2108	2186	2311	2394	2456	2570	2648	1977.0	1982.0	5.0	1975.5	1991.0	15.5	1954.5	1998.5	44.0	1891.0	2023.5	132.5
4304730485				bulk density	10S	21E	20	SL	621289	4420845	5156	2	1373	1418	45	129	1547	1631	84			1711	1757	1905	1917	1947	1997	2070	2153	2276	2349	2409	2520	2596												
4304730548				bulk density	10S	21E	21	SL	622817	4420758	5273	2	1274	1314	40	139	1453	1536	83			1616	1661	1803	1814	1846	1890	1960	2040	2162	2234	2301	2418	2484												
4304730507				bulk density	10S	21E	22	SL	625294	4421545	5233	2	1279	1325	46	136	1461	1548	87			1627	1674	1822	1834	1866	1914	1982	2066	2188	2261	2318	2424	2494												
4304730505				bulk density	10S	21E	24	SL	627609	4421211	5320	2	1281	1330	49	139	1469	1552	83			1632	1679	1823	1835	1868	1919	1982	2068	2184	2256	2312	2422	2492												
4304731084			A-A' - 10	bulk density	10S	21E	26	SL	626366	4420394	5356	1				1456	1456	1529	73			1619	1663	1806	1818	1850	1898	1960	2043	2161	2236	2292	2406	2477	1848.0	1854.0	6.0	1842.0	1860.0	18.0	1820.0	1872.0	52.0	1757.5	1899.0	141.5
4304730360				sonic	10S	21E	27	SL	625230	4419961	5285	0										1522	1566	1703	1715	1747	1795	1856	1942	2060	2132	2196	2298	2367												
4304730482				bulk density	10S	21E	28	SL	623590	4419442	5380	0										1592	1637	1774	1786	1816	1862	1922	2008	2120	2186	2266	2375	2440												
4304730898				bulk density	10S	21E	33	SL	624032	4418236	5401	0										1502	1545	1676	1688	1717	1764	1818	1898	2012	2085	2165	2281	2340												
4304730871				bulk density	10S	21E	35	SL	626007	4418266	5392	0										1479	1522	1657	1668	1699	1744	1797	1878	1992	2056	2135	2252	2309												
4304730425				bulk density	10S	22E	2	SL	636299	4426461	5043	1				1446	1446	1537	91			1610	1657	1822	1835	1871	1941	2012	2122	2210	2298	2372	2444	2508												
4304730724			B-B' - 9	bulk density	10S	22E	3	SL	634994	4425850	5067	1				1421	1421	1516	95			1604	1650	1811	1825	1864	1926	1998	2104	2192	2280	2348	2431	2492	1858.0	1877.0	19.0	1852.5	1901.5	49.0	1787.0	1899.5	112.5	1553.5	1927.0	373.5
4304731251				bulk density	10S	22E	3	SL	634972	4427150	4944	2	1274	1316	42	116	1432	1522	90			1604	1651	1818	1830	1868	1938	2013	2120	2206	2296	2372	2450	2517												
4304731246				bulk density	10S	22E	4	SL	632364	4426774	5023	2	1347	1416	69	126	1542	1634	92			1711	1756	1919	1931	1967	2032	2111	2211	2306	2401	2474	2554	2622												
4304720268			B-B' - 8	bulk density	10S	22E	5	SL	631666	4427050	4908	2	1357	1426	69	124	1550	1642	92			1723	1771	1937	1950	1988	2050	2132	2235	2330	2424	2492	2582	2647	1986.0	1999.0	13.0	1976.5	2019.5	43.0	1946.0	2040.0	94.0	1694.0	2052.0	358.0
4304730533				bulk density	10S	22E	6	SL	629253	4426170	5102	2	1456	1542	86	123	1665	1758	93			1839	1885	2044	2056	2093	2153	2234	2336	2431	2522	2592	2683	2749												
4304730865				bulk density	10S	22E	7	SL	629201	4425044	5244	2	1527	1600	73	121	1721	1812	91			1891	1936	2092	2103	2140	2197	2274	2367	2472	2561	2632	2720	2783												
4304730490				bulk density	10S	22E	8	SL	631055	4425038	5251	2	1493	1555	62	121	1676	1771	95			1847	1890	2044	2056	2092	2152	2226	2327	2421	2512	2581	2662	2731												
4304730484				bulk density	10S	22E	9	SL	632478	4424722	5169	2	1330	1392	62	125	1517	1607	90			1685	1729	1881	1893	1931	1989	2060	2159	2254	2339	2407	2491	2557												
4304730535				bulk density	10S	22E	12	SL	638043	4424472	5262	1				1432	1432	1530	98			1611	1655	1812	1824	1862	1926	1994	2096	2183	2272	2340	2413	2464												
4304730536				bulk density	10S	22E	13	SL	637389	4423063	5295	1				1398	1398	1472	74			1546	1589	1734	1748	1785	1844	1904	2010	2096	2180	2242	2324	2376	1780.0	1796.0	16.0	1774.0	1817.0	43.0	1721.0	1814.0	93.0	1539.5	1842.5	303.0
4304730491				bulk density	10S	22E	14	SL	635694	4423682	5220	2	1239	1305	66	113	1418	1506	88			1587	1633	1784	1795	1844	1894	1960	2061	2150	2237	2301	2384	2442												
4304731102				bulk density	10S	22E	17	SL	631017	4423499	5340	2	1442	1507	65	120	1627	1720	93			1793	1840	1990	2001	2036	2092	2161	2260	2360	2440	2505	2590	2653												
4304737549				bulk density	10S	22E	18	SL	629406	4423321	5148	2	na	na	na	na	na	1573	na			1649	1695	1844	1856	1890	1945	2015	2105	2216	2296	2351	2454	2517												
4304730900				bulk density	10S	22E	21	SL	633069	4422075	5354	2	1305	1363	58	126	1489	1574	85			1656	1704	1850	1861	1899	1954	2017	2108	2212	2287	2352	2436	2495												
4304730838				bulk density	10S	22E	27	SL	634430	4420611	4970	1					926	988	62			1084	1129	1268	1282	1314	1368	1424	1516	1620	1694	1754	1836	1895	1310.5	1323.0	12.5	1304.5	1339.5	35.0	1286.0	1357.5	71.5	1094.0	1368.0	274.0
4304734860				bulk density	10S	22E	29	SL	630726	4419898	5377	1					1358	1422	64			1515	1561	1699	1711	1741	1794	1850	1938	2046	2112	2168	2262	2314												
4304734237				bulk density	10S	22E	30	SL	629555	4420066	5369	1					1386	1451	65			1546	1590	1726	1738	1766	1818	1876	1960	2070	2138	2194	2282	2347	1763.5	1771.0	7.5	1759.5	1781.0	21.5	1739.5	1794.0	54.5	1666.0	1817.0	151.0
4304734590				bulk density	10S	22E	31	SL	630271	4418980	5452	0										1520	1562	1698	1710	1739	1789	1842	1925	2036	2096	2152	2249	2304												
4304734824				bulk density	10S	22E	32	SL	631548	4419038	5469	0										1509	1553	1687	1699	1730	1780	1834	1925	2036	2096	2155	2253	2308												
4304730632				bulk density	10S	23E	4	SL	642825	4426343	5320	1				1460	1554	94				1636	1683	1850	1862	1900	1976	2042	2155	2236	2326	2408	2465	2530												
4304710094				sonic	10S	23E	8	SL	640490	4424596	5326	1				1439	1535	96				1613	1660	1818	1829	1868	1937	2001	2111	2194	2282	2362	2416	2477												
4304734773			B-B' - 10	bulk density	10S	23E	11	SL	645072	4425259	5437	1				1389	1486	97				1564	1612	1774	1786	1830	1897	1959	2070	2152	2244	2324	2380	2440	1824.0	1841.5	17.5	1817.5	1864.5	47.0	1789.0	1895.5	106.5	1563.5	1896.5	333.0
4304715882				sonic	10S	23E	24	SL	646783	4422606	4930	1					na	697	na			779	826	975	985	1022	1088	1136	1249	1329	1414	1494	1534	1589												
4304730280			B-B' - 11	bulk density	10S	24E	5	SL	651025	4426195	5246	1					954	1046	92			1133	1184	1346	1358	1398	1470	1525	1642	1720	1810	1900	1937	1991	1394.5	1414.5	20.0	1386.0	1440.0	54.0	1357.0	1472.0	115.0	1215.0	1600.5	385.5
	U056	P-1	E-E' - 6	core	10S	24E	12	SL	656732	4424894	5284	1					331	431	100	325	436	513	559	710	722	761	831	873	983	1055	1142	1227	na	na												
	U061		B-B' - 12	core	10S	24E	14	SL	654994	4424383	4984	1					214	321	107			403	452	607	620	660	728	x	x	x	x	x	x	x												
	U057	P-2		core	10S	24E	17	SL	651084	4422804	4991	1					427	513	86	398	522	585	630	781	793	835	901	951	1065	1141	1201	1285	na	na												
4304715614				sonic	10S	24E	22	SL	653611	4421920	5292	1					529	606	77			684	728	876	887	925	994	1039	1152	1227	1306	1385	1426	1483												
4304733165				bulk density	10S	24E	30	SL	648340	4419767	5067	1					428	498	70			583	625	766	777	812	872	916	1028	1110	1188	1254	1308	1353	807.0	825.0	18.0	785.5	831.5	46.0	749.5	863.5	114.0	567.5	1030.0	462.5
4304715883				sonic	10S	24E	32	SL	650431	4418497	5635	1					654	718	64			794	836	967	978	1010	1067	1105	1222	1302	1376	1442	1493	1544												
	U130	X-13		core	10S	24E	22	SL	654044	4421465	5484	1					649	720	71	630	728	na	na	988	998	1036	na	na	na	na	na	na	na	na												
	U058	P-3		core	10S	24E	26	SL	655414	4419858	5490	1					446	507	61	407	507	582	625	764	775	812	875	915	1025	1098	1174	na	na	na												
	U059	P-4	B-B' - 13, E-E' - 7	core	10S	25E	19	SL	659365	4422017	5719	1					348	411	63	283	418	487	532	672	683	719	785	822	926	990	1063	1140	na	na												
	U029	Corehole 9		core	10S	25E	32	SL	659586	4418979	5746	1					272	338	66	250	340	417	458	594	603	637	700	737	838	903	972	1049	1074	na	632.5	643.0	10.5	626.0	659.5	33.5	603.5	692.0	88.5	383.0	712.5	329.5
4304731108			C-C' - 9	bulk density	11S	19E	11	SL	606292	4414383	5605	0							0			1345	1386	1519	1533	1565	1613	1668	1730	1852	1908	x	x	x	1564.5	1567.5	3.0	1562.5	1571.0	8.5	1557.0	1589.5	32.5	1526.5	1612.0	85.5
4304736907				bulk density	11S	19E	17	SL	601883	4413158	5711	0							0			1283	1326	1490	1510	1544	1592	1649	1702	1816	1874	2024	x	x	1539.5	1547.5	8.0	1535.5	1558.5	23.0	1529.5	1574.0	44.5	1486.5	1595.0	108.5
4304731178				bulk density	11S	20E	3	SL	613476	4415751	5134	0							0			1049	1089	1216	1228	1258	1303	1351	1406	x	x	x	x	x	1256.5	1260.0	3.5	1252.5	1268.5	16.0	1229.0	1282.5	53.5			130.5
4304731068				bulk density	11S	21E	1	SL	626280	4415919	5567	0							0			1431	1472	1596	1608	1638	1682	1724	1802	1893	1998	2077	2177	x	1636.0	1638.5	2.5	1633.0	1643.5	10.5	1632.5	1658.0	25.5	1604.0	1681.0	77.0
4304730148				bulk density	11S	21E	7	SL	619195	4415246	5539	0							0			1414	1454	1576	1588	1618	1660	1705	1780	1867	1938	x	x	x												
4304734774				bulk density	11S	22E	4	SL	631808	4417212	5593	0							0			1470	1512	1640	1653	1682	1730	1774	1854	1934	2028	2098	2186	2236	1679.0	1686.0	7.0	1676.0	1696.0	20.0	1655.5	1708.5	53.0	1574.5	1727.5	153.0
4304731067				bulk density	11S	22E	8

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Appendix B. *Birds Nest aquifer water chemistry database*

Number	API	Sample Date	Well Name	Field Name	County	UTM E	UTM N	Elevation	Twn	Rng	Sec	Mrd	Data Source	Sample Depth Top	Sample Depth Base	Formation	Sampled by	Type of Sample	Analysis Method	Lab Name	Raw R_w	Temp Raw R_w	TDS	pH	Specific Gravity	Ca	Na	K	Mg	CO_3	Cl	SO_4	Bicarbonate	Anion/ Cation ratio	Used in Mapping the 10,000 TDS boundary	Comments
						NAD 83	NAD 83	GL in ft						ft	ft						ohms-m	°F	mg/L			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L			
1	4304735312	19-Sep-2008	NBU 1020-13E	Natural Buttes	Uintah	617943	4422983	5120	10S	20E	13	SL	Anadarko	1600	1600	Green River - Birds Nest and above	Anadarko		Lab	NALCO			14995	10.8	1.020	31			3	7800	1760	25	3782		Yes	
2	4304730896	6-Apr-2010	CIGE 79D	Natural Buttes	Uintah	628519	4426807	5053	10S	21E	01	SL	Anadarko	1731	1747	Green River - Birds Nest specific	Anadarko		Lab				34170	9.0		17	26430	34	3		7400	100	58560	1.02	Yes	
3	4304731747		CIGE 107D	Natural Buttes	Uintah	627419	4427032	5120	10S	21E	01	SL	Anadarko	1840	1858	Green River - Birds Nest specific	Anadarko						65121												Yes	
4	4304739003	20-Oct-2007	NBU 1021-1P	Natural Buttes	Uintah	628515	4425819	4940	10S	21E	01	SL	Anadarko	1320	1320	Green River - Birds Nest and above	Anadarko		Lab	NALCO	9.30	68	3325	9.4	1.003	16	1526	0	1	573	400	360	1842	1.01	Yes	Used average TDS for mapping - 3915 TDS
5	4304739003	20-Oct-2007	NBU 1021-1P	Natural Buttes	Uintah	628515	4425819	4940	10S	21E	01	SL	Anadarko	1320		Green River - Birds Nest and above	Anadarko		Lab	NALCO	3.86	68	4504	9.6	1.004	24	780	1886	2	1159	350	290	1769	1.00	Yes	Used average TDS for mapping - 3915 TDS
6	4304730853	30-Dec-2010	CIGE 80D	Natural Buttes	Uintah	625919	4426898	5084	10S	21E	02	SL	Anadarko	1630	1875	Green River - Birds Nest specific	Anadarko	Production	Lab	NALCO	0.56	60	14381	7.3	1.012	889	4696	7	137	0	6700	80	4392	1.01	Yes	
7	4304732796	29-Sep-2009	NBU 265	Natural Buttes	Uintah	627068	4426101	5159	10S	21E	02	SL	Anadarko	1804	1872	Green River - Birds Nest specific	Anadarko		Lab	NALCO			53788	9.4	1.059	18	30422	4	1	23400	2200	20	29402	1.00	Yes	
8	4304737540	5-Apr-2007	NBU 1021-2C	Natural Buttes	Uintah	626232	4427005	5093	10S	21E	02	SL	Anadarko	1620		Green River - Birds Nest and above	Anadarko		Lab	NALCO	1.09	68	9126	10.8	1.008	4	4215	15	1	1572	3200	35	2501	1.00	No	Diluted with freshwater above
9		5-Nov-1977	UTAH STATE 13X-2 - U112		Uintah	625850	4426165	5064	10S	21E	02	SL	UGS oil shale database - OFR 469	1542	1542	Green River - Birds Nest specific			Lab				4568	9.8		3	1610	0	1	1197	120	48	1564	1.00	No	Not reliable
10	4304730543	29-Mar-2010	CIGE 57	Natural Buttes	Uintah	625313	4425191	5061	10S	21E	10	SL	Anadarko	1690	1703	Green River - Birds Nest specific	Anadarko		Lab				20861	9.4		12	16790	25	2		3800	80	11492	0.41	Yes	
11	4304738109	18-Sep-2007	NBU 1021-10P	Natural Buttes	Uintah	625523	4423960	5126	10S	21E	10	SL	Anadarko	870	870	Green River - Birds Nest and above	Anadarko		Lab	NALCO			3216	9.1		2	1424		1	348			1135	0.49	Yes	
12	4304736182	20-Oct-2007	NBU 1021-12H	Natural Buttes	Uintah	628687	4425013	4968	10S	21E	12	SL	Anadarko	1350		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.65	68	2845	8.9	1.003	32	1139	0	1	171	360	770	1183	1.00	Yes	
13	4304737433	30-May-2007	NBU 1021-21M	Natural Buttes	Uintah	622771	4420780	5267	10S	21E	21	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko		Lab	NALCO	8.98	68	3920	10.1	1.004	1	2351	3	0	2628	470		98	1.00	Yes	
14	4304737436	14-May-2007	NBU 1021-21J	Natural Buttes	Uintah	623573	4421242	5249	10S	21E	21	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko		Lab		14.88	68	4149	9.8	1.004	12	2423	2	2	2376	160	35	1159	0.97	Yes	
15	4304736577	29-May-2006	NBU 1022-1D	Natural Buttes	Uintah	636805	4427277	4998	10S	22E	01	SL	Anadarko	1470		Green River - Birds Nest and above	Anadarko		Lab	NALCO	2.60	68	5755	8.5	1.000	40	2597	4	12	1440	1510	450	1098	1.02	Yes	
16	4304738516		NBU 1022-4E-1T	Natural Buttes	Uintah	632374	4426771	5032	10S	22E	04	SL	Anadarko	1350		Green River - Birds Nest and above	Anadarko		Lab	NALCO	7.05	68	5440	9.6	1.006	1	2836	7	0	1578	510	125	3355	1.01	Yes	
17	4304738490	20-Oct-2007	NBU 1022-5M-4T	Natural Buttes	Uintah	630722	4425784	5177	10S	22E	05	SL	Anadarko	1490		Green River - Birds Nest and above	Anadarko		Lab	NALCO	9.30	68	3197	9.3	1.003	20	1444	2	1	488	400	500	1586	1.00	Yes	
18	4304735687	28-Sep-2005	NBU 1022-6O	Natural Buttes	Uintah	629632	4425879	5133	10S	22E	06	SL	Anadarko	1300		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	4.18	68	3290	9.6	1.003	29	1529	55	6	720	735	59	1464	1.00	Yes	Used average TDS for mapping - 3745 TDS
19	4304735687	28-Sep-2005	NBU 1022-6O	Natural Buttes	Uintah	629632	4425879	5133	10S	22E	06	SL	Anadarko	1540	1540	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			4199	9.8	1.004	38			7	960	880	70	1953		Yes	Used average TDS for mapping - 3745 TDS
20	4304738570	19-Nov-2007	NBU 1022-7H-4	Natural Buttes	Uintah	630343	4424861	5275	10S	22E	07	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			22776	7.9		759	7667		121				1379	0.06	No	Out of balance
21	4304735856	14-Oct-2005	NBU 1022-8E	Natural Buttes	Uintah	630613	4424963	5219	10S	22E	08	SL	Anadarko	1620		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	4.18	68	2455	8.6	1.002	32	1024	59	11	360	850	38	732	1.01	Yes	
22	4304735864	31-Aug-2005	NBU 1022-8M	Natural Buttes	Uintah	630579	4424244	5267	10S	22E	08	SL	Anadarko	1540	1540	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			2815	9.1	1.003	16			4	720	720	10	976		Yes	Used average TDS for mapping - 3383 TDS
23	4304735864	19-Sep-2005	NBU 1022-8M	Natural Buttes	Uintah	630579	4424244	5267	10S	22E	08	SL	Anadarko	1540	1540	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			3660	9.9	1.003	43			6	240	1010	575	1098		Yes	Used average TDS for mapping - 3383 TDS
24	4304735864	22-Sep-2005	NBU 1022-8M	Natural Buttes	Uintah	630579	4424244	5267	10S	22E	08	SL	Anadarko	1540	1540	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			3675	9.9	1.003	43			6	240	1010	575	1098		Yes	Used average TDS for mapping - 3383 TDS
25	4304735865	19-Sep-2005	NBU 1022-8L	Natural Buttes	Uintah	630533	4424537	5307	10S	22E	08	SL	Anadarko	1590	1590	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			3060	10.0	1.003	60			24	360	805	375	976		Yes	
26	4304735866	25-May-2007	NBU 1022-8K	Natural Buttes	Uintah	630822	4424598	5316	10S	22E	08	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO			22178	7.7		377	8065		29	0			1574	0.07	No	Out of balance
27	4304735867	14-Oct-2005	NBU 1022-8A	Natural Buttes	Uintah	631931	4425413	5124	10S	22E	08	SL	Anadarko	390		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO			2720	9.5		28	1150		8	360	0		1098	0.58	Yes	
28	4304736491	21-Dec-2005	NBU 1022-9M	Natural Buttes	Uintah	632284	4424196	5179	10S	22E	09	SL	Anadarko	840		Green River - Birds Nest and above	Anadarko		Lab	NALCO			5855		0.000										Yes	Used average TDS in mapping - 6625 TDS
29	4304736491	22-Dec-2005	NBU 1022-9M	Natural Buttes	Uintah	632284	4424196	5179	10S	22E	09	SL	Anadarko	1420		Green River - Birds Nest and above	Anadarko		Lab	NALCO	1.05	68	7394	10.3	1.006	13	3199	66	24	1364	3125	25	679	1.01	Yes	Used average TDS in mapping - 6625 TDS
30	4304737170	26-Jun-2007	NBU 1022-10M	Natural Buttes	Uintah	633754	4424171	5215	10S	22E	10	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	12.63	68	2355	8.5	1.002	1	1085	2	0	192	280	180	1793	1.00	Yes	
31	4304738562	8-Feb-2007	NBU 1022-10C-1	Natural Buttes	Uintah	634280	4425649	5296	10S	22E	10	SL	Anadarko	1710		Green River - Birds Nest and above	Anadarko		Lab	NALCO	15.80	68	1855	9.4	1.002	18	816	3	6	540	200	50	915	1.07	Yes	
32	4304736402	29-May-2006	NBU 1022-12I	Natural Buttes	Uintah	638134	4424847	5228	10S	22E	12	SL	Anadarko	1470		Green River - Birds Nest and above	Anadarko	Swab	Lab		3.20	68	2962	8.1	1.002	40	1082	5	15	0	1105	225	976	1.03	Yes	
33	4304739478	19-Dec-2007	NBU 1022-13O1AS	Natural Buttes	Uintah	637424	4423046	5293	10S	22E	13	SL	Anadarko	1410		Green River - Birds Nest and above	Anadarko		Lab	NALCO			1650	8.5		1	729		0	204			793	0.62	Yes	
34	4304739481	19-Nov-2007	NBU 1022-13K3S	Natural Buttes	Uintah	637291	4423006	5287	10S	22E	13	SL	Anadarko	1410		Green River - Birds Nest and above	Anadarko		Lab	NALCO			2113	9.5		1	1015		0	684			342	0.64	Yes	
35	4304739482	19-Nov-2007	NBU 1022-13M1S	Natural Buttes	Uintah	637271	4422983	5287	10S	22E	13	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			1922	9.0		2	859		1	384			671	0.63	Yes	
36	4304739483	19-Nov-2007	NBU 1022-13M2AS	Natural Buttes	Uintah	637287	4423001	5278	10S	22E	13	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			2214	9.5		1	838		0	144			464	0.34	Yes	
37	4304739484	19-Nov-2007	NBU 1022-13N1S	Natural Buttes	Uintah	637278	4422992	5787	10S	22E	13	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			2172	10.6		0	1039		0	624			0	0.46	Yes	
38	4304739485	19-Nov-2007	NBU 1022-13L3S	Natural Buttes	Uintah	637295	4423010	5287	10S	22E	13	SL	Anadarko	1410		Green River - Birds Nest and above	Anadarko		Lab	NALCO			1917	9.5		1	946		0	744			293	0.72	Yes	
39	4304739486	19-Nov-2007	NBU 1022-13L4S	Natural Buttes	Uintah	637299	4423014	5287	10S	22E	13	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			1787	8.6		8	745		5	192			757	0.57	Yes	
40	4304739487	19-Nov-2007	NBU 1022-13N2S	Natural Buttes	Uintah	637283	4422997	5287	10S	22E	13	SL	Anadarko	1410		Green River - Birds Nest and above	Anadarko		Lab	NALCO			2068	9.3		1	1000		0	576			573	0.66	Yes	
41	4304739488	19-Nov-2007	NBU 1022-13M2CS	Natural Buttes	Uintah	637275	4422988	5278	10S	22E	13	SL	Anadarko	1400		Green River - Birds Nest and above	Anadarko		Lab	NALCO			2446	9.3	1.100	1053		0	504				408		Yes	
42	4304737736	20-Sep-2006	NBU 1022-14M2-S	Natural Buttes	Uintah	635492	4422677	5264	10S	22E	14	SL	Anadarko	1410	1410	Green River - Birds Nest and above	Anadarko		Lab	NALCO	7.45	68	1973	8.0	1.002	20	850	5	2	0	500	10	1464	1.00	Yes	
43	4304735943	29-May-2006	NBU 1022-16H	Natural Buttes	Uintah	633265	4423391	5247	10S	22E	16	SL	Anadarko	1530		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.20	68	3391	8.6	1.003	40	1196	2	12	0	1100	575	850	1.03	Yes	Used average TDS for mapping - 3701 TDS
44	4304735943	30-May-2006	NBU 1022-16H	Natural Buttes	Uintah	633265	4423391	5247	10S	22E	16	SL	Anadarko	1320		Green River - Birds Nest and above	Anadarko	Swab	Lab		3.00	68	4011	8.8	1.003	20	1558	5	6	240	1230	900	488	1.00	Yes	Used average TDS for mapping - 3701 TDS
45	4304735948	29-May-2006	NBU 1022-16G	Natural Buttes	Uintah	633009	4423559	5260	10S	22E	16	SL	Anadarko	1560		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	12.01	68	1609	9.5	1.002	2	765	2	5	360	250	25	915	1.02	Yes	
46	4304735986	2-Apr-2006	NBU 1022-17M	Natural Buttes	Uintah	630838	4422646	5281	10S	22E	17	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO	1.09	68	6477	9.7	1.005	40	2141	10	98	372	3250	250	0	1.06	Yes	
47	4304736084	19-Jun-2006	NBU 1022-17G	Natural Buttes	Uintah	631569	4423519	5233	10S	22E	17	SL	Anadarko	1530		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.41	68	3447	9.2	1.003	10	1751	4	6	1220	892	25	671	1.00	Yes	
48	4304737546	20-Oct-2007	NBU 1022-17J	Natural Buttes	Uintah	631483	4423106	5241	10S	22E	17	SL	Anadarko	1530		Green River - Birds Nest and above	Anadarko		Lab	NALCO	3.41	68	2719	9.4	1.002	37	1145	4	24	403	1000	50	695	1.01	Yes	
49	4304737549	29-Jan-2008	NBU 1022-18F	Natural Buttes	Uintah	629406	4423321	5148	10S	22E	18	SL	Anadarko	1380		Green River - Birds Nest and above	Anadarko		Lab	NALCO			1497	8.3		200	353		20	96			439	0.39	Yes	
50	4304737772	24-Oct-2006	NBU 1022-18J	Natural Buttes	Uintah	629782	4423030	5171	10S	22E	18	SL	Anadarko	1430		Green River - Birds Nest and above	Anadarko		Lab	NALCO	12.55	68	2104	9.7	1.002	25	990	4	4	480	300	50	1220	1.02	Yes	
51	4304737774	9-Oct-2006	NBU 1022-18B	Natural Buttes	Uintah	629812	4423742	5347	10S	22E	18	SL	Anadarko	1710		Green River - Birds Nest and above	Anadarko		Lab	NALCO	12.99	38	2056	9.6	1.002	10	952	5	3	480	250	350	732	1.00	Yes	
52	4304737775	18-Apr-2007	NBU 1022-18P	Natural Buttes	Uintah	630376	4422429	5215	10S	22E	18	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO	14.23	68	1873	9.1	1.002	8	872	6	4	252	260	100	1293	1.00	Yes	
53	4304737776	16-Aug-2006	NBU 1022-18D1	Natural Buttes	Uintah	629058	4423746	5046	10S	22E	18	SL	Anadarko	1440		Green River - Birds Nest and above	Anadarko		Lab	NALCO	7.02	68	2321	9.3	1.002	5	1151	4	2	660	500	0	915	1.01	Yes	
54	4304737778	20-Oct-2007	NBU 1022-19H	Natural Buttes	Uintah	630139	4421675	5289	10S	22E	19	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko		Lab	NALCO	3.41	68	2945	8.9	1.003	37	1136	4	22	44	1000	225	1183	1.01	Yes	
55	4304737781	30-May-2007	NBU 1022-19I	Natural Buttes	Uintah	630337	4421419	5265	10S	22E	19	SL	Anadarko	1440		Green River - Birds Nest and above	Anadarko		Lab	NALCO	15.24	68	2185	9.2	1.001	1	1167	4	1	768	240	20	1110	1.00	Yes	
56	4304737782	30-May-2007	NBU 1022-19O	Natural Buttes	Uintah	629859	4420986	5360	10S	22E	19	SL	Anadarko	1530		Green River - Birds Nest and above	Anadarko		Lab	NALCO	9.03	68	2932	9.8	1.003	1	1537	8	0	1176	460	165	708	1.00	Yes	
57	4304737219	7-Jul-2006	NBU 1022-20N	Natural Buttes	Uintah	631206	4421132	5297	10S	22E	20	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO	2.98	68	4464	9.3	1.004	20	2100	5	18	1050	1250	25	1403	1.00	Yes	
58	4304737220	16-Aug-2006	NBU 1022-20L	Natural Buttes	Uintah	630683	4421342	5280	10S	22E	20	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.41	68	3656	9.6	1.003	5	1680	29	128	750	1000	275	915	0.87	Yes	
59	4304737221	16-Oct-2006	NBU 1022-20F	Natural Buttes	Uintah	631183	4421826	5299	10S	22E	20	SL	Anadarko	1420	1420	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	8.00	68	2749	9.7	1.003	12	1478	1	3	1080	250	25	1342	1.01	Yes	
60	4304737355	16-Oct-2007	NBU 1022-20J	Natural Buttes	Uintah	631500	4421550	5366	10S	22E	20	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko		Lab	NALCO	6.54	68	2139	9.6	1.002	5	1053	3	1	600	300	210	817	1.00	Yes	
61	4304736091	20-Oct-2007	NBU 1022-21G	Natural Buttes	Uintah	633043	4421947	5359	10S	22E	21	SL	Anadarko	1560	1560	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.65	68	2803	9.6	1.003	3	1329	1	0	671	380	430	976	1.00	Yes	
62	4304737171	20-Oct-2007	NBU 1022-21M	Natural Buttes	Uintah	632270	4421032	5359	10S	22E	21	SL	Anadarko	1500		Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	6.43	68	2924	9.7	1.003	24	1420	5	1	793	500	190	1147	1.00	Yes	
63	4304736705	26-Jun-2007	NBU 1022-23E	Natural Buttes	Uintah	635315	4422027	5301	10S	22E	23	SL	Anadarko	1380	1380	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	4.69	68	2898	9.2	1.003	1	1221	3	0	240	580	590	1013	1.00	Yes	
64	4304737743	17-Jul-2007	NBU 1022-23E3-S	Natural Buttes	Uintah	635308	4422017	5301	10S	22E	23	SL	Anadarko	1350	1350	Green River - Birds Nest and above	Anadarko		Lab	NALCO	4.82	68	2421	9.4	1.002	1	1070	9	0	360	560	320	769	1.00	Yes	Used average TDS for mapping - 2857 TDS
65	4304737743	17-Jul-2007	NBU 1022-23E3-S	Natural Buttes	Uintah	635308	4422017	5301	10S	22E	23	SL	Anadarko	1440	1440	Green River - Birds Nest and above	Anadarko		Lab	NALCO	4.43	68	3292	9.9	1.003	1	1652	4	0	1068	680	215	781	1.00	Yes	Used average TDS for mapping - 2857 TDS
66	4304736709	26-Jun-2007	NBU 1022-26D	Natural Buttes	Uintah	635470	4420609	5430	10S	22E	26	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO	4.38	68	4394	9.5	1.004	1	2235	2	0	1176	850	0	2086	1.00	Yes	
67	4304735735	12-May-2006	FEDERAL 1022-28O	Natural Buttes	Uintah	633075	4419445	5460	10S	22E	28	SL	Anadarko	1560	1560	Green River - Birds Nest and above	Anadarko		Lab	NALCO	2.83	68	3484	9.3	1.003	44	1284	45	120	660	1324	325	183	1.00	Yes	
68	4304735858	29-Jan-2007	NBU 1022-30C	Natural Buttes	Uintah	629533	4420468	5314	10S	22E	30	SL	Anadarko	1800	1800	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	6.50	68	5352	10.0	1.006	1	2976	10	0	2760	500	25	1525	1.01	Yes	
69	4304735859	29-Jan-2007	NBU 1022-30B	Natural Buttes	Uintah	629966	4420726	5399	10S	22E	30	SL	Anadarko	1800	1800	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	13.19	68	5801	10.0	1.006	1	3365	6	0	3420	300	0	1586	1.01	Yes	
70	4304735755	19-Jun-2006	BONANZA 1023-1K	Natural Buttes	Uintah	647182	4426650	5454	10S	23E	01	SL	Anadarko	1410	1410	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	6.43	68	2135	8.4	1.002	16	771	6	2	60	567	450	580	1.06	Yes	
71	4304735662	20-Mar-2007	BONANZA 1023-2O	Natural Buttes	Uintah	645860	4426171	5457	10S	23E	02	SL	Anadarko	1100	1100	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	14.10	68	1780	8.9	1.002	76	670	3	24	96	350	65	1305	1.02	Yes	
72	4304737094	7-Jul-2006	BONANZA 1023-2D	Natural Buttes	Uintah	644978	4427309	5390	10S	23E	02	SL	Anadarko	1380	1380	Green River - Birds Nest and above	Anadarko		Lab	NALCO	1.64	68	3364	9.0	1.003	10	1406	5	3	420	1520	175	122	1.01	Yes	
73	4304737095	4-Dec-2006	BONANZA 1023-2B	Natural Buttes	Uintah	645793	4427257	5427	10S	23E	02	SL	Anadarko	1590	1590	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	8.05	68	1643	8.6	1.002	5	742	4	1	240	500	0	671	1.01	Yes	
74	4304737224	29-Jan-2007	BONANZA 1023-2N	Natural Buttes	Uintah	645413	4426045	5432	10S	23E	02	SL	Anadarko	1500	1500	Green River - Birds Nest and above	Anadarko		Lab	NALCO	9.30	68	1441	9.1	1.001	40	580	4	6	180	400	25	610	1.00	Yes	
75	4304737225	14-Dec-2006	BONANZA 1023-2L	Natural Buttes	Uintah	645007	4426549	5451	10S	23E	02	SL	Anadarko			Green River - Birds Nest and above	Anadarko		Lab	NALCO	9.30	68	1326	9.5	1.001	10	562	4	6	240	400	50	366	1.03	Yes	
76	4304738762	20-Mar-2007	BONANZA 1023-2O-1	Natural Buttes	Uintah	645985	4426251	5481	10S	23E	02	SL	Anadarko	1470	1470	Green River - Birds Nest and above	Anadarko		Lab	NALCO	18.87	68	1105	8.3	1.001	4	496	8	2	156	175	120	586	1.00	Yes	Used average TDS for mapping - 1390 TDS
77	4304738762	5-Apr-2007	BONANZA 1023-2O-1	Natural Buttes	Uintah	645985	4426251	5481	10S	23E	02	SL	Anadarko	1540	1540	Green River - Birds Nest and above	Anadarko		Lab	NALCO	8.65	68	1674	8.7	1.002	16	710	3	24	252	480	45	683	1.01	Yes	Used average TDS for mapping - 1390 TDS
78	4304735629	14-Oct-2005	BONANZA 1023-4M	Natural Buttes	Uintah	641813	4426007	5354	10S	23E	04	SL	Anadarko	1170	1170	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	4.15	68	2695	8.4	1.002	39	978	35	13	60	710	600	732	1.00	Yes	Used average TDS for mapping - 2888 TDS
79	4304735629	15-Oct-2005	BONANZA 1023-4M	Natural Buttes	Uintah	641813	4426007	5354	10S	23E	04	SL	Anadarko	1470	1470	Green River - Birds Nest and above	Anadarko	Swab	Lab	NALCO	3.40	68	3080	8.2	1.003	40	1148	29	12	0	985	475	976	1.00	Yes	Used average TDS for mapping - 2888 TDS
80	4304737315	18-Sep-2007	BONANZA 1023-4D	Natural Buttes	Uintah	641743	4427198	5280	10S	23E	04	SL	Anadarko	1530	1530	Green River - Birds Nest and above	Anadarko		Lab	NALCO	1.64	68	3437	9.0	1.003	16	1423	0	2	108	1600	3	866	1.00	Yes	
81	4304737328	16-Oct-2007	BONANZA 1023-4B	Natural Buttes	Uintah	642629	4427255	5365	10S	23E	04	SL	Anadarko	1620	1620	Green River - Birds Nest and above	Anadarko		Lab	NALCO	6.54	68	1465	8.3	1.002	12	623	1	5	120	300	180	732	1.00	Yes	
82	4304736741	7-Feb-2007	BONANZA 1023-5K	Natural Buttes	Uintah	640652	4426388	5328	10S	23E	05	SL	Anadarko	1650	1650	Green River - Birds Nest and above	Anadarko		Lab	NALCO	18.87	68	1187	9.0	1.001	20	468	3	6	150	150	25	793	1.04	Yes	
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Appendix III: Task 4 Final Report

Baseline Water Quality and Estimated Quantity for Selected Sites in the Southeastern Uinta Basin, Utah

by:

Janae Wallace

Utah Geological Survey

July 2012

(Will be published as UGS Open-File Report 595 in fall 2012)

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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.

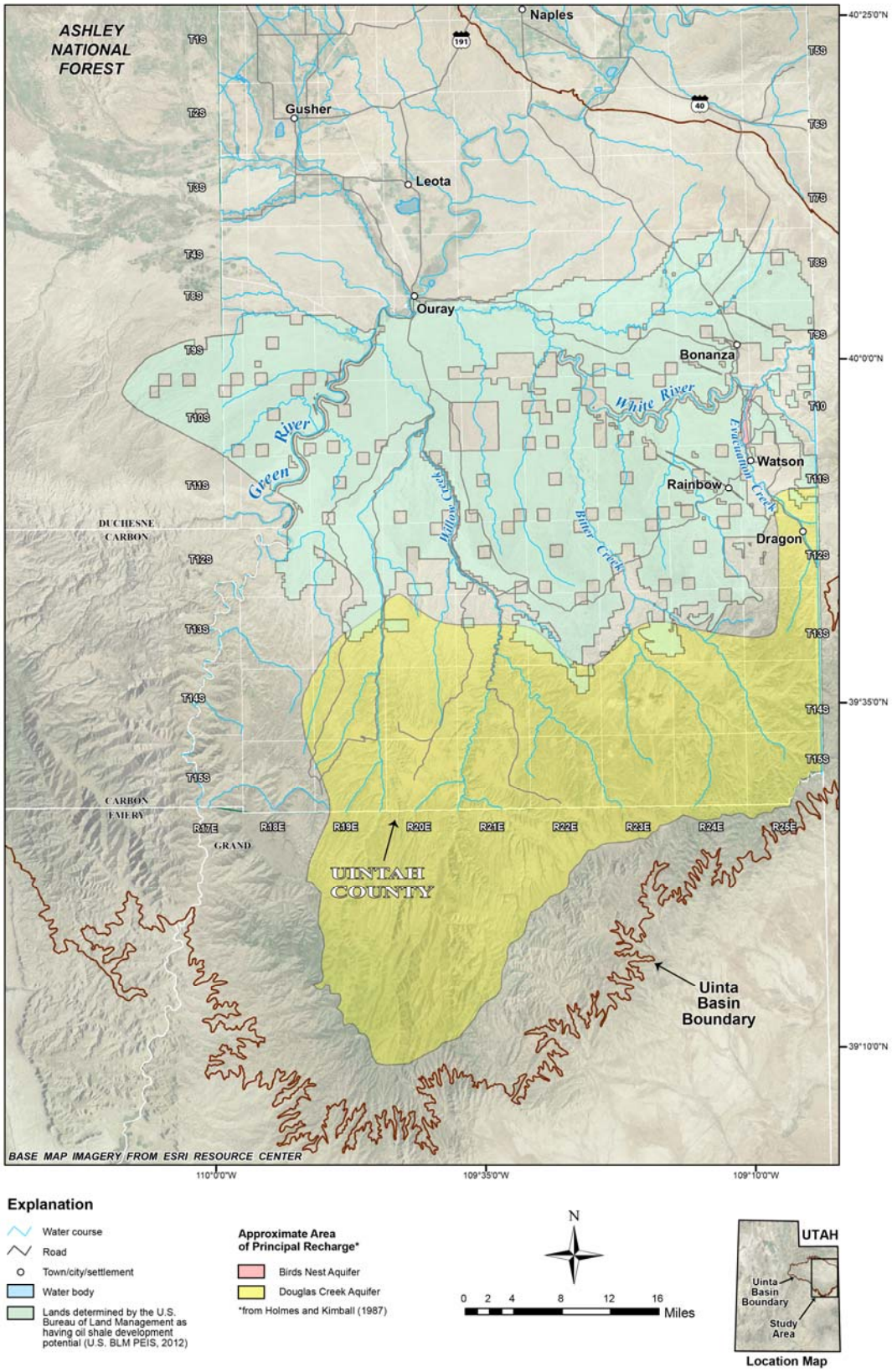

Figure 1. *Location map of the Uinta eastern Basin study area.*

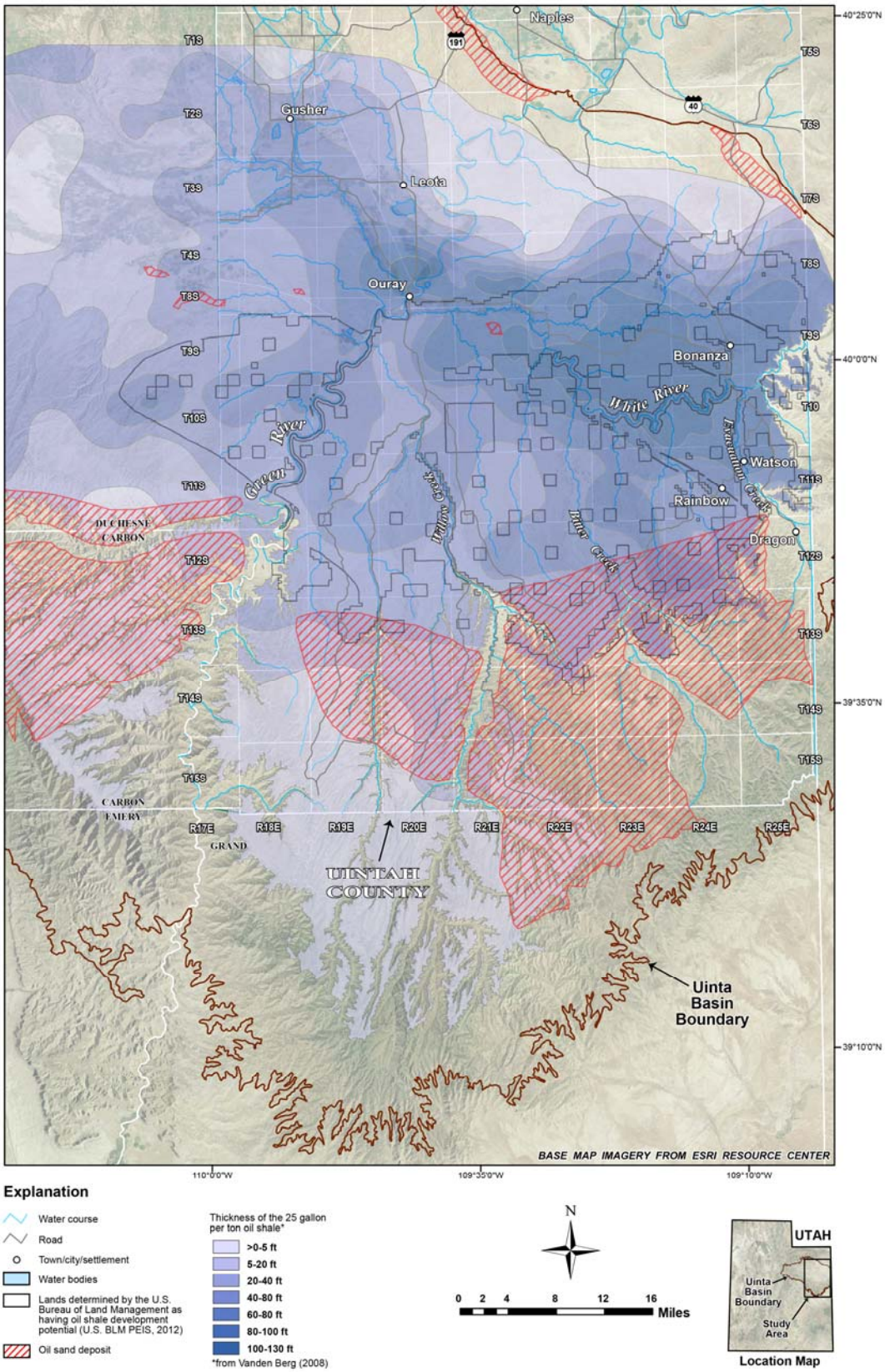

Figure 2. *Oil shale and oil sand deposits in the eastern Uinta Basin.*

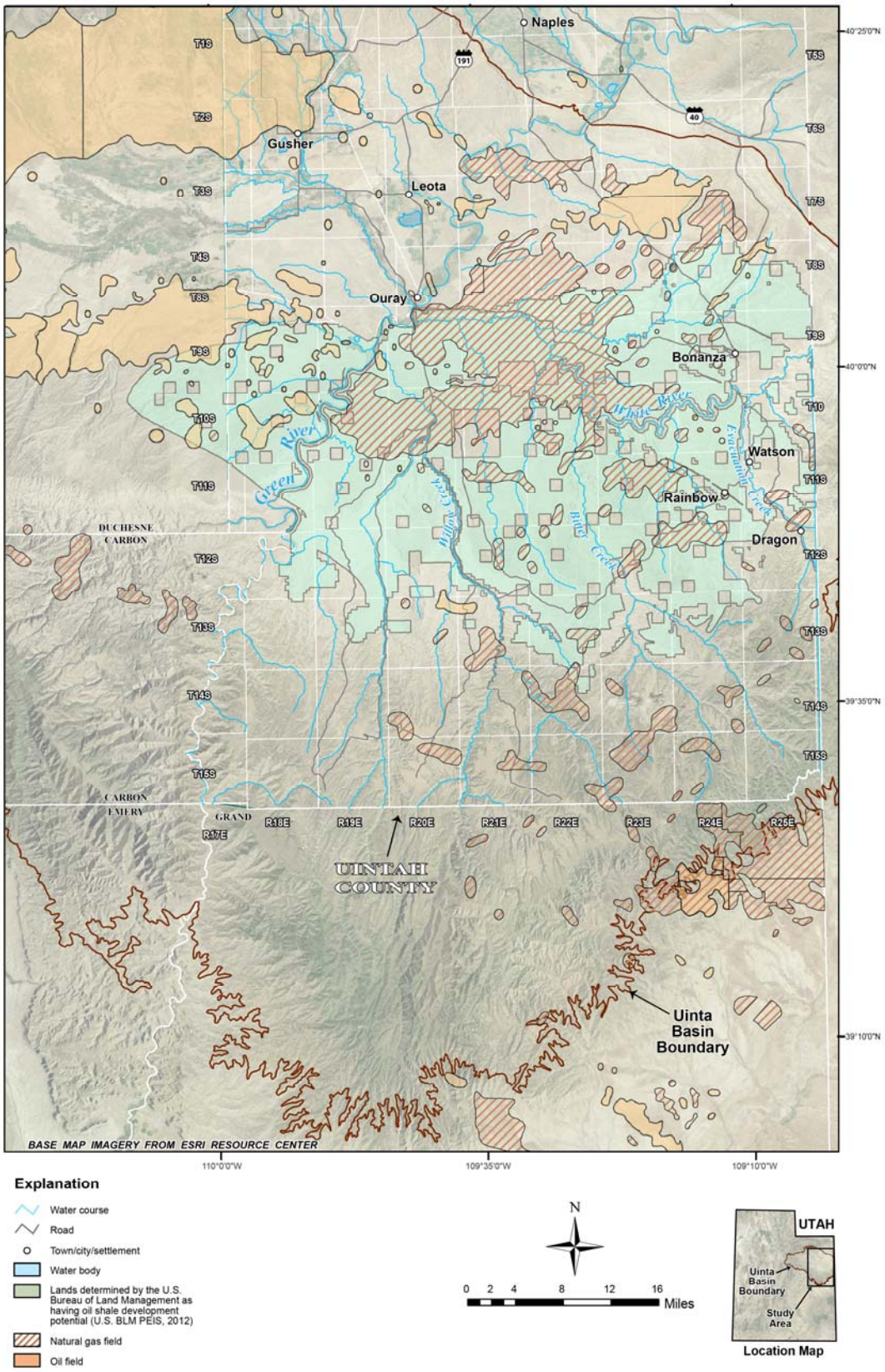

Figure 3. *Natural gas and crude oil fields in the eastern Uinta Basin.*

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. 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). 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 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).

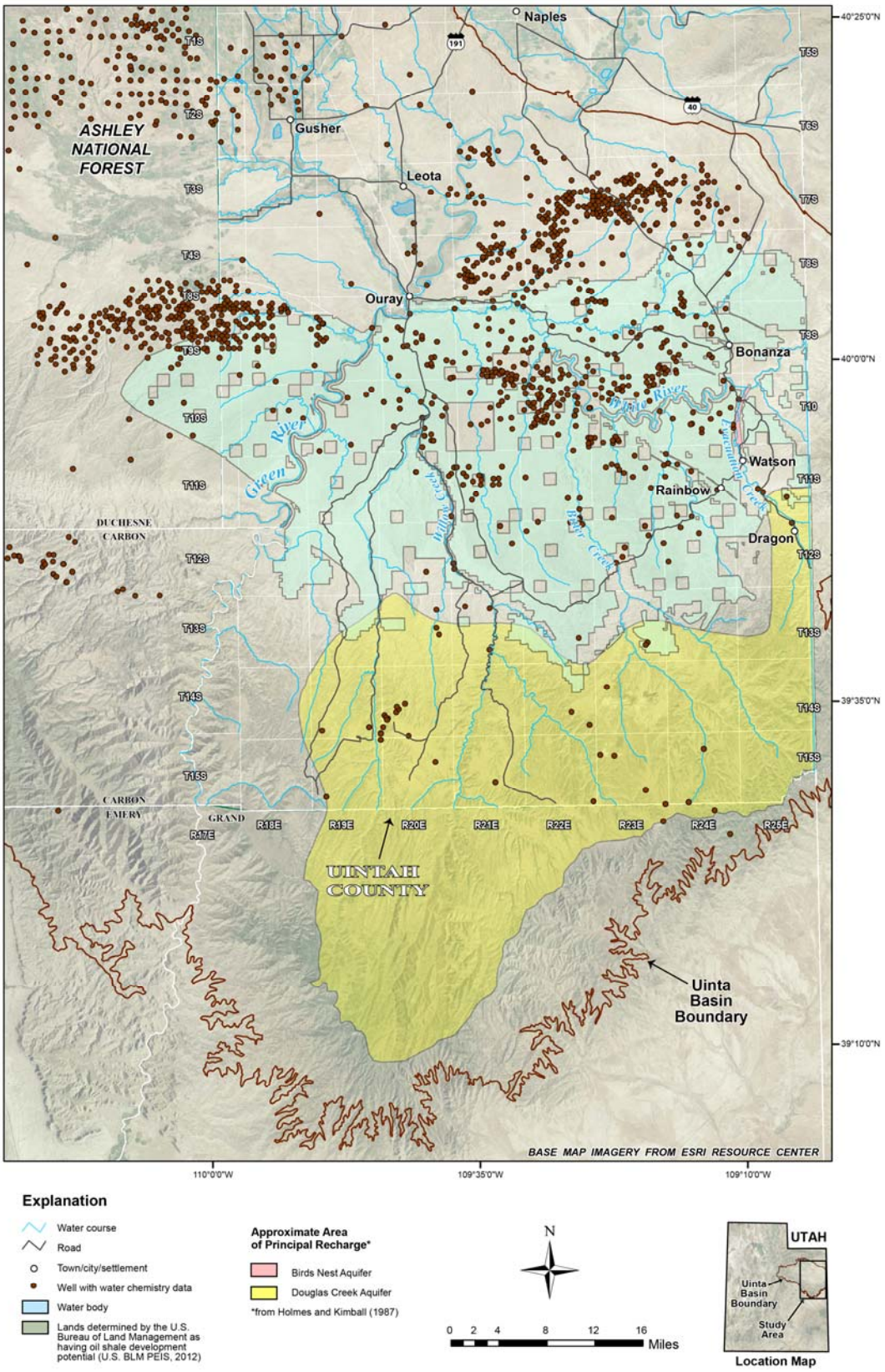

Figure 4. *Location of wells with water-quality data in the eastern Uinta Basin (wells listed in appendix A).*

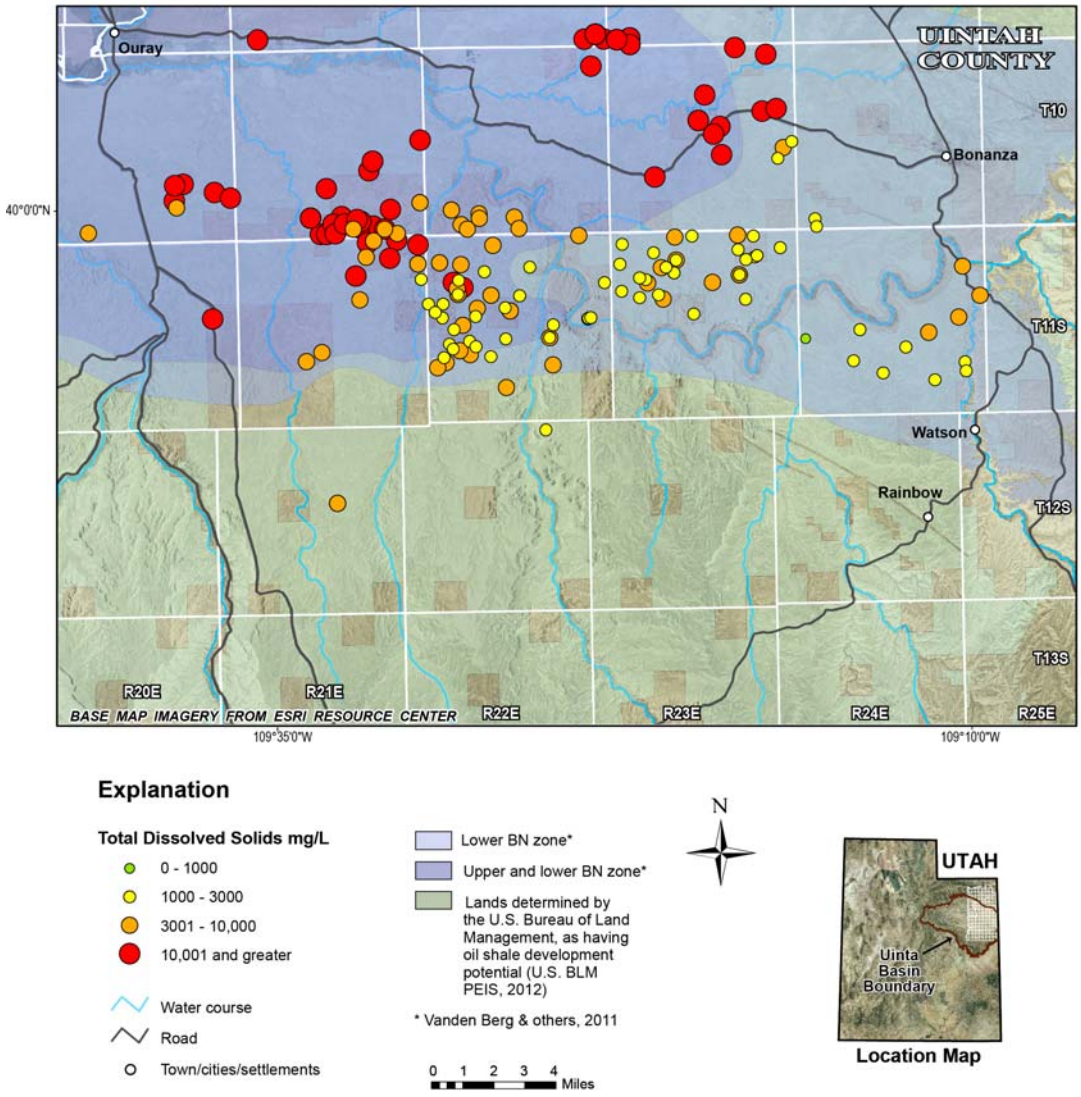

Figure 5. *Total-dissolved-solids concentrations for water in the Birds Nest aquifer.*

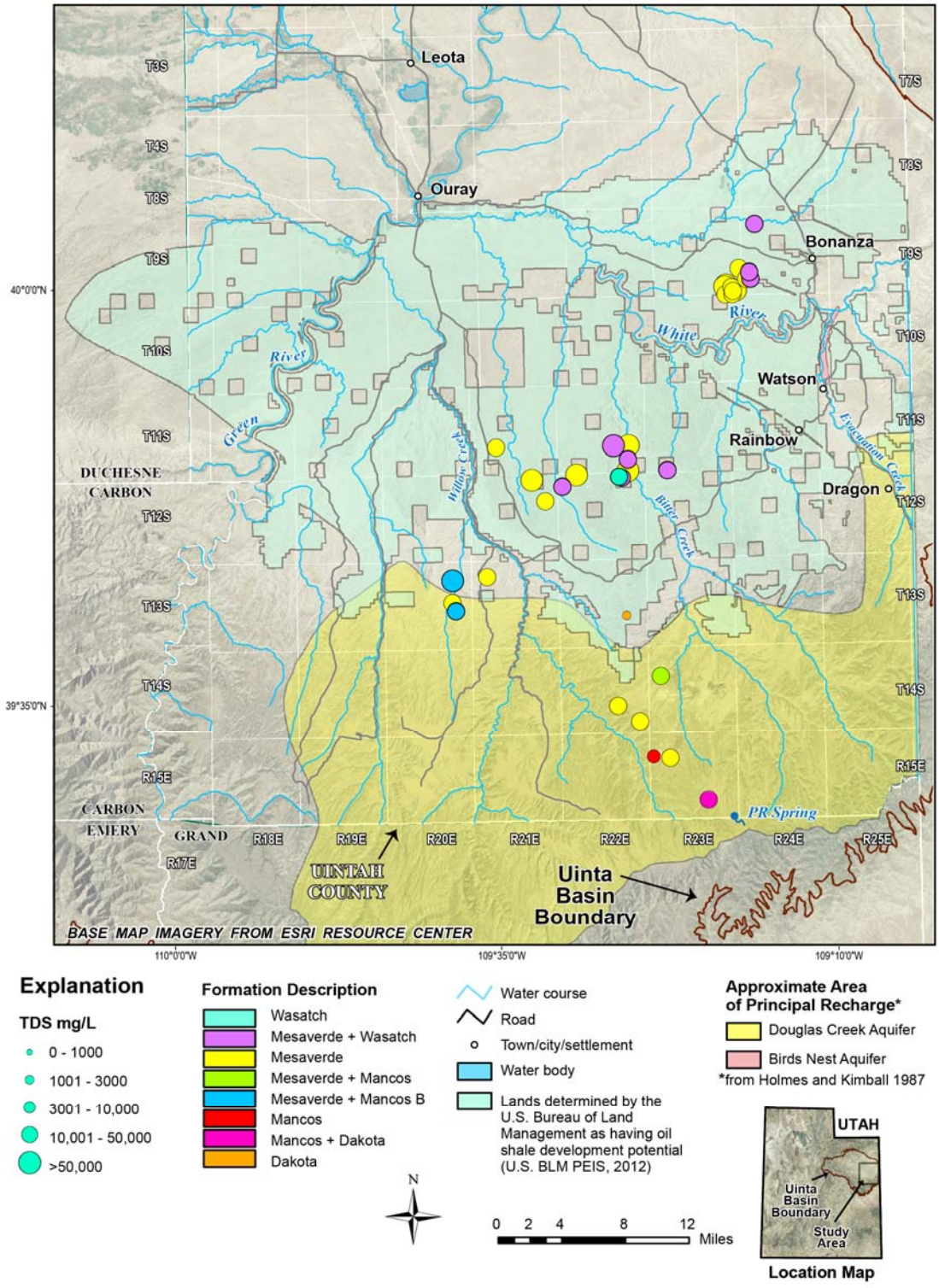

Figure 6. *Total-dissolved-solids concentration data from Zhang and others (2009). The majority (86%) of wells have saline water quality (>10,000 mg/L).*

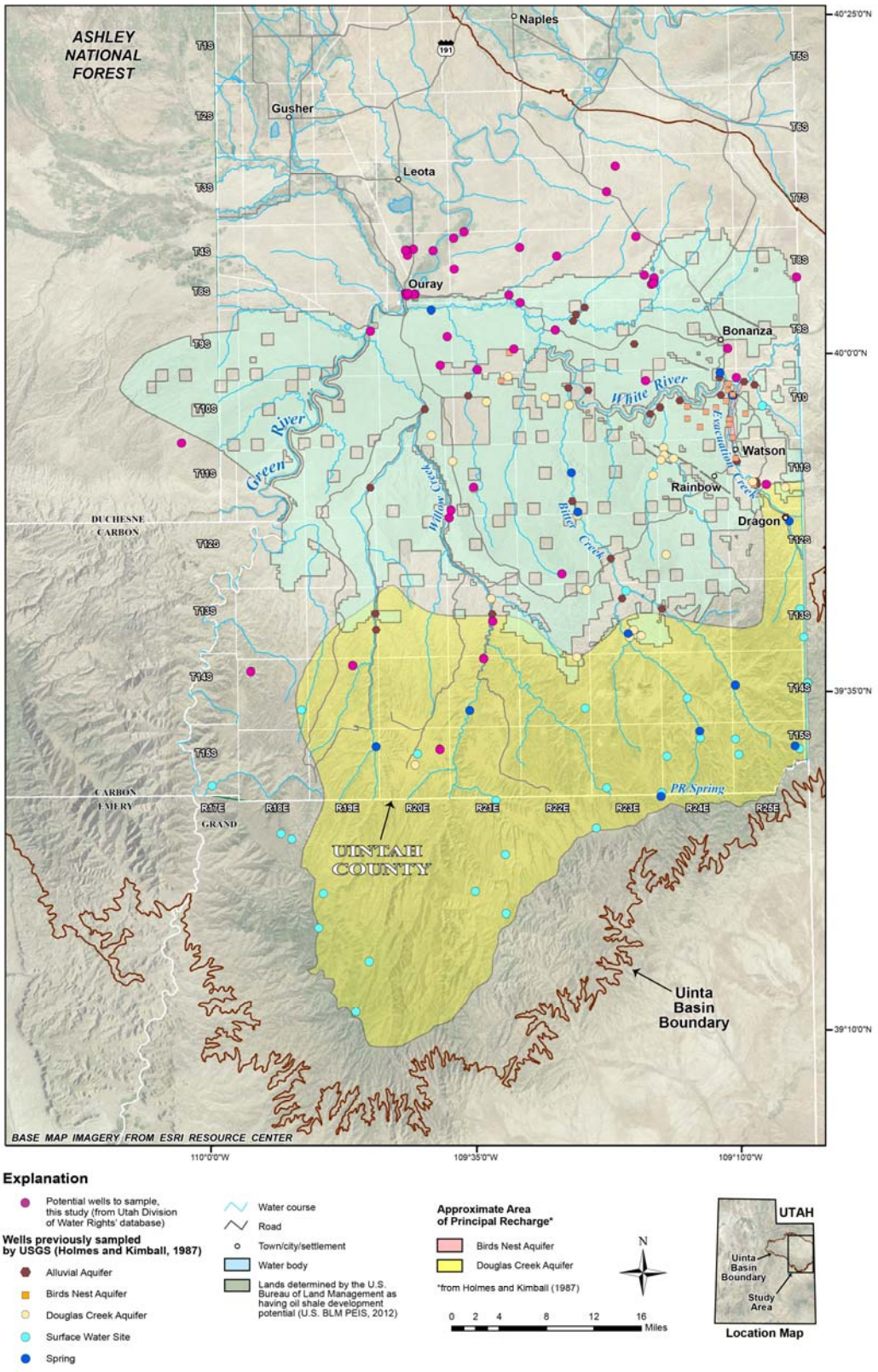

Figure 7. *Pre-study map showing potential wells, and other surface sampling sites; field investigation discovered most of the sites are unavailable.*

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 well1	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 condistions

[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

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

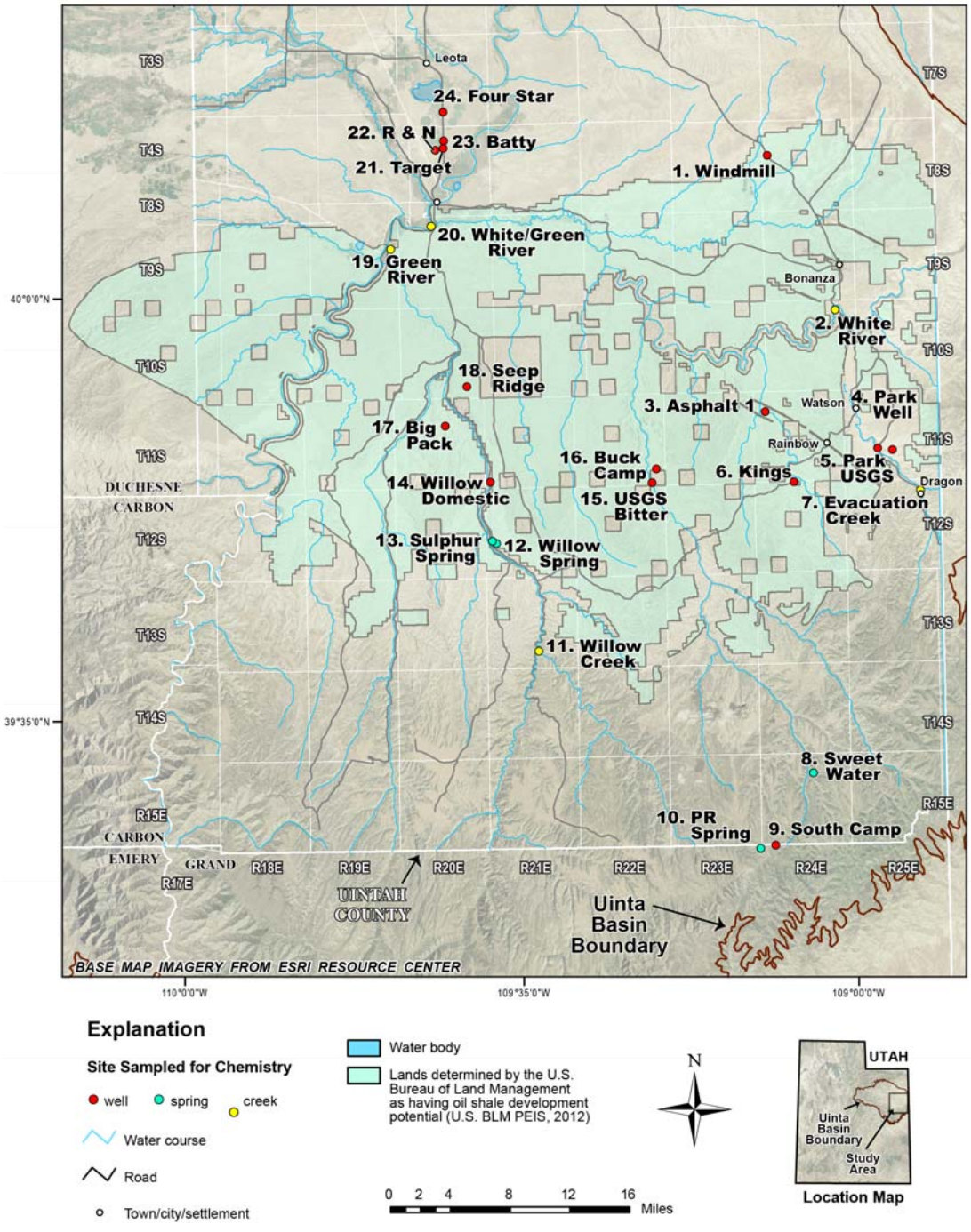

Figure 8. *Sampling sites for this study.*

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 penetrating 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-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

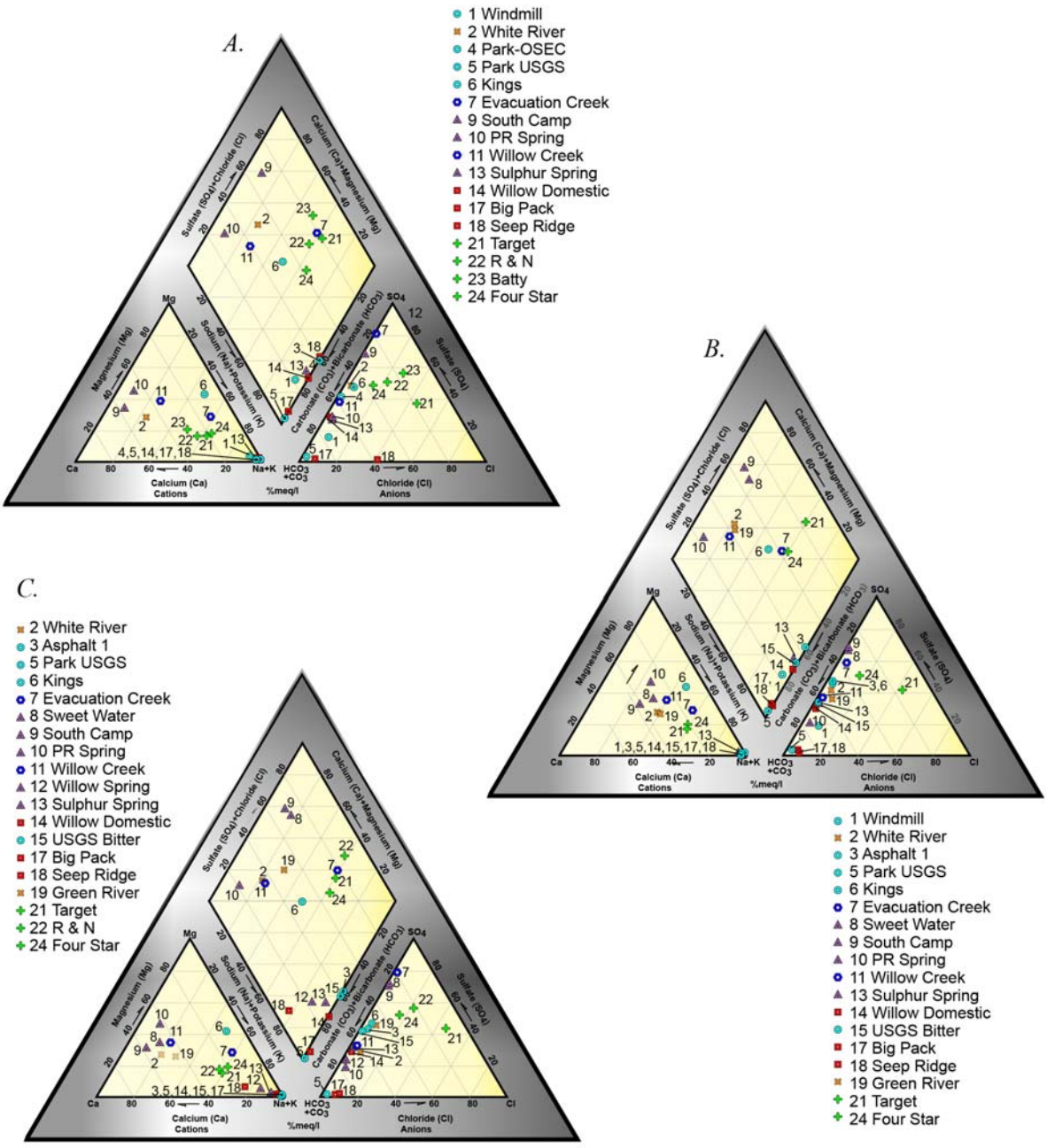

Figure 9. *General solute chemistry for sampling sites for three different years. A) 2009 data for 17 sites, B) 2010 data for 18 sites, and C) 2011 data for 19 sites sampled in the southeastern Uinta Basin. Overall solute chemistry is variable throughout the study area but relatively consistent for each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

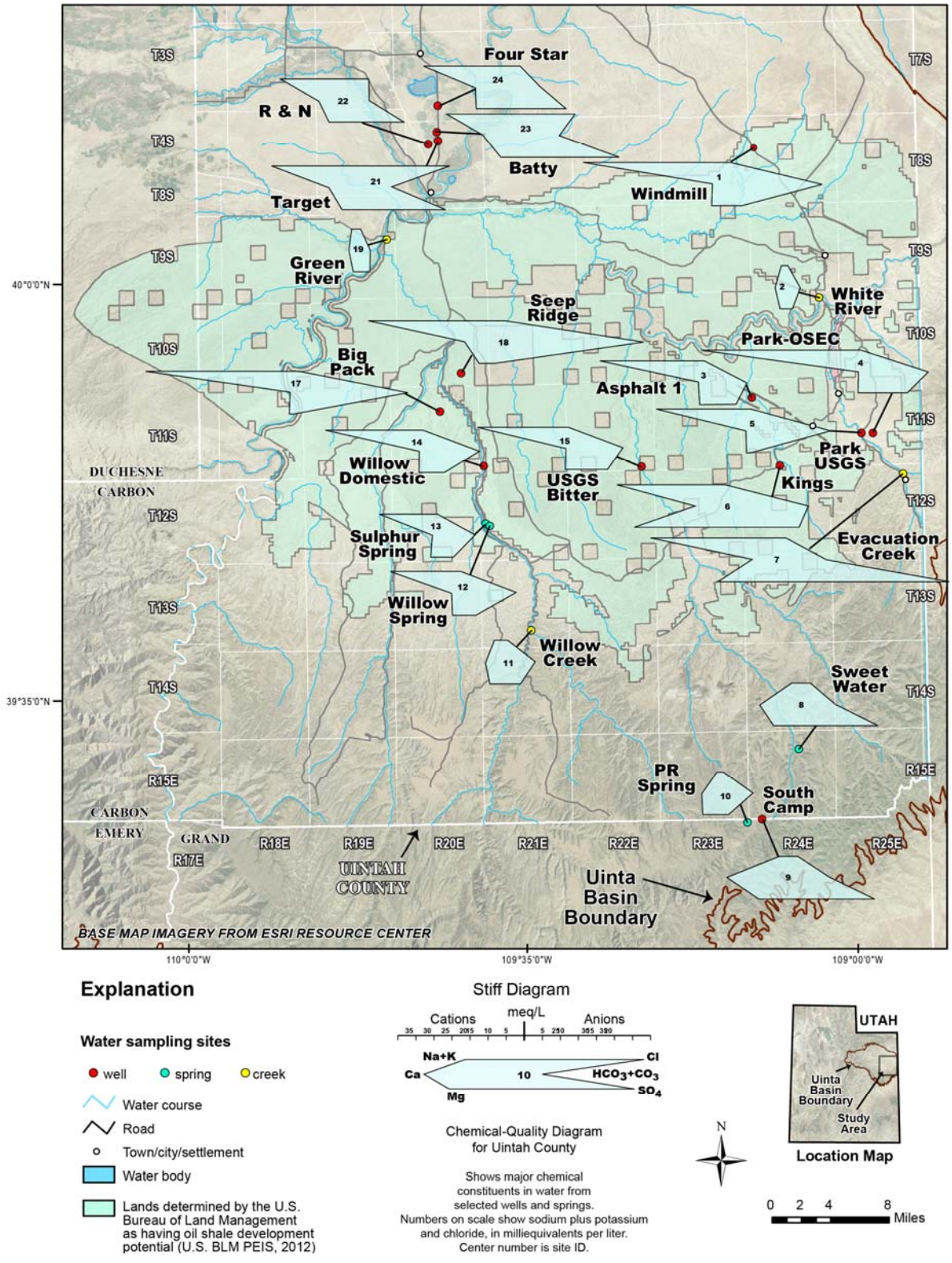

Figure 10. *Stiff diagrams for solute chemistry in the southeastern Uinta Basin. Most data are from 2011, except sites 1, 4, and 23, which were sampled in 2009.*

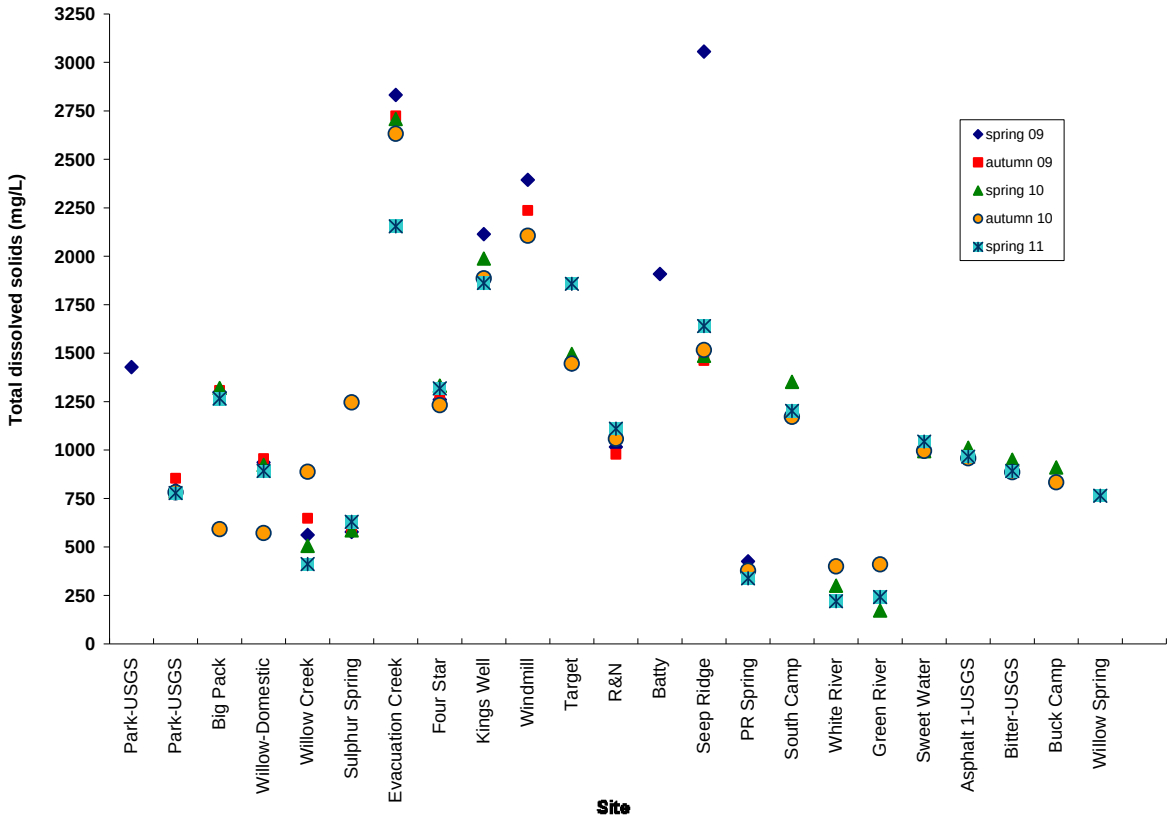

Figure 11. *Total-dissolved-solids concentrations for each sample site for up to five different seasons.*

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 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.

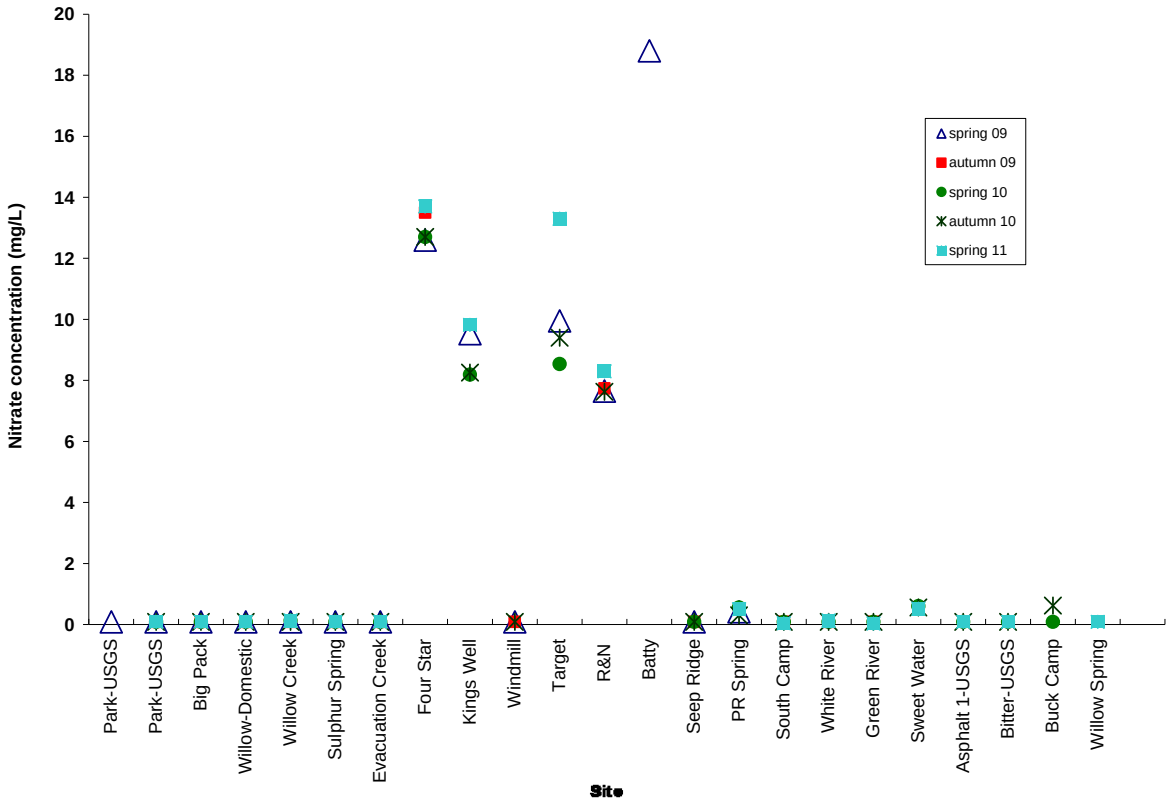

Figure 12. *Nitrate concentration over five different sampling seasons. Points plotting at "0" on the x-axis indicate a lab analysis report of <0.1 mg/L nitrate concentration.*

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

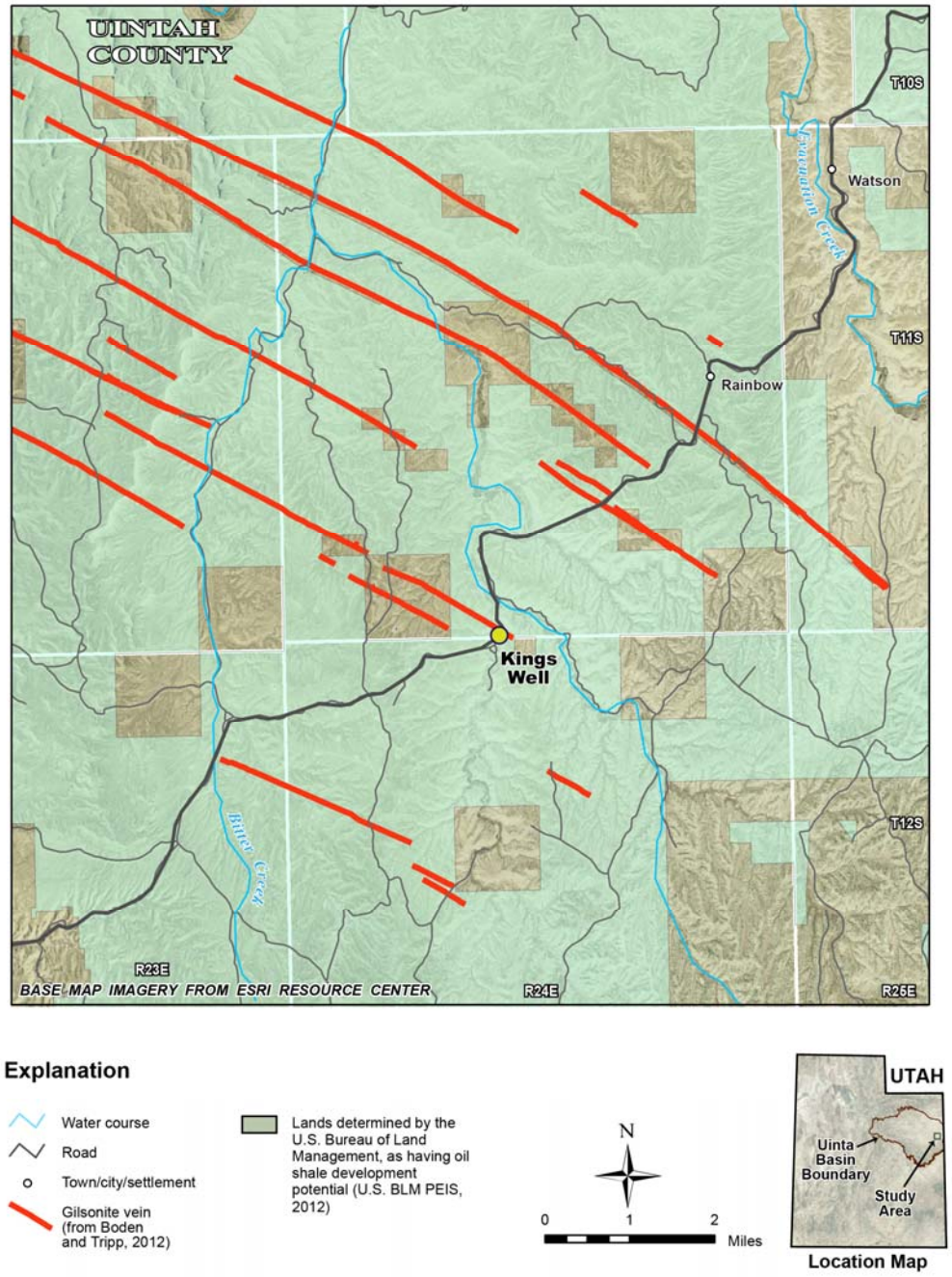

Figure 14. *Gilsonite vein map showing the location of Kings well (site 6) near a gilsonite vein.*

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 concentration 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.

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,

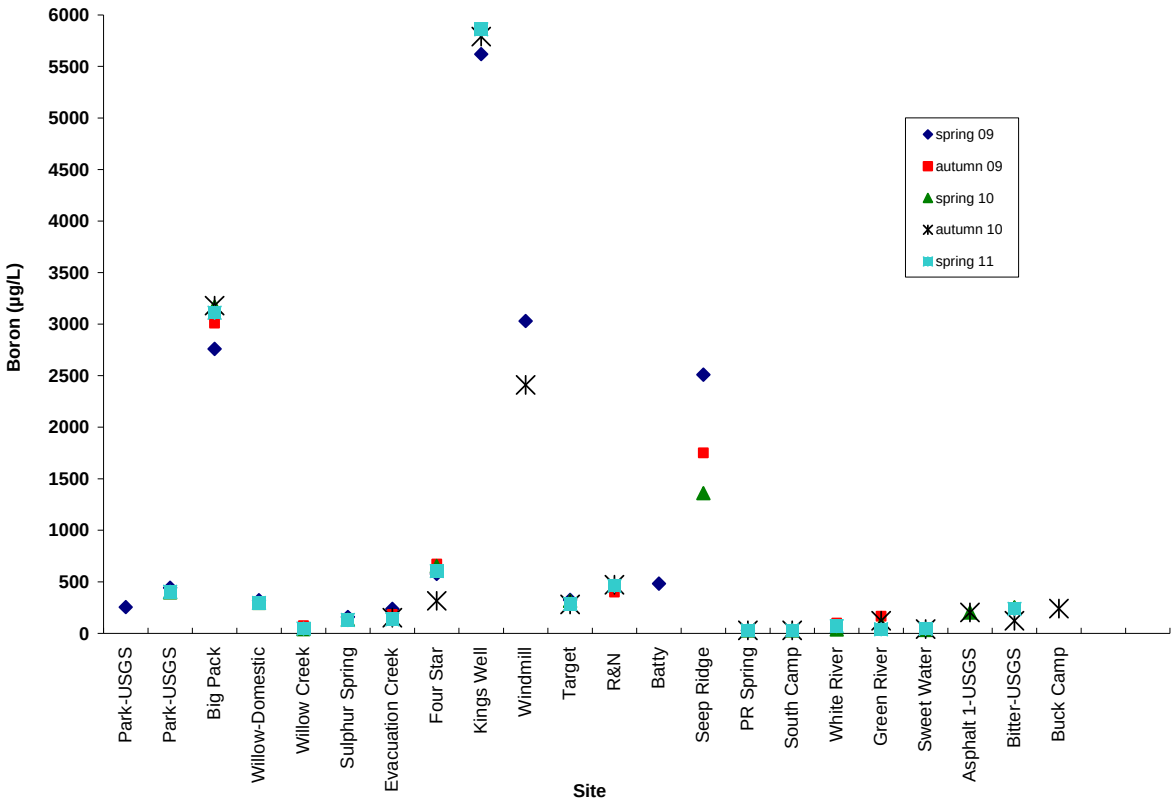

Figure 15. *Boron concentration for each sample site over five different sampling seasons. Points plotting on "0" on the x-axis have concentrations below the detection level of 30 µg/L.*

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 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.

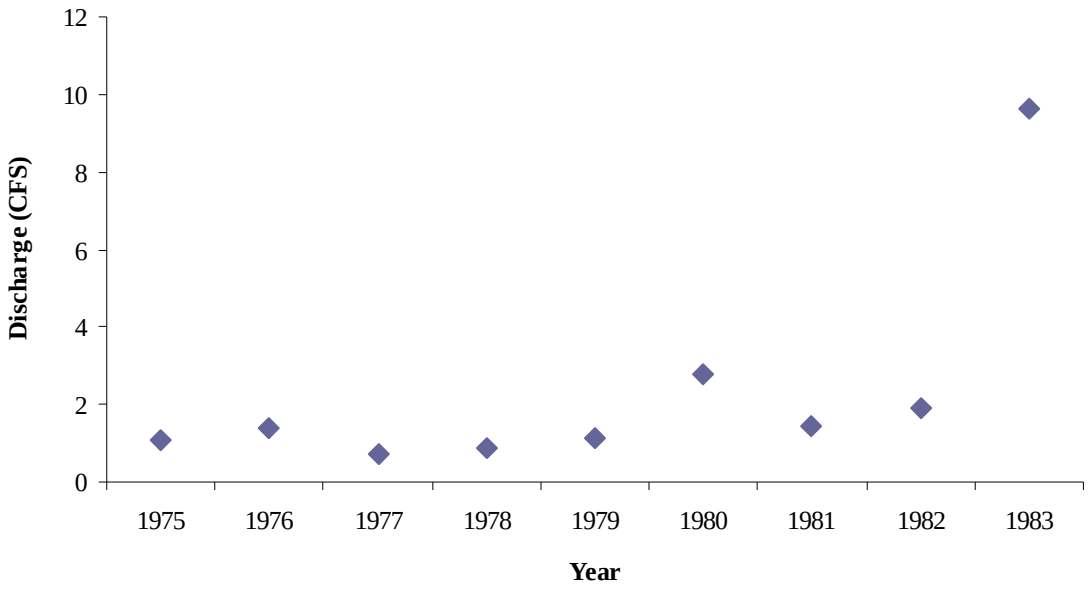

Figure 16. *Discharge versus year for Evacuation Creek; these dates are the only data available for this site (data and graph from the USGS, 2011).*

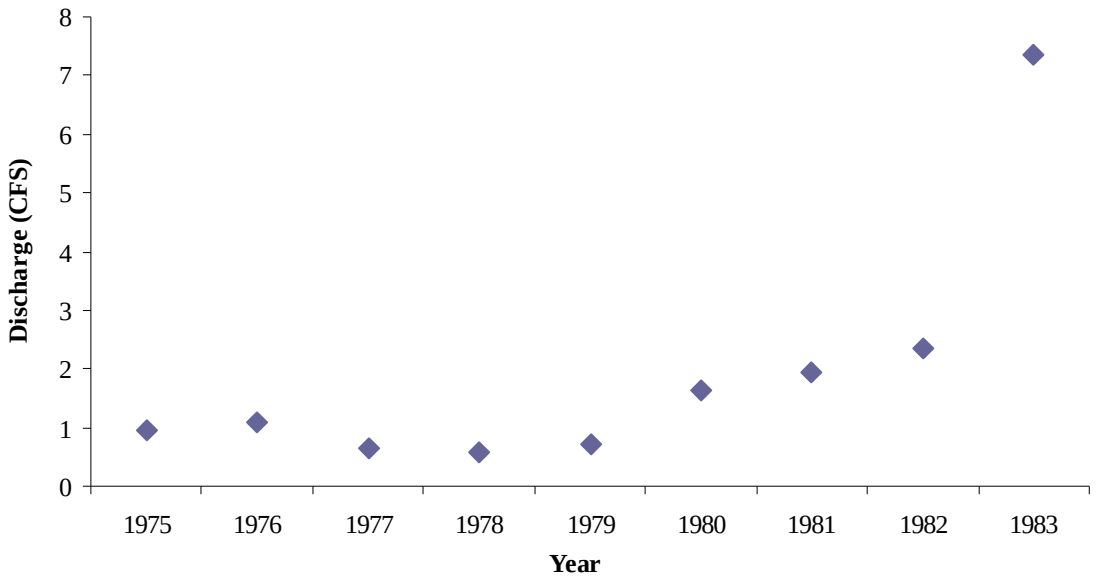

Figure 17. *Discharge versus year for Bitter Creek; these dates are the only available data for this site (data and graph from the USGS, 2011). The station name is formally designated by the USGS and does not indicate the water flows near the community of Bonanza.*

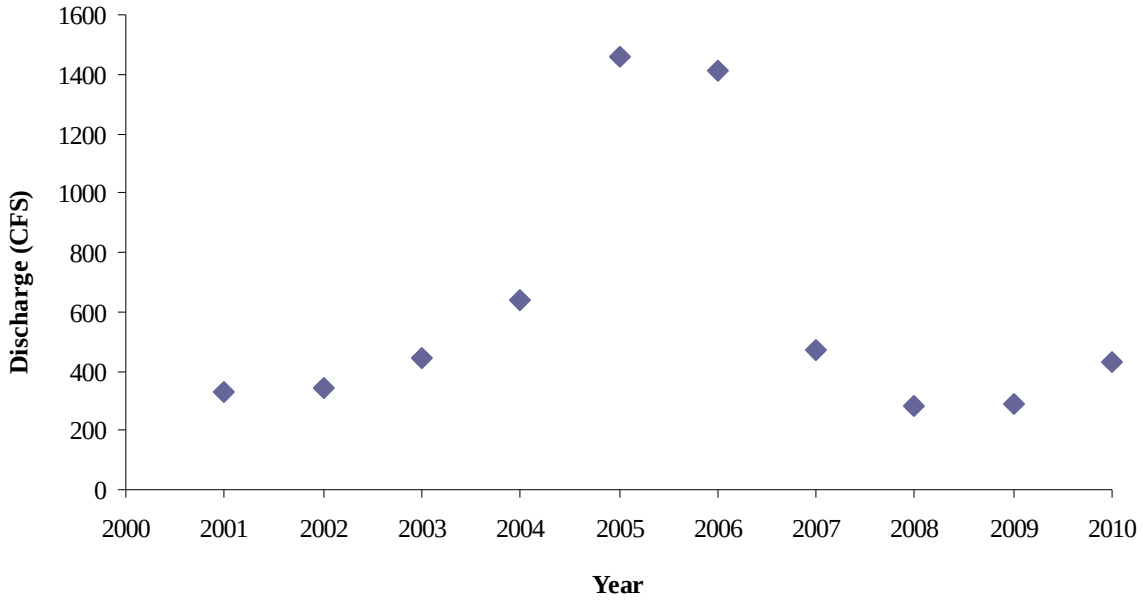

Figure 18. *Discharge versus year for the White River near Watson; the station name is designated by the USGS and does not indicate the water flows near the old site of Watson (data and graph from the USGS, 2011).*

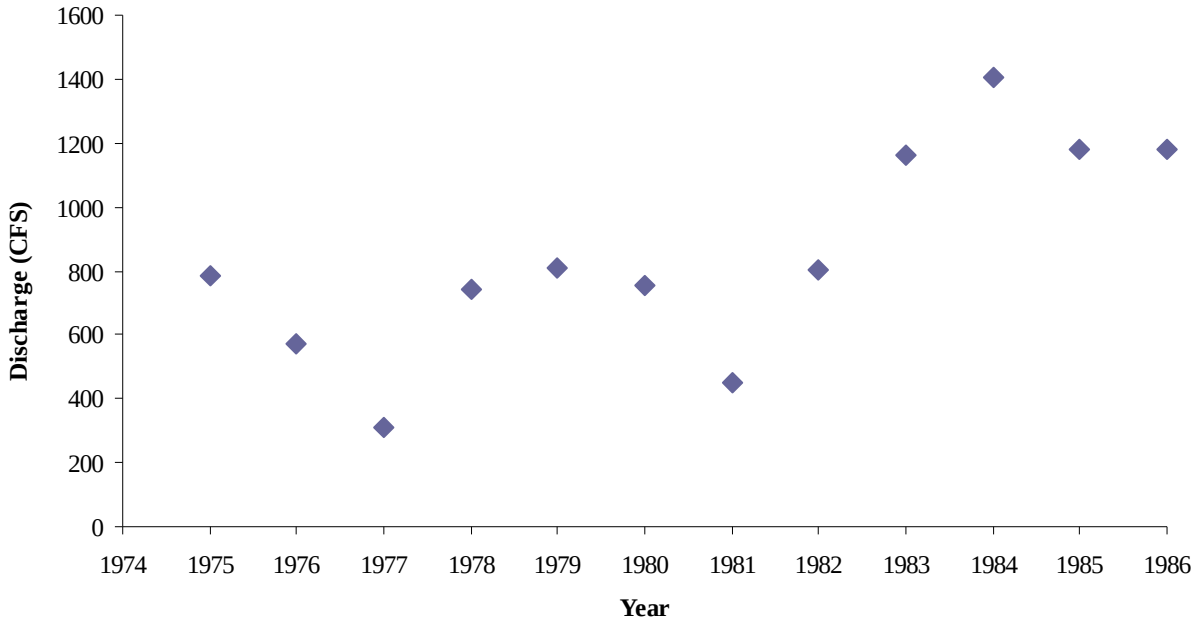

Figure 19. *Discharge versus year for the White River near Ouray (data and graph from the USGS, 2011).*

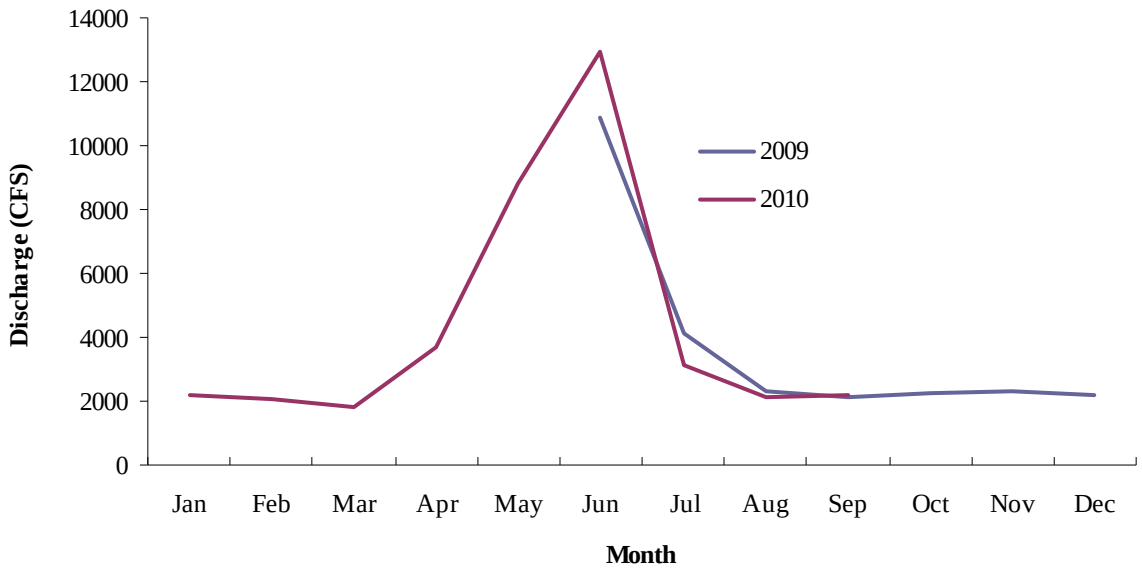

Figure 20. *Discharge versus month for two different years for the Green River near Ouray (data and graph from the USGS, 2011).*

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 aquifer 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 duding 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

This project was generously funded by the U.S. Department of Energy, National Energy Technology Laboratory under project code NT0005671. Additional funding was provided by the Utah Geological Survey. Special thanks to our DOE project officers Traci Rodosta, Virginia Weyland, and Skip Pratt.

Stan Olmsted and Elizabeth Gamber of the U.S. Bureau of Land Management, Vernal office (BLM), provided field assistance and research on some sources of water wells. David Hackford (Utah Division of Oil, Gas, and Mining) helped with field reconnaissance and provided information on potential well sites. Scott Hacking (Utah Department of Environmental Quality [UDEQ]) and Darrin Brown (Tri-County Health Department) provided information on PR Spring and South Camp well sources. Miles Hanberg (Utah Division of Wildlife Resources) confirmed potential sampling sites and staff from the Ouray National Wildlife Refuge helped locate potential sites to sample near the Green River. Critical review comments were provided by Scott Hacking (UDEQ), Elizabeth Gamber (BLM), and Mike Lowe, Michael Vanden Berg, and Mike Hylland (Utah Geological Survey [UGS]). Kim Nay (UGS) prepared the figures and maps for this publication.

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Appendix A. *Water chemistry database for wells in the Uinta Basin, Uintah County, and extended areas in surrounding counties.*
Subset of data from appendix A in Anderson and others, 2012

Number	API	Sample Date	Well Name	Field Name	County	UTM E	UTM N	Elevation	Elevation Datum	Township	Range	Section	Meridian	Data Source	Sample Depth Top	Sample Depth Base	Formation	Sampled by	Type of Sample	Analysis Method	Lab Name	Raw R_w	Temp Raw R_w	TDS	pH	Specific Gravity	Ca	Na	K	Mg	CO_3	Cl	SO_4	Bicarbonate	Anion/ Cation ratio	Used in Mapping BMSW	Comments
						NAD 83	NAD 83	ft							ft	ft						ohms-m	°F	mg/L			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L			
1115	4301930135	30-May-06	ANDERSON FED 1	San Arroyo	Grand	656286	4365501	8240	GR	16S	25E	08	S	Zhang, 2009	6934	7042	Dakota	Zhang	Separator	Lab	U of Wy			364	6.5	1.001	9	72	5	2	113	4	165	1.55417	No	Suspect analysis, carbonate and bicarbonate combined as alkalinity, posted as bicarbonate
1116	4301930567	25-Jul-07	UTON 1		Grand	647276	4367182	8278	GR	16S	24E	05	S	Zhang, 2009	7692	7852	Dakota	Zhang/Sadlier	Separator	Lab	U of Wy			135	8.2	1.000	36	6	1	0	8	16	69	0.80869	No	Out of balance
1117	4301931030	30-May-06	FEDERAL 31-1	East Canyon	Grand	653874	4367053	7714	KB	16S	24E	01	S	Zhang, 2009	6113	6339	Dakota	Zhang	Separator	Lab	U of Wy			135	6.8	1.001	1	9	1	0	5	5	114	4.15275	No	Suspect analysis, carbonate and bicarbonate combined as alkalinity, posted as bicarbonate
1118	4301931046	30-May-06	FEDERAL 34-31	San Arroyo	Grand	654212	4368678	8409	GR	15.5S	25E	31	S	Zhang, 2009	7349	7539	Dakota	Zhang	Separator	Lab	U of Wy			3442	6.7	1.003	161	1087	19	23	1981	31	159	1.02505	No	No water production for years before sample date ??
1119	4301931046	30-May-06	FEDERAL 34-31	San Arroyo	Grand	654212	4368678	8409	GR	15.5S	25E	31	S	Zhang, 2009	7349	7539	Dakota	Zhang	Storage Tank	Lab	U of Wy			12201	6.7	1.010	640	3860	131	97	7136	196	271	0.99361	No	No water production for years before sample date ??
1120	4304710008	12-Oct-61	GOVT-WOLF 2	Love	Uintah	619070	4414998	5497	KB	11S	21E	07	S	UGS Circular 87	4715	4736	Wasatch	Humble Oil	DST	Lab		0.23	68	35961	7.0		804	12457	0	211	0	17500	4827	329	1.00034	Yes	Rec GTS, +300' GCMW & 554' MSW
1121	4304710008	12-Oct-61	GOVT-WOLF 2	Love	Uintah	619070	4414998	5497	KB	11S	21E	07	S	UGS Circular 87	5119	5147	Wasatch	Humble Oil	DST	Lab		0.21	68	39188	6.0		925	13738	0	138	0	19500	4605	573	1.00038	Yes	Rec 1230' MSW, grossly ok
1122	4304710008	12-Oct-61	GOVT-WOLF 2	Love	Uintah	619070	4414998	5497	KB	11S	21E	07	S	UGS Circular 87	6324	6369	Wasatch	Humble Oil	DST	Lab		0.19	68	44212	7.4		375	16716	0	81	0	25000	1638	817	1.00029	No	Rec 135' M & 90' MW
1123	4304710008	12-Oct-61	GOVT-WOLF 2	Love	Uintah	619070	4414998	5497	KB	11S	21E	07	S	UGS Circular 87	5918	5998	Wasatch	Humble Oil	DST	Lab		0.10	68	92395	8.1		123	36018	0	78	0	55000	876	610	1.00028	No	GTS 3 min, .25% MW
1124	4304710008	12-Oct-61	GOVT-WOLF 2	Love	Uintah	619070	4414998	5497	KB	11S	21E	07	S	USGS produced water database	7632	7653	Mesaverde		DST	Lab				13613	8.2		11	5357	0	5	0	7300	255	1074	0.97801	No	Rec 455' WCM, 91 MCW, 572' WC
1125	4304710033		UTE TRIBE "A" 1		Uintah	605194	4439801	5077	KB	4S	2E	28	U	UGS Circular 87	5319	5383	Green River	Amerada Hess	DST	Lab		0.97	77	9784	9.0	1.008	20	3008	0	17	333	823	1663	3921	0.99936	No	Rec 200' O&GCM
1126	4304710059	26-Sep-63	ATLANTIC-ALPINE-SOUTHLAND 22-2		Uintah	624614	4372506	7414	DF	15S	21E	22	S	UGS Circular 87	3134	3142	Wasatch	Atlantic Richfield	DST	Lab		1.79	77	1880			20	664	0	36	12	1070	3	149	1.00745	Yes	Rec 1482' HGCW
1127	4304710059	28-Sep-63	ATLANTIC-ALPINE-SOUTHLAND 22-2		Uintah	624614	4372506	7414	DF	15S	21E	22	S	UGS Circular 87	3466	3480	Wasatch	Atlantic Richfield	DST	Lab		0.68	77	11900			80	3770	0	36	14	355	7580	156	0.99944	Yes	Rec 525' brackish water, SO4 very high?
1128	4304710059		ATLANTIC-ALPINE-SOUTHLAND 22-2		Uintah	624614	4372506	7414	DF	15S	21E	22	S	USGS Salt Lake District Office	3134	3142	Wasatch							1966	8.4		20	663		36		1065	3	173	1.00395	Yes	C14-86
1129	4304710102	22-Sep-65	STAGECOACH U 9-25	Natural Buttes	Uintah	628289	4439929	4758	KB	8S	21E	25	S	UGS Circular 87	3370	3394	Green River	Belco Petroleum	DST	Lab		0.47	68	16613	8.0		17	6781	19	3	0	5600	51	8406	1.00087	Yes	Rec 2980' GCWOSCM, some contamination
1130	4304710102	22-Sep-65	STAGECOACH U 9-25	Natural Buttes	Uintah	628289	4439929	4758	KB	8S	21E	25	S	UGS Circular 87	3516	3525	Green River	Belco Petroleum	DST	Lab		0.28	68	26959	8.0		13	10684	35	3	0	14200	75	3953	1.00083	Yes	Rec 600' GCWOSCM, some contamination
1131	4304710102	22-Sep-65	STAGECOACH U 9-25	Natural Buttes	Uintah	628289	4439929	4758	KB	8S	21E	25	S	USGS produced water database	3370	3394	Green River		DST	Lab				16727	8.2		17	6831	19	3	0	5600	49	8540	1.00079	Yes	Rec 2980' GCWOSCM, some contamination
1132	4304710105	4-Mar-65	WHITE RIVER 40-18	Kennedy Wash	Uintah	639112	4442523	5245	KB	8S	23E	18	S	UGS Circular 87	5344	5374	Green River	Belco Petroleum	DST	Lab		0.42	68	18354	8.1		120	6910	20	36	0	9900	1150	439	1.00119	Yes	Water in sample chamber
1133	4310710201	1-May-56	RWU (47) 41-9F		Uintah	652309	4445115	5461	KB	8S	24E	09	S	UGS Circular 87	1818	1836	Green River	Chevron	DST	Lab		2.59	77	2390			35	890	0	9	84	850	200	630	1.00160	Yes	From recovery of 362' of "muddy water"
1134	4304710201	23-May-56	RWU (47) 41-9F		Uintah	652309	4445115	5461	KB	8S	24E	09	S	UGS Circular 87	1818	1836	Green River	Chevron	DST	Lab		2.85	68	2394	8.3	1.003	35	897	0	9	84	853	206	632	0.99989	Yes	From recovery of 362' of "muddy water"
1135	4304710203	20-Apr-60	RWU 100 (43-21A)	Red Wash	Uintah	632961	4450579	5345	KB	7S	22E	21	S	UGS Circular 87	5760	5790	Green River	Chevron	Production	Lab		0.59	68	14510	8.3		47	5976	0	7	1	2740	453	10736	0.99941	Yes	
1136	4304710204	31-Oct-61	RWU 157 (34-35B)		Uintah	645447	4446980	5574	KB	7S	23E	35	S	UGS Circular 87	2649	2689	Green River	Chevron	DST	Lab		2.30	68	3671	8.4		6	1459	0	2	288	820	424	1365	1.00001	No	DST 3, rec 1825' SOCGMW
1137	4304710204	31-Oct-61	RWU 157 (34-35B)		Uintah	645447	4446980	5574	KB	7S	23E	35	S	UGS Circular 87	2648	2682	Green River	Chevron	DST	Lab		2.20	68	3674	8.7		80	1370	0	16	276	660	420	1730	1.00020	No	DST 2, rec 1922' GCMW
1138	4304710205	2-Jul-62	RED WASH 169 (21-35A)		Uintah	635429	4448219	5487	KB	7S	22E	35	S	UGS Circular 87	6681	6707	Wasatch	California Oil	DST	Lab		0.25	68	28636	7.3		368	10612	0	85	0	16000	1325	500	1.00033	Yes	Rec 90' WCM, 650' MW, 450' W
1139	4304710205	3-Jul-62	RED WASH 169 (21-35A)		Uintah	635429	4448219	5487	KB	7S	22E	35	S	UGS Circular 87	5195	5211	Green River	California Oil	DST	Lab		3.35	68	2280	8.6		20	888	0	3	48	190	380	1525	0.99983	No	Rec 75' MW
1140	4304710205	3-Jul-62	RED WASH 169 (21-35A)		Uintah	635429	4448219	5487	KB	7S	22E	35	S	UGS Circular 87	5929	5947	Green River	California Oil	DST	Lab		0.98	68	3394	8.0		68	2464	0	12	0	3150	205	1146	1.00312	No	Rec 180' MW
1141	4304710205	3-Jul-62	RED WASH 169 (21-35A)		Uintah	635429	4448219	5487	KB	7S	22E	35	S	USGS produced water database	4980	5000	Green River		DST	Lab				17496	7.9		31	7061				7400	0	6100	1.00011	Yes	Rec 85' SGCMW, 840' SGCW
1142	4304710206	17-Apr-63	RWU 187 (32-31C)	Red Wash	Uintah	648626	4447856	5328	KB	7S	24E	31	S	UGS Circular 87	3788	3805	Green River	Chevron	DST	Lab		2.83	77	2330			1	1000	2	0	132	124	12	2160	0.99883	Yes	Rec 3092' SGCW
1143	4304710206	17-Apr-63	RWU 187 (32-31C)	Red Wash	Uintah	648626	4447856	5328	KB	7S	24E	31	S	UGS Circular 87	4990	5007	Green River	Chevron	DST	Lab		1.00	68	7528	8.2		17	2668	8	3	72	3100	74	1586	1.00024	Yes	Rec 311' GCW
1144	4304710206	17-Apr-63	RWU 187 (32-31C)	Red Wash	Uintah	648626	4447856	5328	KB	7S	24E	31	S	UGS Circular 87	3895	3912	Green River	Chevron	DST	Lab		1.02	68	11182	8.4		11	3279	10	5	264	870	20	6722	1.00055	Yes	Rec 233' GCW
1145	4304710209	29-Oct-65	RWU 211 (32-35C)	Red Wash	Uintah	655043	4447948	5556	GR	7S	24E	35	S	UGS Circular 87	3390	3408	Green River	Chevron	DST	Lab		10.90	68	669	8.8		6	274	1	3	60	16	50	549	0.99995	No	DST 4, rec 850' SG&MCW
1146	4304710209	29-Oct-65	RWU 211 (32-35C)	Red Wash	Uintah	655043	4447948	5556	GR	7S	24E	35	S	UGS Circular 87	2145	2185	Green River	Chevron	DST	Lab		5.25	68	1385	8.5		9	547	1	1	120	148	200	732	0.99937	Yes	DST 5, rec 2145' HGCW
1147	4304710209	29-Oct-65	RWU 211 (32-35C)	Red Wash	Uintah	655043	4447948	5556	GR	7S	24E	35	S	UGS Circular 87	4793	4823	Green River	Chevron	DST	Lab		2.35	68	3008	8.3		36	1132	10	7	24	680	428	1403	1.00036	No	DST 2, rec 547' SGC&MCW
1148	4304710210		WRU 2	Kennedy Wash	Uintah	634680	4443636	4920	DF	8S	22E	10	S	UGS Circular 87	3985	4086	Green River	Standard of California	DST	Lab		1.00	68	7531	8.2		1	3158	0	1	167	1580	16	5300	0.99878	No	Rec 3827' G&WCM
1149	4304710210		WRU 2	Kennedy Wash	Uintah	634680	4443636	4920	DF	8S	22E	10	S	USGS produced water database	5840	5853				DST	Lab				45206	6.8		1151	16160		215		27000	481	405	1.00030	No	Rec 60' salt water, 940' M
1150	4304710211	17-Apr-62	WRU 10 (41-4D)	White River	Uintah	632943	4446566	5179	KB	8S	22E	04	S	UGS Circular 87	5675	5686	Green River	California Oil	DST	Lab		0.22	68	36747	7.7		162	14091	0	104	0	20500	940	1928	0.99980	Yes	Last rec 616' water
1151	4304710262	27-Feb-53	MC CONKIE FEE 1		Uintah	620857	4480264	5534	KB	4S	21E	16	S	DOGM well file	7805	7867	Weber			Continental Oil Company		11.39		714	8.6	1.001	28	120		26	28	213	183	1.37377	No	DST contamination likely, out of balance
1152	4304710262	3-Mar-53	MC CONKIE FEE 1		Uintah	620857	4480264	5534	KB	4S	21E	16	S	DOGM well file	5852		Navajo			Continental Oil Company		2.05		1894	11.7	1.006	35	675			261	71	705			0.81585	No	DST contamination likely, out of balance
1153	4304710298	8-May-64	PARIETTE BENCH U 5	8 Mile Flat North	Uintah	594566	4432773	4990	KB	9S	18E	09	S	UGS Circular 87	3783	3786	Green River	Davis Oil	Swab	Lab		0.50	68	14349	7.8		22	5624	40	24	0	5900	650	4233	1.00246	Yes	Sample just prior to plugging; added top depth interval (?), questionable
1154	4304710401		COTTONWOOD WASH U 1	Love	Uintah	621976	4411338	5755	GR	11S	21E	21	S	UGS Circular 87	4725	4768	Wasatch	Great Lakes Natural Gas	Swab	Lab		0.16	68	51474	6.8		1279	17697	0	439	0	27300	4687	145	1.00037	Yes	
1155	4304710451	14-May-64	WVU 16	Wonsits Valley	Uintah	628487	4446083	5167	GR	8S	22E	06	S	UGS Circular 87	4808	4816	Green River	Gulf	DST	Lab		0.63	68	10958	6.5		1040	2213	48	383	0	5750	136	988	1.00180	No	Assumed perfs per well file, may not be representative, no production
1156	4304710451		WVU 16	Wonsits Valley	Uintah	628487	4446083	5167	GR	8S	22E	06	S	UGS Circular 87	5850	5871	Green River	Gulf	DST	Lab		0.12	77	59631	7.3	1.042	333	22546	0	178	0	34594	886	1094	1.00021	Yes	Rec 90' M, 270' MW, 3914' Salt W
1157	4304710451		WVU 16	Wonsits Valley	Uintah	628487	4446083	5167	GR	8S	22E	06	S	UGS Circular 87	5850	5871	Green River	Gulf	DST	Lab		0.12	77	61541	7.1	1.043	334	23386	0	117	0	35670	939	1095	1.00018	Yes	Rec 90' M, 270' MW, 3914' Salt W
1158	4304710575	1-Nov-61	HAGER 1	Natural Buttes	Uintah	645818	4427038	5452	GR	10S	23E	02	S	UGS Circular 87	4592	4614	Wasatch	Humble Oil	DST	Lab		0.26	68	29941	7.7		702	10305	0	126	0	13500	5103	415	1.00044	No	Test failed
1159	4304710578	5-Jul-62	ROBERTS FED 1	Walker Hollow	Uintah	648461	4456696	5253	KB	7S	24E	06	S	UGS Circular 87	4312	4332	Green River	Humble Oil	DST	Lab		3.90	68	2116	8.4		9	901	1	1	120	100	1	2100	1.03865	Yes	Rec 3150' of gas cut water
1160	4304710578	5-Jul-62	ROBERTS FED 1	Walker Hollow	Uintah	648461	4456696	5253	KB	7S	24E	06	S	UGS Circular 87	3561	3594	Green River	Humble Oil	DST	Lab		2.10	68	3648	8.5		9	1557	0	1	288	220	1	3196	0.99923	No	Rec 268' of mud and water, contaminated
1161	4304710578	5-Jul-62	ROBERTS FED 1	Walker Hollow	Uintah	648461	4456696	5253	KB	7S	24E	06	S	UGS Circular 87	3478	3510	Green River	Humble Oil	DST	Lab		2.12	68	3788	8.3		23	1598	0	1	144	190	42	3636	0.99837	No	Rec 698' of muddy water, contaminated
1162	4304710578	5-Jul-62	ROBERTS FED 1	Walker Hollow	Uintah	648461	4456696	5253	KB	7S	24E	06	S	UGS Circular 87	4629	4642	Green River	Humble Oil	DST	Lab		1.60	68	5124	8.4		11	2206	0	1	288	60	1	5197	0.99896	Yes	Rec 3630' fresh water
1163	4304710578	27-Sep-62	ROBERTS FED 1	Walker Hollow	Uintah	648461	4456696	5253	KB	7S	24E	06	S	UGS Circular 87	4906	4918	Green River	Humble Oil	DST	Lab		3.22	68	2394	8.5		8	1016	0	2	132	150	5	2196	0.99928	Yes	Rec 526' of fresh water
1164	4304710579	8-Mar-52	ROCKWOOD BROWN 1		Uintah	609748	4474836	7532	DF	5S	20E	05	S	UGS Circular 87	5475	6495	Green River	Carter Oil	DST	Lab		2.64	77	2440			21	975	1	1	180	470	21	1450	0.99812	Yes	Rec 1750' of gas cut water
1165	4304710579	19-Mar-51	ROCKWOOD BROWN 1		Uintah	609748	4474836	7532	DF	5S	20E	05	S	UGS Circular 87	6894	6915	Green River	Carter Oil	DST	Lab		3.82	77	1900			0	697	0	0	141	180	140	1080	1.00244	Yes	Rec 720' of water
1166	4304710584	2-Nov-48	VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	UGS Circular 87	4291	4311	Wasatch	Carter Oil	DST	Lab		0.92	77	8260			11	2720	0	3	445	1750	18	3320	0.99909	Yes	DST 4, rec 70' GCW
1167	4304710584	3-Nov-48	VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	UGS Circular 87	4397	4411	Green River	Carter Oil	DST	Lab		0.83	77	11110			13	3300	0	7	410	1000	48	6160	0.99352	No	Rec 2175' GCM
1168	4304710584	3-Nov-48	VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	UGS Circular 87	4397	4411	Wasatch	Carter Oil	DST	Lab		0.83	77	11110			13	3330	0	7	410	1080	48	6160	1.00007	No	Rec 2175' GCM
1169	4304710584	4-Nov-48	VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	UGS Circular 87	6717	6731	Wasatch	Carter Oil	DST	Lab		1.46	77	5340			11	1660	0	14	164	832	278	2380	0.99759	No	Rec 1350' GCM
1170	4304710584	5-Nov-48	VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	UGS Circular 87	7068	7079	Wasatch	Carter Oil	DST	Lab		0.33	77	18180			123	6720	0	49	0	10000	238	793	0.99194	Yes	Rec 156' O
1171	4304710584		VERNAL U 4 (R NELSON 1)		Uintah	621549	4465782	5330	DF	5S	21E	33	S	USGS Salt Lake District Office	4397	4411	Green River - Lower							11000	7.0		13	3332	0	7		1080	48	6998	1.00018	No	C13-421
1172	4304710586	1-May-56	WHITE ROCKS U 2		Uintah	591300	4485506	6530	DF	1N	1E	06	U	UGS Circular 87	4658	4690	Wasatch	Carter Oil	DST	Lab		1.36	77	4400			18	1700	0	18	338	1500	18	1430	1.01393	Yes	Rec 3300 fresh water
1173	4304710586	2-May-56	WHITE ROCKS U 2		Uintah	591300	4485506	6530	DF	1N	1E	06	U	UGS Circular 87	4957	4976	Wasatch	Carter Oil	DST	Lab		3.82	77	1460			9	510	0	15	168	200	43	720	1.00289	Yes	Rec 3200' gas cut fresh water
1174	4304710586	12-Jun-56	WHITE ROCKS U 2		Uintah	591300	4485506	6530	DF	1N	1E	06	U	UGS Circular 87	4957	4976	Wasatch	Carter Oil	DST	Lab		4.20	68	1303	8.5	1.001	9	512	0	15	168	200	43	721	1.00105	Yes	Rec 3200' gas cut fresh water
1175	4304710586	12-Jun-56	WHITE ROCKS U 2		Uintah	591300	4485506	6530	DF	1N	1E	06	U	UGS Circular 87	4658	4690	Wasatch	Carter Oil	DST	Lab		1.50	68	4375	8.6	1.004	18	1749	0	18	339	1536	18	1430	0.99981	Yes	Rec 3300 fresh water
1176	4304710829	20-Jan-65	FED STABLEFORD 1		Uintah	629770	4458319	4973	GR	6S	22E	29	S	UGS Circular 87	5049	5068	Green River	Pan American Petroleum	DST	Lab		1.44	68	4783	8.6		14	1949	20	3	156	1250	1	2818	1.00500	No	DST rec 1022' of mud&PW - questionable
1177	4304710829	29-Jan-65	FED STABLEFORD 1		Uintah	629770	4458319	4973	GR	6S	22E	29	S	UGS Circular 87	5049	5068	Green River	Pan American Petroleum	DST	Lab		1.55	68	4746	8.6		14	1935	20	2	168	1240	1	2891	1.00511	No	DST rec 1022' of mud&PW - questionable
1178	4304710868	31-Jan-64	USA JA JACKS 1	Kennedy Wash	Uintah	641798	4443709	5362	KB	8S	23E	09	S	UGS Circular 87	3890	3950	Green River	H.P. Mc Lish	DST	Lab		0.69	77	10810	8.4	1.009	12	3661	0	22	163	3542	61	3349	0.99897	No	Rec 2967 HGCM, 112' SGCMW
1179	4304710868	15-Feb-64	USA JA JACKS 1	Kennedy Wash	Uintah	641798	4443709	5362	KB	8S	23E	09	S	UGS Circular 87	3890	3950	Green River	H.P. Mc Lish	DST	Lab		0.70	68	10202	8.6		51	4023	30	15	540	3800	263	3001	1.00173	No	Rec 2967 HGCM, 112' SGCMW
1180	4304710869		USA LYLE LINGELBACH 1	Horseshoe Bend	Uintah	621325	4458073	4877	GR	6S	21E	29	S	UGS Circular 87	5590	5608	Green River	Luff Exploration	DST	Lab		0.41	77	19642	8.4	1.013	16	6565	0	5	170	5886	20	6979	0.99902	Yes	Last rec 290' water
1181	4304710870	7-Mar-64	MCLISH UNIT 1	Horseshoe Bend	Uintah	633901	4456837	5117	GR	6S	22E	34	S	UGS Circular 87	6100	6109	Green River	Pan American Petroleum	DST	Lab		0.49	68	14202	8.1		20	5582	13	17	0	7600	74	1818	1.00076	Yes	Rec 102' WCM, 260' salt water
1182	4304710870		MCLISH UNIT 1	Horseshoe Bend	Uintah	633901	4456837	5117	GR	6S	22E	34	S	UGS Circular 87	5514	5528	Green River	Pan American Petroleum	DST	Lab		0.89	77	9170	8.0	1.007	40	2855	0	15	0	2074	17	4168	0.99789	No	Rec 180' SGCMW
1183	4304710870		MCLISH UNIT 1	Horseshoe Bend	Uintah	633901	4456837	5117	GR	6S	22E	34	S	UGS Circular 87	6100	6109	Green River	Pan American Petroleum	DST	Lab		0.43	77	14945	9.1	1.011	11	5687	0	1	285	7744	34	1182	1.00011	Yes	Rec 102' WCM, 260' salt water
1184	4304710870		MCLISH UNIT 1	Horseshoe Bend	Uintah	633901	4456837	5117	GR	6S	22E	34	S	USGS produced water database	3432	3509	Green River							14099	8.0		10	4961		8		5696	0	3424	0.99927	Yes	Rec 150' M, 60' WCM, 1242' fresh water
1185	4304710872		PARIETTE BENCH U 3	Pariette Bench	Uintah	599778	4433651	4722	DF	9S	19E	07	S	USGS produced water database	4885	4935	Green River							47570	7.7		311	18072		185		27800	571	1281	1.00030	Yes	Rec 465' WCM, 1185' slightly salty water
1186	4304710873	9-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	4437	4447	Green River	Pan American Petroleum	DST	Lab		0.30	77	25432	8.7	1.021	61	8661	0	25	349	6514	5769	4053	1.00029	No	Rec 30' O
1187	4304710873	9-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	4610	4622	Green River	Pan American Petroleum	DST	Lab		0.09	77	93098	7.5	1.063	850	34312	0	259	0	48579	8504	594	1.00055	Yes	Rec 2507 salt water
1188	4304710873	9-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	4610	4622	Green River	Pan American Petroleum	DST	Lab		0.08	77	98495	7.1	1.067	1002	36214	0	299	0	51856	8643	481	1.00048	Yes	Rec 2507 salt water
1189	4304710873	10-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	4852	4858	Green River	Pan American Petroleum	DST	Lab		0.73	77	10853	8.5	1.059	40	3506	0	24	79	2079	2523	2613	1.00070	No	Rec 20' of mud
1190	4304710873	11-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	5038	5078	Green River	Pan American Petroleum	DST	Lab		0.42	77	21784	9.2	1.014	24	7449	0	24	1197	5111	2809	5171	1.00020	Yes	Rec 730' oil, 15' MW
1191	4304710873	12-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	5044	5078	Green River	Pan American Petroleum	DST	Lab		0.52	77	14076	8.7	1.011	24	4884	0	24	176	4448	2325	2193	1.00014	No	Rec 85' of O&WCM
1192	4304710873	23-Mar-64	PARIETTE BENCH U 6	Pariette Bench	Uintah	601387	4434435	4725	DF	9S	19E	05	S	UGS Circular 87	5317	5332	Green River	Pan American Petroleum	DST	Lab		0.19	77	49245	8.8	1.036	104	17292	0	76	466	16887	8029	6392	1.00033	No	Rec 60' OCM
1193	4304710877	18-Oct-65	LYNN S RICHARDS USA 1	Wonsits Valley	Uintah

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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	UTM N	Date of Sample	Discharge	Depth to top of interval sampled	Depth to bottom of interval sampled	Water temperature	Specific conductance	pH	Dissolved solids, residue at 180°C	Dissolved solids, sum of constituents	Dissolved Ca	Dissolved Mg	Dissolved Na	Sodium-adsorption ratio	Dissolved K	Bicarbonate as HCO3	Carbonate as CO3	Alkalinity as CaCO3	Dissolved CO2	Total S	Dissolved SO4	Dissolved CI	Dissolved F	Dissolved Br	Dissolved SiO2	Dissolved NO2 + NO3 as N
								NAD 83	NAD 83		gal/min	ft	ft	°C	µmho/cm		mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/18/1976	1	1,888	2,650	26.5	10,300	8.2	6,110	6,120	8.5	5.3	2,300	153	9.5	1,180		968	12	--	270	2,900	4.9	12	10	0
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/19/1976	3.3	1,507	1,622	26	2,070	8.8	1,340	1,310	2.3	1	480	67	1.4	574	24	511	1.6	--	440	59	2	0.4	13	0
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/19/1976	8.1	1,080	1,285	26	2,070	8.7	1320	1,310	2.2	0.9	480	69	1.6	607	19	530	2.1	--	380	110	2.1	0.6	13	0
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	7/20/1976	6	750	950	25	1,970	8.6	1,260	1,230	3.2	1.2	450	54	1.8	602	12	514	2.5	--	350	92	2.2	0.4	13	0
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	11/11/1976	4	1,092	1,158	21.5	1,800	--	--	965	1.1	0.2	360	83	0.8	611	--	501	--	--	250	38	1.4	--	12	0.01
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	11/12/1976	2	1,250	1,260	22	1,720	--	--	974	1.3	0.2	350	76	0.7	481		395	--	--	360	13	0.9	--	11	0.01
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	647934	4415544	3/23/1979	10	1,092	1,576	25	1,800	9	--	1,080	1.3	0.5	390	74	0.9	--	--	430	--	7.7	390	22	1.1	--	12	0.03
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	645054	4391298	6/29/1977	0	0	40	15	9,000	8.7	--	4,920	3.4	4.5	2,300	193	3.8	2,430	200	2,330	9.1	--	39	980	110	--	9.2	--
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	645054	4391298	7/7/1978	11	40	1,290	18.5	1,130	7.2	927	906	54	44	190	4.7	0.7	240	0	200	24	0.2	470	12	0.3	0.1	8.9	0.39
3	USGS	Test Hole 3	(D-13-21)10ada-1	13S	21E	10	NE SE NE	624780	4396546	3/22/1978	211	250	1,092	16.5	900	8.1	--	651	17	15	190	8.1	0.9	280	--	230	3.6	--	270	9.3	0.2	--	10	0.08
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	647985	4402283	3/26/1978	10	100	800	10	4,000	9.2	--	2,350	15	79	760	17	4.6	1,270	--	1,040	1.3	--	820	39	0.4	--	6.3	0.2
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	647985	4402283	3/28/1978	42	800	1,402	22	1,300	8.6	--	948	4.5	1.8	340	34	1	370	--	300	1.5	--	400	7.4	0.5	--	8.1	0.02
5	USGS	Test Hole 5	(D-11-25)26aab-1	11S	25E	26	NE NE NW	663634	4410692	5/23/1978	12	117	798	16.5	3,680	7.4	3,030	3,070	130	140	690	10	1.9	490	0	400	31	0	1,800	33	0.8	0.2	19	0.01
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	4/3/1978	16	135	764	18	10,900	9.2	--	9,870	6.6	300	3,100	38	10	1,200	1,250	3,070	3.8	--	4,300	280	2.2	--	12	0.05
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	4/7/1978	125	1,000	1,497	23.5	1,370	--	--	959	4.5	0.7	360	42	1.5	620	--	509	--	--	260	13	1.2	--	12	0
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	635960	4407465	5/5/1978	15	135	860	23.5	1,350	9	--	921	1.7	0.4	60	65	0.8	700	15	599	1.2	--	150	32	1.9	--	13	0.03

Test Hole	Operator	Well Name	Location	Twn	Rng	Sec	1/4 1/4	Dissolved ammonia as N	Dissolved ammonia as NH4	Ammonia + organic total as N	Total phosphorus as P	Total phosphorus as PO4	Dissolved orthopho-sphorus as P	Dissolved orthophos-phate as PO4	Dissolved Al	Dissolved As	Dissolved Ba	Dissolved B	Dissolved Cd	Dissolved Cr	Dissolved Cu	Dissolved Fe	Dissolved Pb	Dissolved Li	Dissolved Mn	Dissolved Hg	Dissolved Mo	Dissolved Se	Dissolved Sr	Dissolved V	Dissolved 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)
								mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	12	15	11	0.16	0.49	--	--	280	3	300	3,200	1	0	2	160	5	530	30	0	8	0	1,200	1.4	80	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	0.76	0.98	0.84	0.05	0.15	0.06	0.18	30	1	0	310	0	0	0	70	5	100	90	0	1	0	220	0	20	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	0.79	1	1.3	0.06	0.18	0.05	0.15	140	1	0	380	0	0	1	130	4	110	10	0	0	0	200	0	20	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	0.79	1	1.5	0.06	0.18	0.07	0.21	10	1	0	430	1	0	2	140	13	110	10	0	0	0	180	0	40	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	--	--	--	--	--	0	0	--	--	--	370	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	--	--	--	--	--	0.01	0.03	--	--	--	140	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1	USGS	Asphalt Wash 1	(D-11-24)acd-1	11S	24E	7	NE SW SE	--	--	--	--	--	--	--	50	--	--	200	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	--	--	--	--	--	--	--	--	--	--	70000	--	--	--	140	--	--	8	--	--	--	--	--	--	--	--	--
2	USGS	Test Hole 2	(D-13-23)26bdc-1	13S	23E	26	NW SE SW	0.01	0.01	0.24	0.01	0.03	0.01	0.03	0	1	200	170	1	10	0	1,600	5	40	20	0	2	0	3,800	0	30	2.4	<3.4	<3.1
3	USGS	Test Hole 3	(D-13-21)10ada-1	13S	21E	10	NE SE NE	--	--	--	--	--	0	0	--	--	--	630	--	--	--	40	--	--	10	--	--	--	--	--	--	--	--	--
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	--	--	--	--	--	0	0	--	--	--	1,800	--	--	--	40	--	--	60	--	--	--	--	--	--	--	--	--
4	USGS	South Uinta Basin 12	(D-12-24)19dbc-1	12S	24E	19	SE NW SW	--	--	--	--	--	0	0	--	--	--	130	--	--	--	2100	--	--	60	--	--	--	--	--	--	--	--	--
5	USGS	Test Hole 5	(D-11-25)26aab-1	11S	25E	26	NE NE NW	0.69	0.89	0.9	0.03	0.09	0	0	0	5	0	770	1	0	5	2,100	4	260	700	0	11	0	6,800	0	300	3.9	<8.5	--
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	--	--	--	--	--	--	--	--	--	--	12000	--	--	--	730	--	--	40	--	--	--	--	--	--	--	--	--
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	--	--	--	--	--	0.01	0.03	--	--	--	250	--	--	--	170	--	--	20	--	--	--	--	--	--	--	--	--
6	USGS	Test Hole 6	(D-12-22)1bbb -1	12S	22E	1	NW NW NW	--	--	--	--	--	0.03	0.09	--	--	--	460	--	--	--	10	--	--	10	--	--	--	--	--	--	--	--	--

Appendix C

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 River: 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 C. *Water-quality data for selected sites for five different sampling intervals.*

All volatile organic compounds are reported as µg/L

Highlighted values indicate concentration exceeds the U.S. EPA maximum contaminant level

| Site ID | Field ID | Site Name | Cadastral Location | LAT | LON | water use (if known) | API # or DWR# | Well Depth (feet) | Completion date | perforated zone | water level (feet) | Sample Date | Nitrogen NO2 + NO3 (mg/L) | Solids, residue @180oC, dissolved (mg/L) | Field Temperature, (°C) | Field Specific Conductance (µmhos) | Lab, Specific Conductance (µmhos) | pH, Field | pH, Lab | Field, Dissolved Oxygen | Aluminum, dissolved (µg/L) | Ammonia (mg/L) | Arsenic, dissolved (µg/L) | Barium, dissolved (µg/L) | Boron (µg/L) | Bicarbonate (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) | 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 (µg/L) | Phosphate, total (mg/L) | Potassium, dissolved (mg/L) | Selenium, dissolved (µg/L) | 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 | chloroform | chloro-methane | bromo-methane | ethyl-benzene | benzene | chloro-benzene | Xylene | Toluene | 1,2,4-Trimethylbenzene | naphthalene | chloro di-bromomethane | bromo dichloro-methane |
|---|---|---

Appendix IV: Technology Transfer Activities

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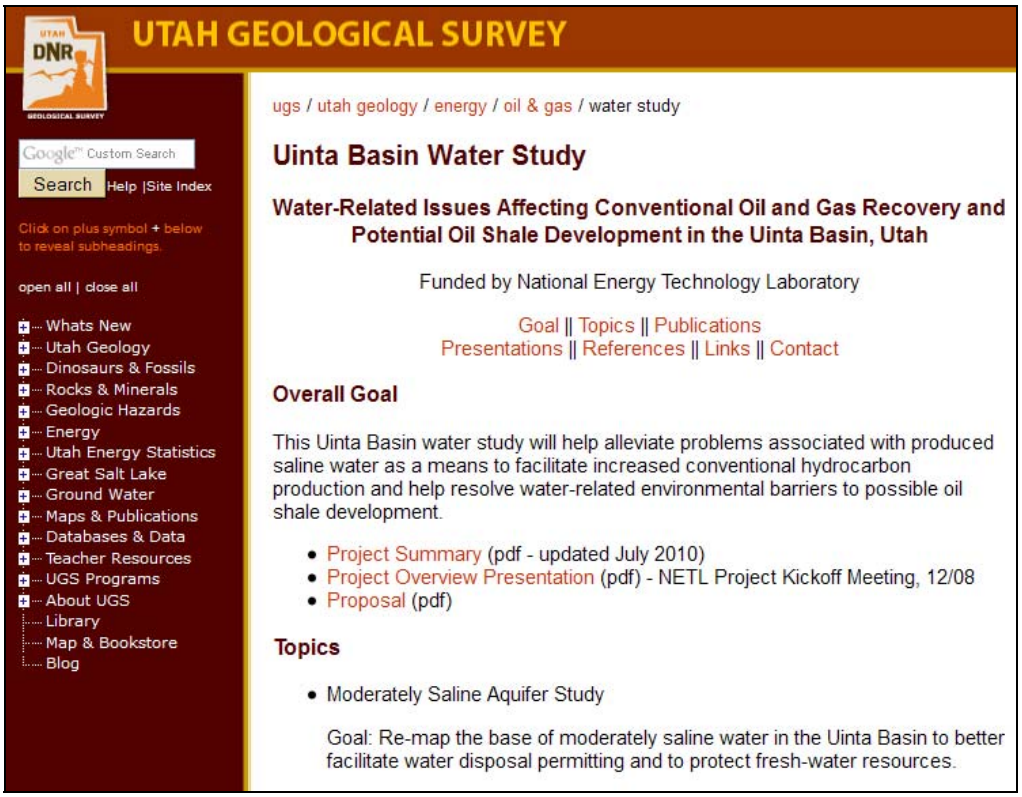
UGS Website

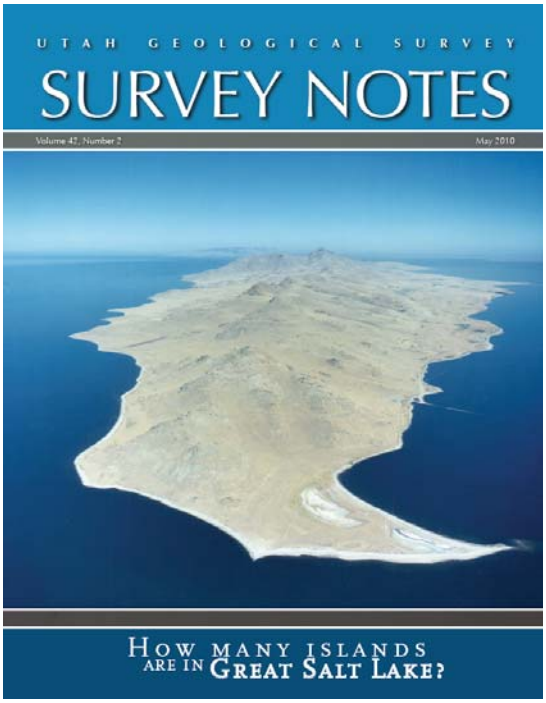
UGS has maintained a project website detailing the progress of the project. The website includes all project-related abstracts, reports, and presentations. This site will also host the final report.

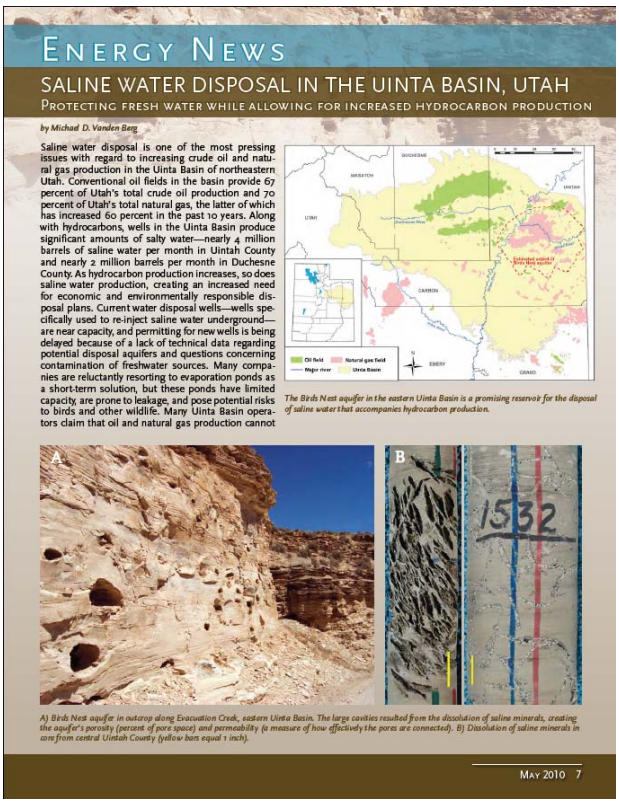
http://geology.utah.gov/emp/UBwater_study/index.htm



Article in UGS *Survey Notes* Newsletter

The PI wrote an article for the May 2010 *Survey Notes* newsletter (Volume 42, Number 2) describing the project and its goals. *Survey Notes* is distributed to over 5,000 individuals interested in Utah geology.





ENERGY NEWS

SALINE WATER DISPOSAL IN THE UINTA BASIN, UTAH

PROTECTING FRESH WATER WHILE ALLOWING FOR INCREASED HYDROCARBON PRODUCTION

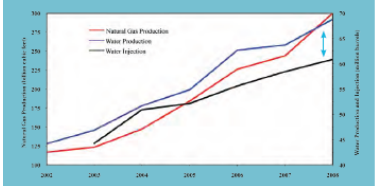
by Michael D. Vanden Berg

Saline water disposal is one of the most pressing issues with regard to increasing crude oil and natural gas production in the Uinta Basin of northeastern Utah. Conventional oil fields in the basin provide 67 percent of Utah's total crude oil production and 70 percent of Utah's total natural gas, the latter of which has increased 60 percent in the past 10 years. Along with hydrocarbons, wells in the Uinta Basin produce significant amounts of salty water—nearly 4 million barrels of saline water per month in Uintah County and nearly 2 million barrels per month in Duchesne County. As hydrocarbon production increases, so does saline water production, creating an increased need for economic and environmentally responsible disposal plans. Current water disposal wells—wells specifically used to re-inject saline water underground—are near capacity, and permitting for new wells is being delayed because of a lack of technical data regarding potential disposal aquifers and questions concerning contamination of freshwater sources. Many companies are reluctantly resorting to evaporation ponds as a short-term solution, but these ponds have limited capacity, are prone to leakage, and pose potential risks to birds and other wildlife. Many Uinta Basin operators claim that oil and natural gas production cannot reach its full potential until a suitable, long-term saline water disposal solution is determined.

The Birds Nest aquifer in the eastern Uinta Basin is a promising reservoir for the disposal of saline water that accompanies hydrocarbon production.

A) Birds Nest aquifer in outcrop along Evacuation Creek, eastern Uinta Basin. The large cavities resulted from the dissolution of saline minerals, creating the aquifer's porosity (percent of pore space) and permeability (a measure of how effectively the pores are connected). B) Dissolution of saline minerals in core from central Uintah County (yellow bars equal 1 inch).

The Utah Geological Survey (UGS) is currently half-way through a three-year, joint UGS–U.S. Department of Energy-funded study investigating the aquifers in the Uinta Basin to help facilitate the development of prudent saline water disposal plans. The project is divided into three parts: (1) re-mapping the base of the moderately saline aquifer in the Uinta Basin, (2) creating a detailed geologic characterization of the Birds Nest aquifer, a potential reservoir for large-scale saline water disposal, and (3) collecting and analyzing water samples from the eastern Uinta Basin to establish baseline water quality.



Natural gas production, water production, and water injection in the Uinta Basin, Utah, 2002–2008. The gap between water production and water injection (indicated by blue arrow) has widened as natural gas production has increased, leading to a need for the development of mitigation strategies.

Birds Nest aquifer outcrop along the White River, eastern Uinta Basin, Utah.

Part 1: Regulators currently stipulate that saline water must be disposed of into aquifers that already contain moderately saline water (water that averages at least 10,000 parts per million total dissolved solids). These underground zones are currently determined using 25-year-old data compiled on a less-than-useful paper map. The UGS plans to re-map this moderately saline water boundary in the subsurface using a combination of actual water chemistry data collected from various sources and by analyzing geophysical well logs. By re-mapping the base of the moderately saline aquifer using more robust data and more sophisticated computer-based mapping techniques, regulators will have the information needed to more expeditiously grant water disposal permits while still protecting freshwater resources.

Part 2: Eastern Uinta Basin gas producers have identified the Birds Nest aquifer, located in the Parachute Creek Member of the Green River Formation, as the most promising reservoir suitable for large-volume saline water disposal. This aquifer, ranging in thickness from less than 100 feet on the basin margins to greater than 900 feet in the basin's center, formed from the dissolution of saline minerals which left behind large open cavities and fractured rock. Understanding the aquifer's areal extent, thickness, water chemistry, and zones of differential dissolution will help determine possible saline water disposal volumes and safe disposal practices, both of which could directly impact the success of increased hydrocarbon production in the region.

Part 3: The UGS has determined a regulatory need for baseline water quality and quantity data for lands identified in the eastern Uinta Basin as having oil shale development potential. Water-quality degradation could result from new oil shale developments via mining and surface retort or in-place processes. The UGS has identified 17 sites in the area, including wells, springs, and streams, that will be sampled and analyzed on a bi-annual basis. This information will provide a baseline water quality profile, which can be used to compare with future data after petroleum development begins.

This multifaceted study will provide a better understanding of the aquifers in the Uinta Basin, giving regulators the tools needed to protect precious freshwater resources while still allowing for increased hydrocarbon production. To find out more about this study or to download quarterly reports and recent presentations, visit the UGS Web site: geology.utah.gov/emp/UBwater_study.

Project Presentations at National and Regional Conferences

All abstracts and presentations can be downloaded from the UGS project website

Anderson, P., Vanden Berg, M., Carney, S., Morgan, C., and Heuscher, S., 2012. "Mapping Potentially Useable Strata for Underground Water Disposal, Uinta Basin, Utah." *2012 AAPG-RMS Annual meeting*, Grand Junction, CO, September 9-12, 2012.

Vanden Berg, M., Carney, S., Morgan, C., 2012. "Geologic Characterization of the Birds Nest Aquifer in the Uinta Basin, Utah: Assessing the Aquifer's Potential as a Significant Saline Water Disposal Zone." *2012 AAPG Annual meeting*, Long Beach, CA, April 22-25, 2012.

Anderson, P., Vanden Berg, M., Carney, S., Morgan, C., 2012. "Mapping Potentially Useable Strata for Underground Water Disposal, Uinta Basin, Utah." *2012 AAPG Annual meeting*, Long Beach, CA, April 22-25, 2012.

Vanden Berg, M., Carney, S., Morgan, C., Lehle, D., 2011. "Stratigraphic Characterization of the Birds Nest Aquifer in the Uinta Basin, Utah: Updated Research Regarding the Aquifer's Potential as a Significant Saline Water Disposal Zone." *2011 AAPG-RMS meeting*, Cheyenne, WY, June 26-29, 2011.

Wallace, J., 2011. "Analysis of Seasonal Water-Quality Data in the Uinta Basin, Eastern Utah." *2011 GSA-RMS meeting*, Logan, UT, May 18-20, 2011.

Vanden Berg, M., Anderson, P., Morgan, C., Carney, S., 2011. "New Insights Regarding Aquifers in the Uinta Basin, Utah: Implications for Saline Water Disposal." *2011 AAPG Annual meeting*, Houston, TX, April 11-13, 2011.

Vanden Berg, M., 2010. "Saline Water Disposal into the Birds Nest Aquifer in the Uinta Basin, Utah: Updated Research on the Implications for Oil Shale Development." *30th Oil Shale Symposium*, Colorado School of Mines, Golden, CO, October 18-20, 2010.

Vanden Berg, M. Carney, S., Morgan, C., Laine, M., 2010. "Stratigraphic Characterization of the Birds Nest Aquifer in the Uinta Basin, Utah: Implications for Saline Water Disposal from Natural Gas Production." *2010 AAPG-RMS meeting*, Durango, CO, June 13-16, 2010.

Vanden Berg, M., 2010. "Understanding the Aquifers in the Uinta Basin, Utah: A Key to Solving the Basin's Saline Water Disposal Problem." *2010 AAPG Annual Meeting*, New Orleans, LA, April 11-14, 2010.

Vanden Berg, M., 2009. "Saline Water Disposal into the Birds Nest Aquifer in Uintah County, Utah: Implications for Potential Oil Shale Development." *29th Oil Shale Symposium*, Colorado School of Mines, Golden, CO, October 19-21, 2009.

Vanden Berg, M., 2009. "Understanding the Birds Nest Aquifer in Uintah County, Utah: A Potential Source for Large-Scale Saline Water Disposal." *Water/Energy Sustainability Symposium*, GWPC, Salt Lake City, UT, September 13-17, 2009.

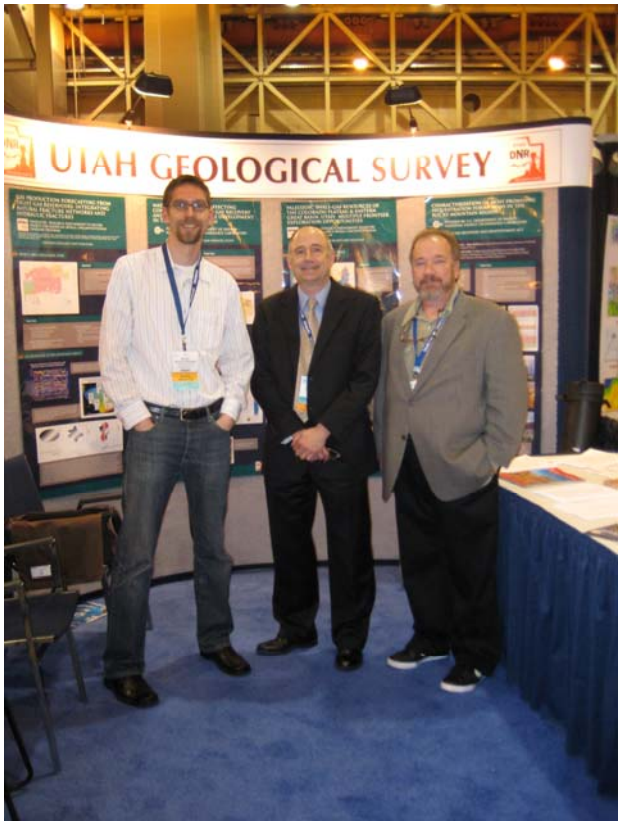
Vanden Berg, M., Carney, S., Anderson, P., Morgan, C., Laine, M., 2009. "Saline water disposal in the Uinta Basin, Utah: The single most pressing issue with regard to increasing petroleum production and protecting freshwater aquifers." *2009 AAPG Annual Meeting*, Denver, CO, June 7-10, 2009.

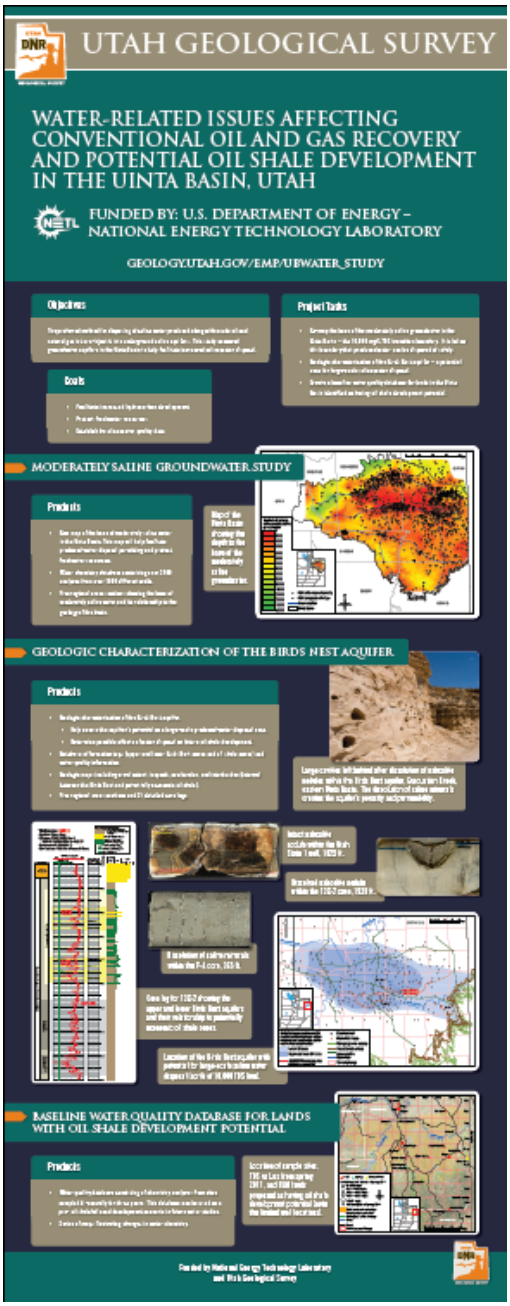
Lehle, D., Vanden Berg, M., 2009. "Comparing the depositional characteristics of the oil-shale-rich Mahogany and R-6 zones of the Uinta and Piceance Creek Basins." *2009 GSA-RMS meeting*, Orem, UT, May 11-13, 2009.

Project Displays at American Association of Petroleum Geologists Conferences

Project materials, plans, objectives, and results were displayed at the UGS exhibit booth during the following meetings of the AAPG:

AAPG Annual Convention, June 7-10, 2009, Denver, Colorado
AAPG Annual Convention, April 11-14, 2010, New Orleans, Louisiana
AAPG Rocky Mountain Section Meeting, June 13-16, 2010, Durango, Colorado
AAPG Annual Convention, April 10-13, 2011, Houston, Texas
AAPG Rocky Mountain Section Meeting, June 25-29, 2011, Cheyenne, Wyoming
AAPG Annual Convention, April 22-25, 2012, Long Beach, California
AAPG Rocky Mountain Section Meeting, September 9-12, 2012, Grand Junction, Colorado

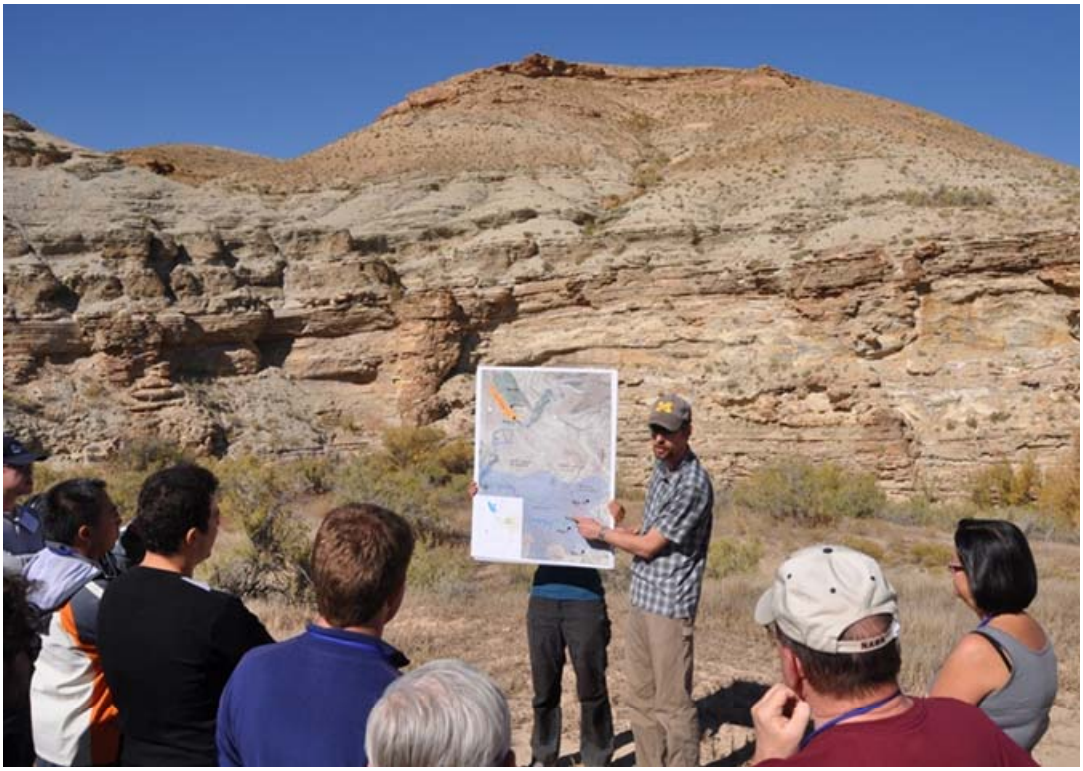




Field Trips

Several fieldtrips were run as part of various conferences. Stops were made at classic Birds Nest aquifer outcrop locations in the eastern Uinta Basin, Utah.

- May 2009 – University of Utah Uinta Basin field trip
- October 2010 – 30th Oil Shale Symposium
- November 2010 – UGS board field trip
- May 2011 – University of Utah Unconventional Fuels Conference
- October 2011 – 31st Oil Shale Symposium



Annual Review Meetings

Two review meetings were held in Vernal, Utah, highlighting the progress of the project. Maps and posters were on display as well as representative core from the Birds Nest aquifer.

First review meeting – October 2009 – 16 participants

Second review meeting – January 2011 – 33 participants

Presentations from the review meetings can be downloaded from the UGS project website.

Quarterly Reports

The PI wrote and distributed 14 quarterly reports, each highlighting the project's progress from the previous quarter. All quarterly reports can be downloaded from the UGS project website.

Project Closeout Meeting

The PI presented the final project results to DOE/NETL staff in March 2012. This presentation is available for download on the UGS project website.

Final Publications

Each of the three main project tasks will be published as separate UGS publications (in fall 2012) (Task 5 will be published by researchers at the University of Utah):

Task 2 – UGS Special Study 144
Moderately Saline Groundwater in the Uinta Basin, Utah

Task 3 – UGS Special Study 145
Geological Characterization of the Birds Nest Aquifer, Uinta Basin, Utah: Assessment of the Aquifer's Potential as a Saline Water Disposal Zone

Task 4 – UGS Open-File Report 595
Baseline Water Quality for Selected Sites in the Southeastern Uinta Basin, Utah