THE STATE OF WYOMING

Water Development Office

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TECHNICAL MEMORANDUM

TO: Water Development Commission

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FROM: 2001 Bear River Basin Planning Team
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REFERENCE: Bear River Basin Plan Update, 2011

SUBJECT: Groundwater Resources Investigation – *Tab V (2011)*

Contents

1.0 Introduction

For the 2011 Bear River Basin Plan Update, this memorandum is issued as a revision to the corresponding memorandum that was produced for the 2001 Bear River Basin Plan (previous Plan). The original memorandum, produced December 12, 2000 can be found at http://waterplan.state.wy.us/plan/bear/techmemos/gwmemo.html.

The majority of updates to the previous Plan occurred within and is documented in the appendix to this memorandum (Appendix A: Groundwater Availability).

Note that all figures referenced in this memorandum and within the appendix are included at the end of the text, respectively.

2.0 Approach

To accomplish the task objectives, the following approach was taken:

1. Collect hydrogeologic and groundwater quality reports and basic data,
2. Compile the data into graphical decision-making tools, and
3. Use the collected and compiled data to analyze the groundwater resources.

2.1 Data Collection

Data useful in analyzing the groundwater resource of a basin include:

- Aquifer type (alluvial or bedrock), formation, areal extent, and saturated thickness;
- Well location, aquifer completion, and yield;
- Water levels and flow directions;
- Aquifer properties (permeability and specific yield);
- Recharge locations and amounts;
- Spring locations and amounts; and
- Water quality (springs and wells).

Water quality is important for determining whether groundwater is suitable for various uses. Domestic and municipal water supplies generally require higher quality water than do agricultural, industrial, and stock watering supplies.

Data were obtained from existing reports, existing databases, and websites as described below:

<u>Existing Reports</u>

Reports and articles were obtained through searches at the following libraries:

- U.S. Geological Survey (USGS), Lakewood, Colorado
- U.S. Bureau of Reclamation Library, Lakewood, Colorado
- The Water Resources Data System (WRDS) Library, Laramie, Wyoming

A list of the reports reviewed is included in the References section of this memorandum. Extensive information was obtained from reports by the USGS (Robinove and Berry, 1963; Glover, 1989; Eddy-Miller et al., 1996). Most of the aquifer descriptions came from the report by Eddy-Miller et al. (1996) on the water resources of the Lincoln County portion of the basin.

Existing Databases

The principal sources of data were from the USGS and State of Wyoming databases. USGS sources include the Ground Water Site Inventory (GWSI) and Water Quality (WQ) databases. These databases were also the primary data sources used for the Eddy-Miller et al. (1996) report. The USGS's GWSI database contained data for 119 wells and springs located in the basin. Database information includes:

- Well location
- Well water level
- Well and spring aquifer classification
- Reported yield and spring discharge
- Well use
- Well depth

The USGS Water Quality database (WQ database) contains data on approximately 1,800 parameters. USGS provided us with a query of well and spring samples from the Bear River Basin. The query contains analyses from 57 wells and 49 springs and includes 24 parameters that are general water quality indicators.

The State Engineer's Office (WSEO) Water Well Inventory database (WSEO database) reports compiled administrative information from 1,015 wells in the basin including the following information:

- Locations
- Permit number
- Priority data
- Reported well yield
- Well depth

Websites

Several websites were investigated to understand the available information for the Bear River basin, including the on-line library listings for the USGS and WRDS. The most useful websites include the Wyoming Geographic Information Science Center at the University of Wyoming (WyGISC) (http://www.uwyo.edu/wygisc/) and the WRDS site (http://www.wrds.uwyo.edu/).

2.2 Data Compilation

The GIS coverage of the geologic map of Wyoming, developed by Love and Christiansen (1985), was obtained from SDVC and clipped to show only the geology of the Bear River Basin. In addition, a new polygon theme was created that combined the alluvial aquifers into one polygon and the bedrock aquifers into another polygon. This basemap, described in more detail under the hydrogeology subsection, provides a simple visual representation of the location of alluvial versus bedrock aquifers.

Information stored in the two USGS databases and the WSEO Water Well Inventory database pertain to specific geographic points, i.e., well locations. Therefore, their usefulness as a tool for understanding groundwater issues can be greatly enhanced by placing them into a GIS format. GIS point coverages were created from both the GWSI database and the WSEO database showing the location of the wells and springs. The attributes from the respective database were assigned to each point in the GIS coverages. Some of the more useful attributes from the GWSI coverage include well yield, well aquifer name where available, and well use code (i.e., domestic, irrigation, etc.). To further enhance its usefulness, for each well in a defined aquifer both the geologic description and the water-bearing characteristics of the formation were added as attributes to the coverage.

The GIS coverage developed from the WSEO database includes attributes similar to the GWSI coverage. In addition, depth to groundwater information is available for some locations. Again, for each well in a defined aquifer both the geologic description and the water-bearing characteristics of the formation were added as attributes to the coverage.

A GIS point coverage was also created from the WQ database. Attribute information in this coverage includes sample results for total dissolved solids (TDS), fluoride, iron, sulfate, chloride, and other constituents.

Because data are limited, the GIS coverages are useful tools with which to base general conclusions concerning the groundwater resources in specific basin areas. Planners can use the tool to identify the aquifers that have been developed in the vicinity of proposed new developments. Qualified hydrogeologists can use the coverage to extrapolate the data and come to more educated conclusions concerning site specific aquifer potential and likely water quality. Note that site-specific investigations will still need to be conducted to come to more definite conclusions concerning any specific area's groundwater development potential.

2.3 Analysis Approach

Information was used from the existing reports, databases, and the GIS tools developed as part of this task:

- Identify existing wells and springs and the aquifers they produce from;
- Compile general geological information and aquifer descriptions;
- Plot reported well yield data to determine if spatial relationships exist;
- Plot reported spring yield information to determine if spatial relationships exist;
- Compile general water quality data;
- Plot well and spring water quality data to determine if aquifer/water quality or spatial relationships exist; and
- Compare groundwater quality results with Wyoming standards and general agricultural standards.

3.0 Results

3.1 Existing Well and Spring Data

Figure 1 shows the distribution of wells and springs that are included in the WSEO and GWSI databases. (Note that figures referenced in this memorandum are included at the end of the text.) This figure of the two well data GIS coverages developed for this project shows that most wells are in the vicinity of the Bear River in the Uinta County portion of the basin. Well depth information from the State coverage indicates that most of these wells are producing from the alluvial aquifer. Most of the inventoried springs are located in the central portion of the study area in the vicinity of Twin Creek.

3.2 Geology

Geology controls the occurrence and movement of groundwater. The geology of the Bear River Basin is extremely complex. The Bear River Basin is located in part of Wyoming's "Overthrust Belt." Overthrust geology is characterized by folded and faulted sedimentary rocks, which have been eroded to form ridges and valleys. Several mountain ranges make up the Overthrust Belt and divided the Bear River Basin from the Green River Basin to the east and the Great Salt Lake Basin to the west. There are several publications that describe the geology of the Overthrust Belt in greater detail, primarily for use by geologists, listed in the References section.

Figure 2 is the modified version of the Geologic Map of Wyoming by Love and Christiansen (1985) that shows the surface exposure of numerous sedimentary formations. The geologic description and water-bearing characteristics of each formation, reported by Eddy-Miller et al. (1996), have been included alongside the geographic reference. The descriptions may include observations from outside the Bear River Basin. This figure is an extremely useful tool for understanding the geology in the basin.

The rock sequences in the Overthrust Belt were deposited by alternating transgressive and regressive seas throughout geologic history and range in thickness from several feet to several thousand feet. After deposition, the flat lying deposits were subsequently faulted and folded which is reflected by the present north – south outcrop orientation in Figure 2. The direction formations currently slant or dip depends on local faults and folds. These faults and folds have as strong influence on groundwater flow rates and direction. Younger formations exist beneath older formations as a result of low-angle thrust faulting. Some formation names are different for similar deposits located outside the Bear River Basin.

3.3 Hydrogeology

An aquifer is a geologic unit that provides usable water to wells and springs. Several potential aquifers are located at depths within reach of typical drilling rigs. Due to the complex geology and numerous formations, the water bearing geologic formations have been grouped into alluvial and bedrock formations shown on most figures. Alluvial formations include all Quaternary unconsolidated deposits described on Figure 2 including:

- Alluvium;
- Gravel, pediment, and fan deposits;
- Landslide deposits;

- Undivided surficial deposits; and
- Terrace deposits.

Bedrock formations include older consolidated Tertiary, Mesozoic, and Paleozoic rocks. Most well entries in the two well coverage databases do not report the formation wells draw water from. However, based on the well locations shown in Figure 1, it appears that most wells are completed in alluvial materials.

3.4 Alluvial Aquifer

That aquifer that consists of saturated stream alluvium within approximately two miles of the Bear River is referred to herein as the Alluvial Aquifer. Alluvium consists of sand and gravel interbedded with silt and clay (Robinove and Berry, 1963). Groundwater within the Alluvial Aquifer is stored and transmitted between grains (intergranular flow). This “pore” space is reportedly large (up to 25 percent by volume) in the Alluvial Aquifer making it very permeable and productive.

Alluvial Aquifer thickness is generally less than 100 feet, but may exceed 200 feet in some areas (Lines and Glass, 1975). The average depth of the 35 alluvial wells with reported depth information in the WSEO database is 106 feet. The outline of alluvial formations shaded on most figures is a general outline of the Alluvial Aquifer.

Figure 3 shows the geologic formations from which wells identified in both the GWSI and WSEO database reportedly produce water. As shown, most wells in the database do not have the producing formation identified. Of the 56 wells with formation data, twenty-eight wells are completed in the alluvium. The number of wells without formation information that physically fall within the boundaries of the alluvium formations, as shown in Figure 3, suggest that the Alluvial Aquifer is the most utilized aquifer. The wells that are spatially within the Alluvial Aquifer boundary have reported well yields that range from 5 to 1,930 gallons per minute (gpm).

3.5 Bedrock Aquifers

The Eddy-Miller et al. (1996) reports that 35 formations yield small to moderate quantities of water to wells in Lincoln County. Some bedrock formations may contain several aquifers. Bedrock aquifers include sandstone, conglomerate, and limestone beds. Bedrock formations that are made of relatively impermeable materials are considered aquifers if they contain water in interconnected joints, fractures, or faults.

Figure 3 shows: the distribution of the 20 wells identified in the WSEO or GWSI databases as completed in 8 bedrock formations; their reported yields; and brief aquifer descriptions. The average depth of these 20 bedrock wells is 440 feet, with a range from 26 to 1,200 feet deep. Table 1 shows the number of wells that reportedly produce water from each formation. The Wasatch and Adaville formations have the most reported wells of the bedrock aquifers in the basin with 7 and 6 wells, respectively. The highest reported bedrock well yield is from the Wasatch Formation near Evanston (1,300 gpm).

The GIS well coverages developed and shown in Figure 3 provide a useful tool for decision-makers. For instance, if there was interest in developing a new well near Evanston, Figure 3 shows that existing wells in the vicinity yield 200, 427, and 1,300 gpm. The GIS coverages can also be used to visually depict any attribute including well depth, aquifer type, water level, well use (domestic, irrigation, etc.), and water rights information (permit number, priority date).

3.6 Groundwater Flow

The Alluvial Aquifer is recharged through precipitation, agricultural diversions, and discharge from bedrock aquifers. Glover (1989) reports that groundwater in the Bear River alluvium flows toward or parallel to the Bear River, except where local pumping exists.

Bedrock aquifers are generally recharged by precipitation and flow between aquifers. Groundwater generally flows towards springs and streams through aquifer pore spaces or through fractures. The rate and amount of groundwater flow in bedrock aquifers is less than flow in the Alluvial Aquifer. The direction of groundwater flow in bedrock aquifers is locally controlled by fold and fault structures. The amount of flow between aquifers and the localized flow direction could not be determined because of a lack of data. However, the general dip (i.e., slant) of the basin is towards the east, therefore, water recharging bedrock formations in the Bear River Basin may discharge to the Green River Basin.

Table 1: Well Yield and Spring Discharge

Completed Into Formation	Wells				Springs			
	Wells Reported	Wells With Yield Data	Yields Range (gpm)	Average Well Yield (gpm)	Springs Reported	Springs with Discharge Data	Discharge Range (gpm)	Total Spring Discharge (gpm)
Alluvial Formations								
Alluvium (alluvial aquifer)	28	10	5 – 1,930	420	0	--	--	--
Landslide deposits	0	--	--	--	1	1	2,000	2,000
Terrace gravel deposits	7	1	14	14	1	1	20	20
TOTAL Alluvial Formations	**35**	**11**	**5 – 1,930**	**--**	**2**	**2**	**20 – 2,000**	**2,020**
Bedrock Formations								
Pliocene formations	2	0	nm	nm	0	--	--	--
Fowkes Formation	0	--	--	--	3	3	5 – 125	132
Green River Formation (Fossil Butte Member)	0	--	--	--	7	7	5 – 200	284
Wasatch Formation	7	2	10 – 1,300	437	9	8	1 – 15	43
Evanston Formation	1	1	1	1	1	1	25	25
Upper Cretaceous Formations	2	0	nm	nm	0	--	--	--
Adaville Formation	6	1	20	20	0	--	--	--
Sage Junction Formation	0	--	--	--	1	0	nm	nm
Thomas Fork Formation	0	--	--	--	2	1	nm to 1	1
Gannett Group	0	--	--	--	8	6	1 - 700	837
Preuss Formation	0	--	--	--	3	2	1 - 50	70
Twin Creek Limestone	0	--	--	--	2	2	15 - 25	40
Nugget Sandstone	0	--	--	--	6	5	2 – 42	59
Thaynes Limestone	1	1	12 – 150 *	81	3	3	20 – 300	365
Woodside Formation	0	--	--	--	2	2	2 – 10	12
Phosphoria Formation	1	1	200	200	1	1	300	300
Wells Formation	1	1	300	300	0	--	--	--
TOTAL Bedrock Formations	**21**	**7**	**1 – 1,300**	**--**	**48**	**41**	**1 – 700**	**2,168**
Uncertain Formations	87	25	5 – 811	89	6	3	1 – 50	120
TOTAL	**143**	**43**	**1 – 1,930**	**--**	**56**	**46**	**1 – 700**	**4,308**

Note: nm = discharge or yield not measured
** This well reports two different yields from separate measurements*
Source: U.S. Geological Survey Ground Water Site Inventory (GWSI) database

3.7 Springs

The perennial flow in the Bear River results from groundwater discharge from bedrock aquifers to springs or alluvium. Eddy-Miller et al. (1996) report that 35 formations yield small to moderate quantities of water to springs in Lincoln County. Figure 4 shows the spring distribution including:

- Spring formation source
- Reported discharge
- Aquifer descriptions

The Wasatch Formation has the most bedrock springs followed by the Gannett Group and Nugget Sandstone. Table 1 also includes a summary of spring formation and discharge data. Nine springs in the Wasatch Formation discharge between 1 and 15 gpm. Sandstone and conglomerate beds in the Gannett Group reportedly discharge the most water to streams (total discharge of 837 gpm) from eight springs that reportedly discharge between 1 and 700 gpm. Although no wells are reported to produce from the Nugget Sandstone, it has the third highest number of reported springs (6), which yield between 2 and 42 gpm.

According to the GWSI database, two springs were measured from alluvial formations. One spring reportedly discharges from a landslide deposit, classified as a Quaternary unconsolidated deposit, at a rate of 2,000 gpm in the northeastern portion of the study area. The source of this spring may be the underlying Nugget Sandstone and not the overlying alluvial formation. Note other springs exist that are not included in the GWSI database.

3.8 Storage

Groundwater storage is a function of aquifer area and amount of producible water contained in the pore spaces and fractures. As shown in Figures 1, 2, and 4, the areal extent of the Bear River alluvium equals approximately 107,530 acres. Based on information published for other areas, and engineering experience, 20 percent of the alluvial aquifer volume was estimated to be recoverable groundwater. The average saturated thickness of 26 wells reportedly completed in the alluvium is 106 feet. Alluvium is thinner along the edges and in the Bear River tributaries. If the average saturated thickness is estimated at 25 feet, the amount of producible groundwater in storage is approximately 500,000 acre-feet.

Note that there are many uncertainties associated with estimating the amount of producible groundwater from storage. However, the general magnitude suggests that it is significant. No attempt was made to determine the amount of groundwater in storage in bedrock aquifers due to the complex geology and lack of aquifer storativity data.

3.9 Yield

Yield is defined in terms of well yield and long-term aquifer yield. The long-term aquifer yield is discussed under the groundwater development potential later in this memorandum.

Well Yield

Well yield is important to consider when planning the number of wells and amount of storage needed for development. Well yield is the maximum rate at which a well can pump without lowering the water in the well below the pump intake (Freeze and Cherry, 1979). The maximum amount a well can produce is a function of well construction, aquifer characteristics, and the location, number and pumping amounts of nearby wells. Well characteristics include:

- Well location, diameter, and depth;
- Drilling method; and
- Construction materials

Aquifer properties used to determine maximum well yields include aquifer:

- Permeability;
- Saturated thickness;
- Extent;
- Storage properties; and
- Recharge potential.

Well yield is also a function of how long the well is pumped and the effects of nearby pumping wells. Since these data are scarce, reported well yield data were used as a subjective measure of the physical well potential from various aquifers.

Reported Well Yield

Reported well yields are either permitted amounts; instantaneous measurements by the pump installer (a function of the pump size); or actual long-term test data. Reported well yields are used as a qualitative measure of well yield considering the following qualifying assumptions:

Reported well yields for domestic wells usually represent the size of the pump and not the aquifer potential. Reported domestic well yield data often underestimates the well yield potential of permeable aquifers (Alluvial Aquifers) and may overestimate the long-term yield of lower permeability bedrock aquifers.

In our experience, reported well yields from agricultural and municipal wells are usually better indicators of aquifer potential.

Figure 5 shows reported well yield ranges. Based on the available information, it appears that most high capacity wells (>500 gpm) are completed in the Alluvial Aquifer. The large number of high capacity wells in the vicinity of Evanston confirms that the Alluvial Aquifer is a source of municipal and industrial supply. The City of Evanston has three Alluvial Aquifer wells ranging in depth from 65 to 185 feet that yield between 425 and 730 gpm (Robinvove and Berry, 1963). There are also six wells in the vicinity of Cokeville that are completed in the Alluvial Aquifer ranging in depth from 117 to 248 feet and yield between 400 and 4,500 gpm (Lines and Glass, 1975; and Robinvoe and

Berry, 1963). The even distribution of high capacity alluvial wells south of Cokeville suggests that the Alluvial Aquifer is an important agricultural water supply source in that area.

Most of the low yield wells throughout Uinta County that have an identified use in the WSEO database are classified as domestic wells. Therefore, the low yields should not by considered a limitation on potential yields of the aquifers. As shown, several high yield bedrock wells also exist in the County. The City of Evanston has a bedrock aquifer well completed in the Wasatch Formation that yields 1,300 gpm (TriHydro Corporation, 2000). The GIS coverage can be used to show the range of expected well yields from various geologic formations.

3.10 Groundwater Quality

Water quality data were obtained from the WQ database, which contains data on approximately 1800 parameters. The USGS provided a database query of wells and springs located in the Bear River Basin that includes 24 water quality parameters that are considered general water quality indicators. The queried database contains 121 water quality analysis records from 57 wells and springs. A GIS coverage was developed from this database that provides a spatial reference for the water quality samples. The water quality parameters that were reported in the database and the corresponding GIS attribute table include:

- Total dissolved solids, TDS (dissolved) (mg/L)
- Nitrogen NO_2+NO_3 (dissolved) (mg/L)
- Phosphorus (Total) (mg/L)
- Magnesium (dissolved) (mg/L)
- Calcium (dissolved) (mg/L)
- Sodium (dissolved) (mg/L)
- Potassium (dissolved) (mg/L)
- Chloride (dissolved) (mg/L)
- Sulfate (dissolved) (mg/L)
- Fluoride (dissolved) (mg/L)
- Arsenic (dissolved) (µg/L)
- Boron (dissolved) (mg/L)
- Iron (dissolved) (mg/L)

<u>State of Wyoming Groundwater Quality Standards</u>

The State of Wyoming groundwater standards define five classes of groundwater:

- Class I groundwater is classified as water suitable for domestic use. (Table 2 lists some of the standards; also see Wyoming Department of Environmental Quality (WDEQ) Water Quality Standards.)
- Class II groundwater is classified as water suitable for agricultural use where soil conditions and other factors are adequate.
- Class III groundwater is classified as water suitable for livestock.
- Class IV groundwater is suitable for industry.
- Class Special (A) groundwater is suitable for fish and aquatic life.

Since agriculture, livestock, domestic, and municipal uses are the primary uses in the basin, water quality results were compared to the Class 1 – III standards. Table 2 shows the standards for the water quality parameters that were exceeded in at least one well sample (chloride, fluoride, iron, sulfate, and TDS). The number of samples for water quality parameters other than TDS is too small to base conclusions on, therefore TDS is the only parameter discussed in more detail.

Table 2: Water Quality Standards

Parameter	Class I Domestic (mg/L)	Class II Agriculture (mg/L)	Class III Livestock (mg/L)
Chloride	250	100	2,000
Fluoride	1.4 – 2.47	--	--
Iron	0.3	5.0	--
Sulfate	250	200	3,000
Total dissolved solids (TDS)	500	2,000	5,000

Source: Wyoming Department of Environmental Quality (WDEQ)

Total Dissolved Solids

TDS is a measure of dissolved solid mineral content and is a general indicator of the suitability of water for various uses. The U.S. Environmental Protection Agency (USEPA) and the Wyoming Ground Water Standard for TDS in public water systems is 500 mg/L. The Wyoming Ground Water Standard for agricultural use is 2,000 mg/L and for livestock use is 5,000 mg/L. Table 3 lists the USEPA-recommended guidelines for TDS in irrigation water and its effects on crops.

Table 4 shows TDS sample results from wells and springs completed in various geologic formations. Twenty-four of the results were estimated by multiplying reported specific conductances by a factor of 0.64 (Todd, 1964).

Table 3: Recommended Guidelines for TDS in Irrigation Water

TDS Concentration (mg/L)	Guidelines
<500	Water for which no detrimental effects are usually noticed.
500 – 1,000	Water that can have detrimental effects on sensitive crops.
1,000 – 2,000	Water that can have adverse affects on many crops; requires careful management practices.
2,000 – 5,000	Water that can be used for tolerant plants on permeable soils with careful management practices.

Source: National Academy of Science and Engineering (1973)

Table 4: Aquifer TDS from Wells and Springs

COMPLETED INTO FORMATION	Number of Samples	Range of TDS			
		<500 mg/L	500-1,000 mg/L	1,000-2,000 mg/L	>2,000 mg/L
Alluvial Formations					
Alluvium (alluvial aquifer)	24	16	6	2	0
Landslide deposits	1	1	0	0	0
Terrace gravels	8	4	3	1	0
TOTAL Alluvial Formations	**33**	**21**	**9**	**3**	**0**
Bedrock Formations					
Pliocene formations	2	0	2	0	0
Fowkes Formation	3	3	0	0	0
Fossil Butte Member of Green River Formation	7	1	6	0	0
Wasatch Formation	14	7	4	2	1
Evanston Formation	2	0	1	0	1
Upper Cretaceous formations	2	1	0	1	0
Sage Junction Formation	1	1	0	0	0
Thomas Fork Formation	1	1	0	0	0
Gannett Group	8	6	2	0	0
Twin Creek Limestone	1	1	0	0	0
Nugget Sandstone	6	5	1	0	0
Preuss Formation	3	1	1	1	0
Thaynes Limestone	4	4	0	0	0
Woodside Formation	2	2	0	0	0
Phosphoria Formation	2	0	0	1	1
Wells Formation	1	0	1	0	0
TOTAL Bedrock Formations	**59**	**33**	**18**	**5**	**3**
Uncertain formations	14	9	2	3	0

Source: USGS WQ database

Thirty-three (33) alluvial wells were tested for TDS. TDS concentrations ranged from 190 to 1,030 mg/L.

- Twelve (12) out of 33 wells (36%) completed in alluvial formations exceed the domestic standard (500 mg/L); and
- Three (3) out of 33 wells (9%) completed in alluvial formations exceed the livestock standard (5,000 mg/L).

Fifty-nine (59) wells with TDS analysis were completed in bedrock deposits. TDS concentrations from bedrock wells and springs range from 54 to 5,403 mg/L. As shown in Table 4, only five of the bedrock formations have more than three TDS measurements. Therefore, conclusions cannot be drawn for most of the formations. However, the limited information in Table 4 may suggest that:

- TDS measurements from the Fossil Butte Member of the Green River Formation are below 1,000 mg/L, with the majority (86%) between 500 and 1,000 mg/L.

Based on the 7 samples, this formation likely yields water that is of sufficient quality for agricultural use, but not for domestic use without treatment.
- The majority (75%) of TDS measurements from the Gannett Group are below 500 mg/L. Based on the 8 samples, this formation likely yields water that is of sufficient quality for domestic and agricultural use.
- The majority (83%) of TDS measurements form the Nugget Sandstone are below 500 mg/L. Based on the 6 samples, this formation likely yields water that is of sufficient quality for domestic and agricultural use.

TDS measurements from Thaynes Limestone are below 500 mg/L. Based on 6 samples, this formation likely yields water that is of sufficient quality for domestic use.

The Wasatch Formation has a wide range of TDS measurements. Fifty percent of the measurements are below 500 mg/L, and 79 percent of the measurements are below 1,000 mg/L. Therefore, this formation may yield water that is of sufficient quality for agricultural and potentially domestic use. However, three measurements show TDS exceeds 1,000 mg/L. All three of these measurements (2 from wells and 1 from a spring) are in the Twin Creek area.

Figure 6 highlights the TDS concentrations from wells and springs from the GIS coverage containing the water quality measurement results from the quality database. This figure shows that TDS concentrations increase from south to north in the Alluvial Aquifer. This is likely a result of high TDS bedrock spring discharge in the Twin Creek drainage area and increased agricultural return flows. As shown in the Figure 6, measured TDS in the Alluvial Aquifer rarely exceeds the 1,000 mg/L standard for agriculture use.

The following conclusions regarding the Alluvial Aquifer are based on the water quality measurements and corresponding GIS coverage. The Alluvial Aquifer groundwater quality:

- Is generally good, but may exceed domestic standards in some areas;
- Usually meets agricultural and livestock standards, and
- Is generally better in the southern (upstream) portion of the basin.

3.11 Aquifer Sensitivity/Vulnerability

The WDEQ in conjunction with the Wyoming Department of Agriculture, University of Wyoming SDVC, the Wyoming State Geological Survey, and the USEPA developed a system to assess the sensitivity and vulnerability of groundwater to surface water contamination. Aquifer vulnerability maps were developed to define the potential for surface contamination to impact groundwater in the uppermost aquifer.

Figure 7 is a map of aquifer sensitivity to contamination. The highest rated lands are located primarily on alluvial deposits adjacent to rivers, streams, and lakes or in highly fractured bedrock areas. Figure 8 is a map of aquifer vulnerability to pesticide contamination in the uppermost aquifer. Groundwater is vulnerable in areas with high water tables, sandy soils, and presumed pesticide application. The areas with the highest vulnerability are found in the floodplains of the major streams.

4.0 Groundwater Development Potential

The groundwater development potential is the difference between the existing level of development and the maximum withdrawal rate that is sustainable without causing undesirable impacts.

Impacts for each developed aquifer include:

- Declines in water levels which cause increased pumping costs and decreased well yields;
- Declines in spring discharges;
- Declines in surface water flows which impact surface water right holders; and
- Declines in water quality.

The physical ability of an aquifer to produce water is a function of the same aquifer properties that are important in determining well yield. In addition, long-term aquifer yield is a function of the amount of recharge that occurs. If pumping exceeds recharge, aquifer dewatering (lowering water table) will result and yields will diminish. Recharge includes:

- Infiltrating precipitation;
- Return flows from agricultural and lawn irrigation;
- Recharge from surface water features (lakes and rivers); and
- Seepage from other aquifers.

Any reduction in these inflows will eventually reduce the long-term yield and development potential of groundwater in the basin.

4.1 Bear River Alluvial Aquifer Long-Term Yield

Wells in the Bear River Alluvial Aquifer cans sustain high well yields because aquifer drawdown is minimized by recharge from Bear River surface water. Because of this, long-term well yield is probably not constrained by declining water levels. Additional aquifer development is possible as long as water from the Bear River is available for recharge. The amount of additional development depends on whether existing water rights and interstate compacts are satisfied.

Water quality issues may constrain long-term yields in the future. Increased agricultural use could degrade groundwater quality through the introduction of fertilizer and other contaminants to the alluvial aquifer. Municipal effluent recharge may also degrade aquifer water quality. Although no significant decline in groundwater quality has been reported, it may limit ultimate development.

4.2 Bedrock Aquifer Long-Term Yield

Limited recharge and relatively low permeability are the primary reasons why bedrock aquifers have low well yields and low long-term aquifer yields. Away from streams, bedrock aquifer recharge consists of effective precipitation and seepage between aquifers. These amounts are usually low. Therefore, additional bedrock development could exceed these inflows and cause unacceptable water level declines or reduced spring yields.

Spring discharge can be used as subjective measure of long-term aquifer yield. Table 1 shows measured spring discharge from individual aquifers. Although these measurements do not represent all spring discharge in the basin, they can be assumed to represent the minimum aquifer recharge.

The sum of measured spring discharges from the Gannett Group is 837 gpm. If this is assumed to be a conservative measure of aquifer recharge, 837 gpm of additional water may be available to wells without causing significant aquifer water level declines. Likewise, the sum of the other measured spring discharges from bedrock aquifers is around 4,300 gpm, so conservatively 4,300 gpm, or around 7,000 acre-feet per year, may be available for future development.

In other studies of western basins, long-term bedrock aquifer yield has been estimated to be equal to the effective precipitation recharge (precipitation that reaches the groundwater system). A conservative estimate of effective precipitation is around 2 percent of the average basin precipitation of 11 inches, or 14,000 acre-feet per year. The precipitation and the distribution of recharge varies, however, 14,000 acre-feet per year is believed to be a better minimum recharge estimate than 7,000 acre-feet per year.

Like Alluvial Aquifers, the groundwater development potential for bedrock aquifers is also constrained by depletions to the surface water system caused by pumping. Additional withdrawals could reduce spring discharges to unacceptable levels. Under certain conditions, bedrock pumping can immediately reduce spring discharges even if the well is located several miles away. Bedrock pumping also reduces the amount of subsurface recharge to the Alluvial Aquifer, which discharges into the Bear River. Depletions caused by bedrock well pumping usually occur over a longer time scale and depend on how hydraulically connected the aquifer is to the surface water system. In general, bedrock well depletions take longer to occur the further away (distance and depth) the well is from the surface water system.

Water quality issues also can constrain future bedrock aquifer development. Pumping an aquifer with good water quality could induce recharge of poorer quality from another aquifer.

In addition, the presence or development of oil, gas and minerals could influence groundwater quality and development.

5.0 Conclusions

Much of the effort associated with groundwater resource investigation was spent developing spatial data tools, i.e., GIS coverages. These tools were then used, along with information from previous studies, to generalize the existing aquifer development and to estimate development potential. These tools are useful for water administrators, decision-makers, and others interested in future development potential in the Bear River basin. The GIS coverages should be updated as additional groundwater information is developed or existing data from other sources becomes available.

The groundwater development potential is the difference between the level of existing development and the maximum sustainable withdrawal rate that does not cause undesirable impacts. Based on the available data and existing studies, it appears that no significant undesirable affects have yet occurred in the basin and that groundwater is available for additional development.

FIGURES

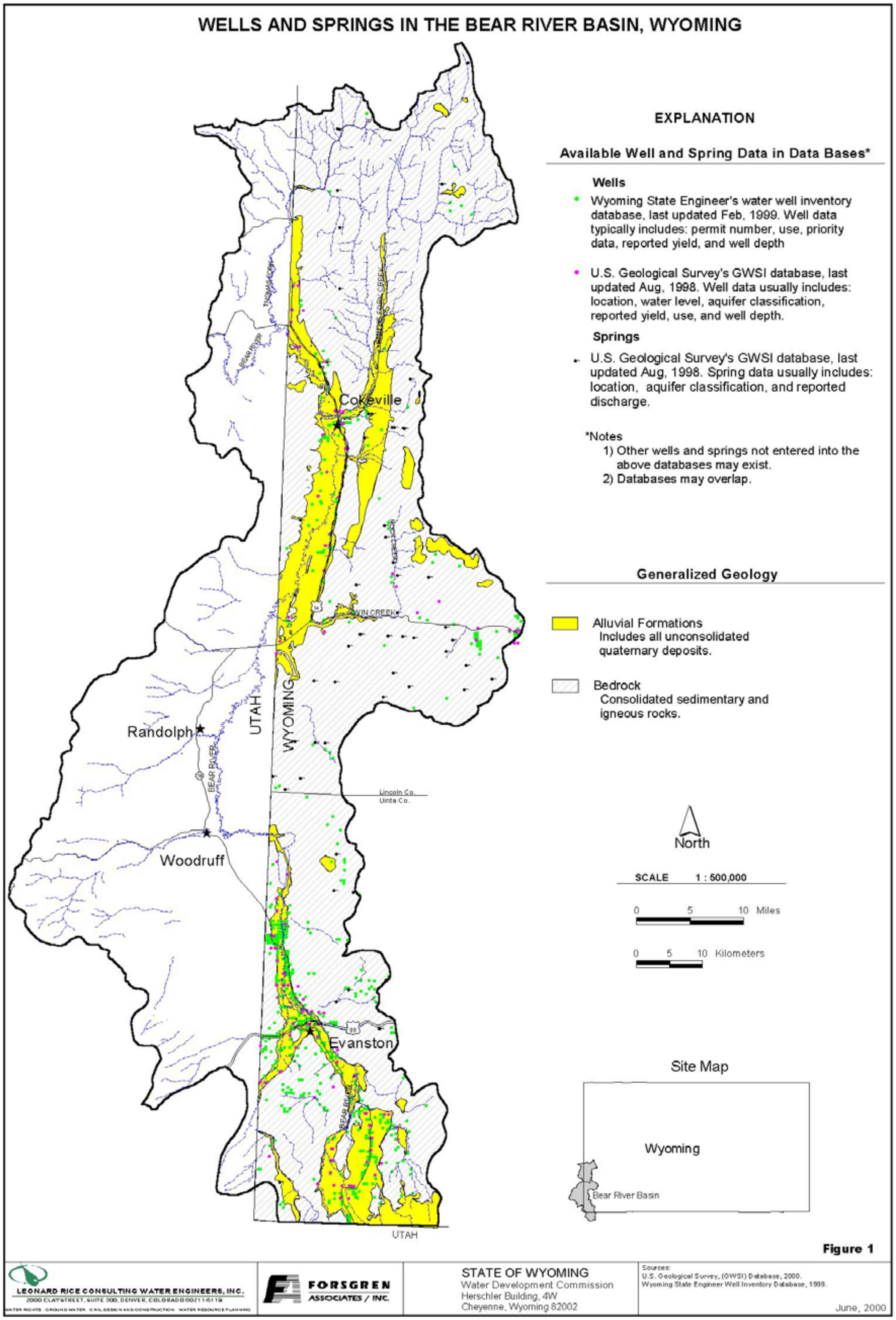

Figure 1: Wells and Springs

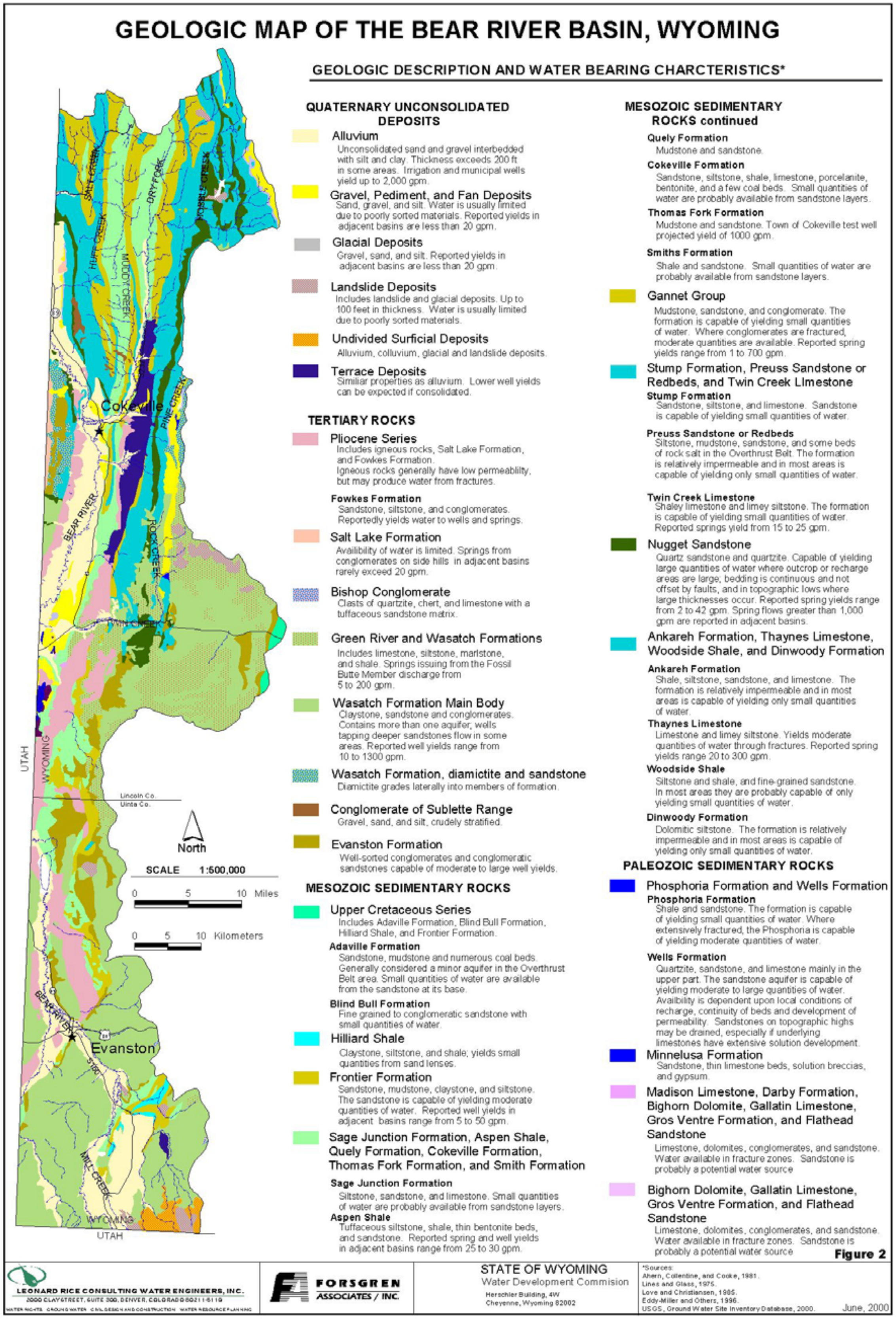

Figure 2: Geologic Map

Figure 2 (continued): Geologic Map

CENOZOIC HYDROGEOLOGIC UNITS

<u>Cenozoic Sedimentary Rocks</u>

Quaternary Unconsolidated Deposits

Alluvium and colluvium
Gravel pediment and fan deposits
Glacial deposits
Landslide deposits
Quaternary deposits (undivided)
Terrace deposits

Tertiary Sedimentary Rocks

Pliocene formations (undivided)
- *Fowkes Formation*

Salt Lake Formation
Bishop Conglomerate
Green River and Wasatch Formations
- *Wasatch Formation – Main body*
- *Wasatch Formation – Diamictite and sandstone unit*

Conglomerate of Sublette Range
Evanston Formation

MESOZOIC HYDROGEOLOGIC UNITS

<u>Mesozoic Sedimentary Rocks</u>

Upper Cretaceous formations (undivided)
- *Adaville Formation*
- *Blind Bull Formation*

Adaville Formation
Hilliard Shale
Blind Bull Formation
Frontier Formation
Sage Junction Formation, Aspen Shale, Quealy Formation, Cokeville Formation, Thomas Fork Formation, and Smiths Formation
- *Sage Junction Formation*
- *Aspen Shale*
- *Quealy Formation*
- *Cokeville Formation*
- *Thomas Fork Formation*
- *Smiths Formation*

Gannett Group
- *Smoot Formation*
- *Draney Limestone*
- *Bechler Conglomerate*
- *Peterson Limestone*
- *Ephraim Conglomerate*

Stump Formation, Preuss Sandstone or Redbeds, and Twin Creek Limestone
- *Stump Formation*
- *Preuss Sandstone or Redbeds*
- *Twin Creek Limestone*

Nugget Sandstone
Ankareh Formation, Thaynes Limestone, Woodside Formation, Dinwoody Formation
- *Ankareh Formation*
- *Thaynes Limestone*
- *Woodside Formation*
- *Dinwoody Formation*

PALEOZOIC HYDROGEOLOGIC UNITS

Paleozoic Sedimentary Rocks

Phosphoria Formation and Wells Formation
- *Phosphoria Formation*
- *Wells Formation*

[*Minnelusa Formation is <u>not</u> present in Wyoming except in the Powder River Basin*]
Amsden Formation and Tensleep Sandstone]
Madison Limestone, Darby Formation, Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone
- *Madison Limestone*
- *Darby Formation*
- *Bighorn Dolomite*
- *Gallatin Limestone*
- *Gros Ventre Formation*
- *Flathead Sandstone*

Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone
- *Bighorn Dolomite*
- *Gallatin Limestone*
- *Gros Ventre Formation*
- *Flathead Sandstone*

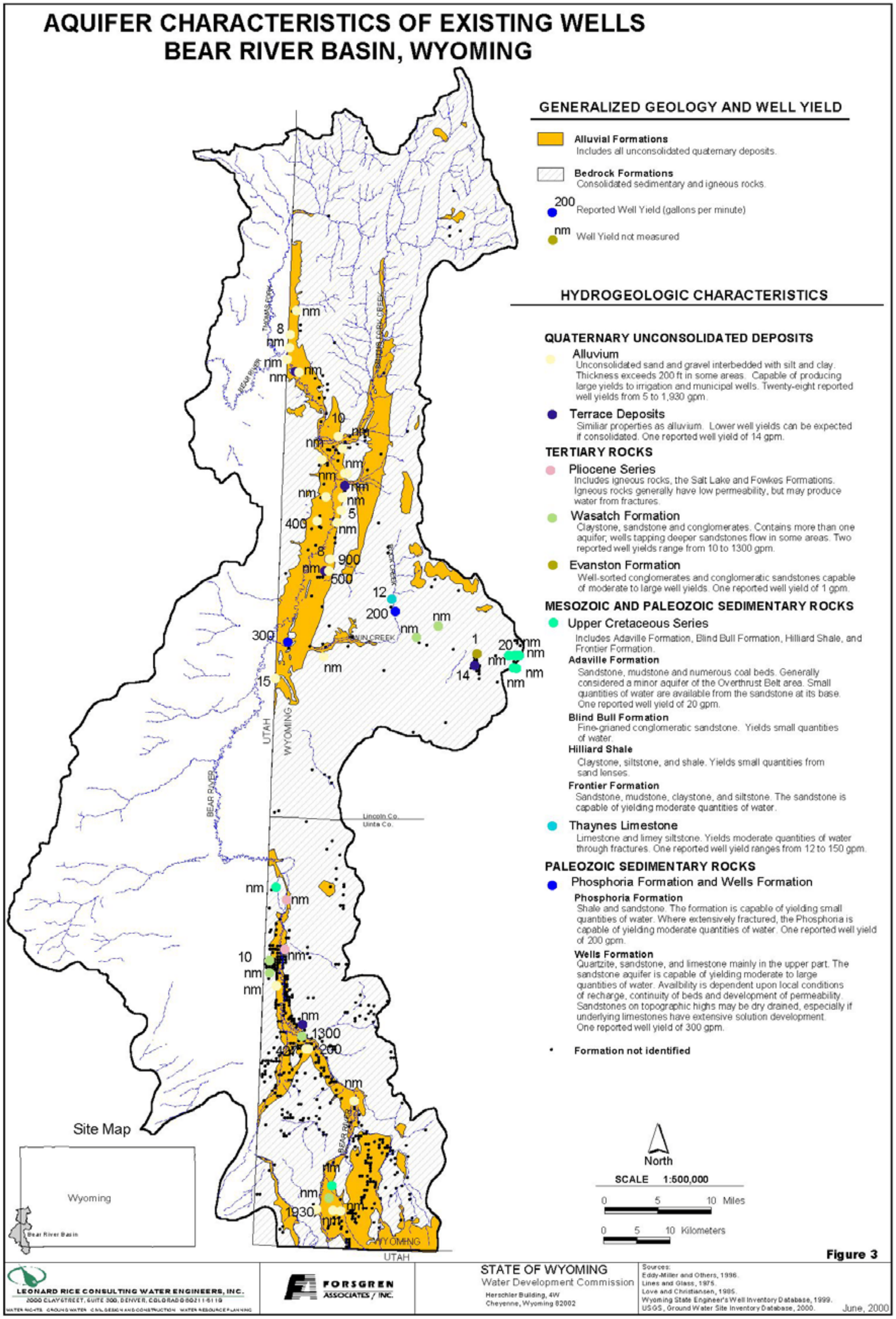

Figure 3: Aquifer Characteristics

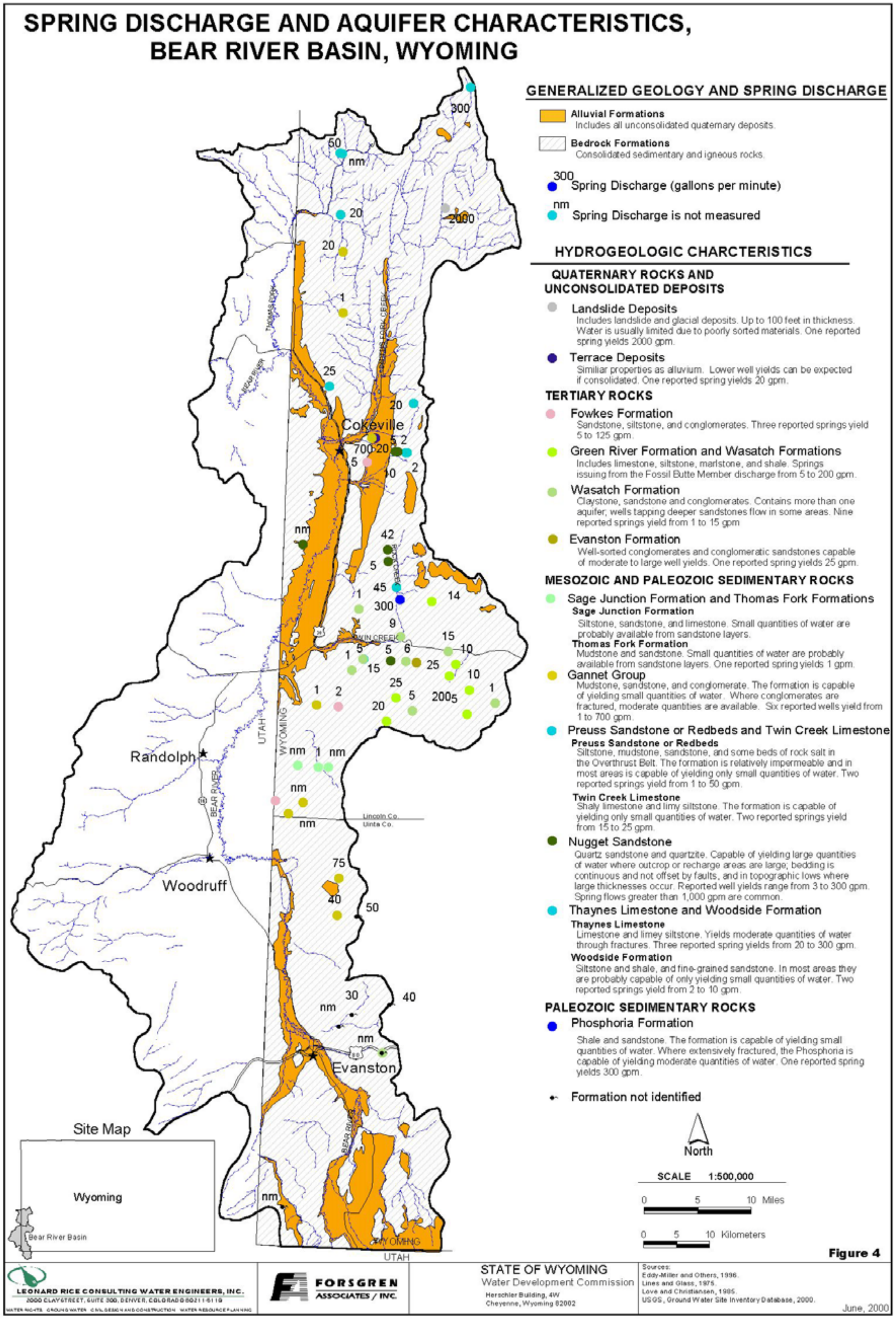

Figure 4: Spring Discharge and Aquifer Characteristics

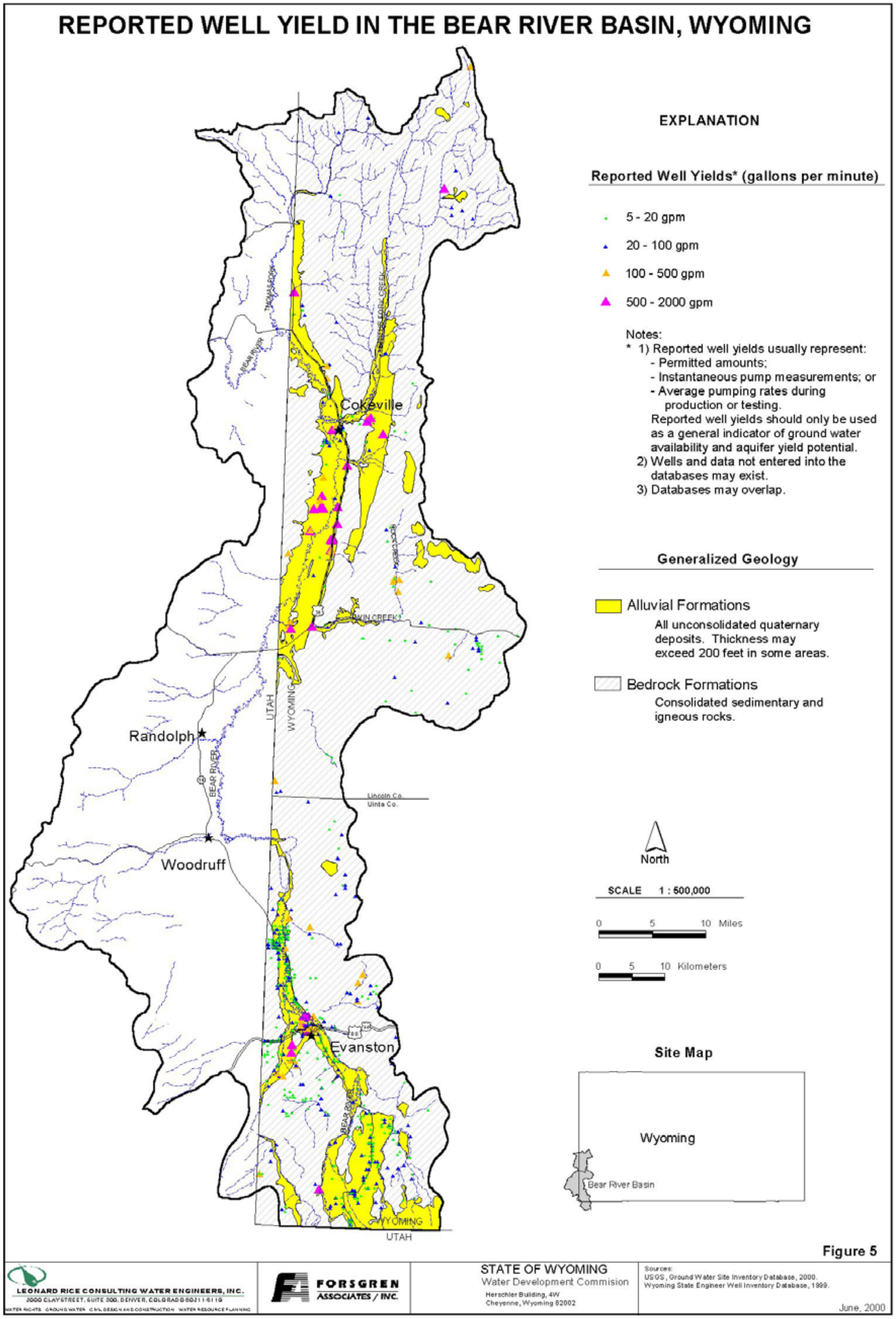

Figure 5: Reported Well Yield

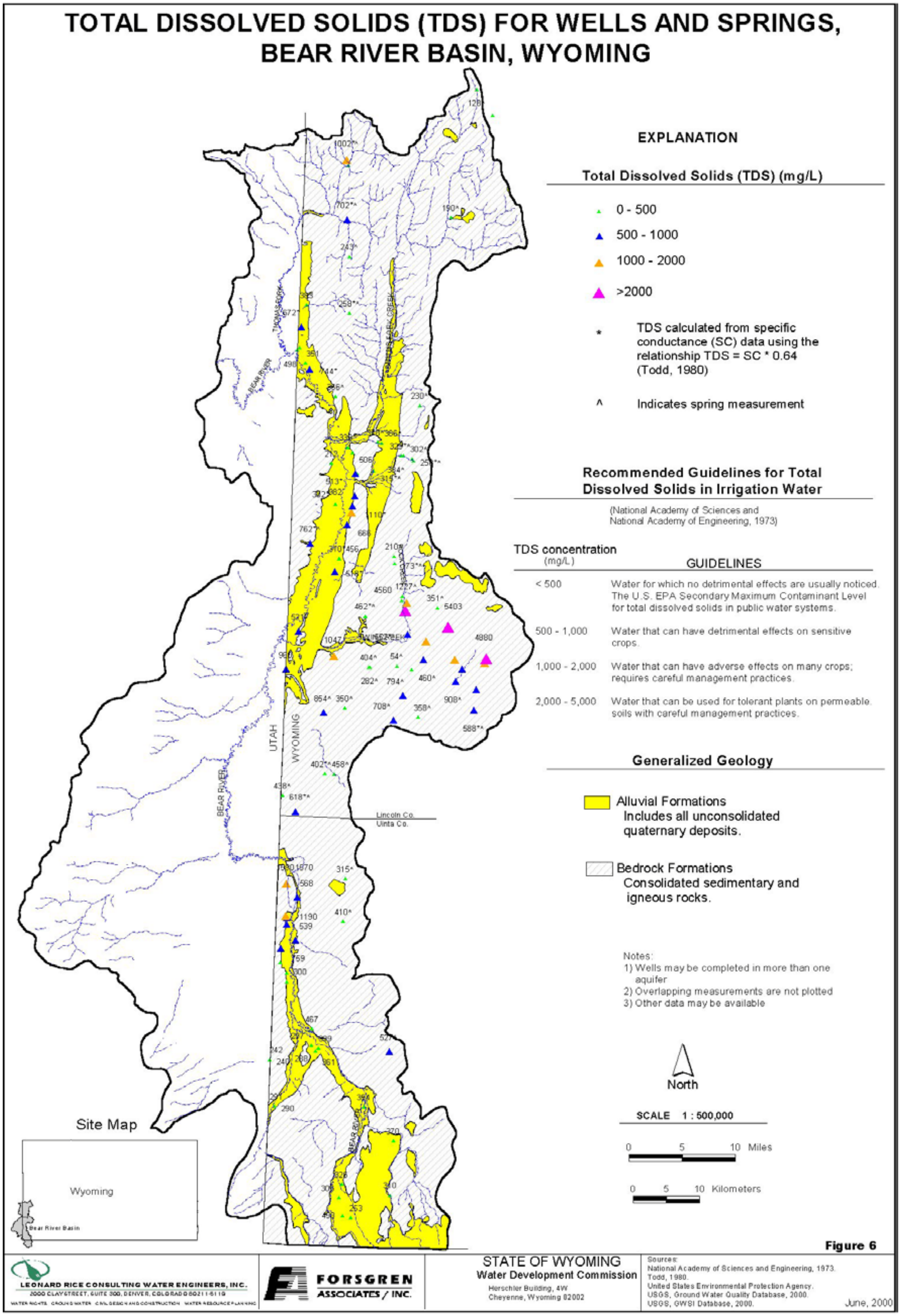

Figure 6: Total Dissolved Solids (TDS) for Wells and Springs

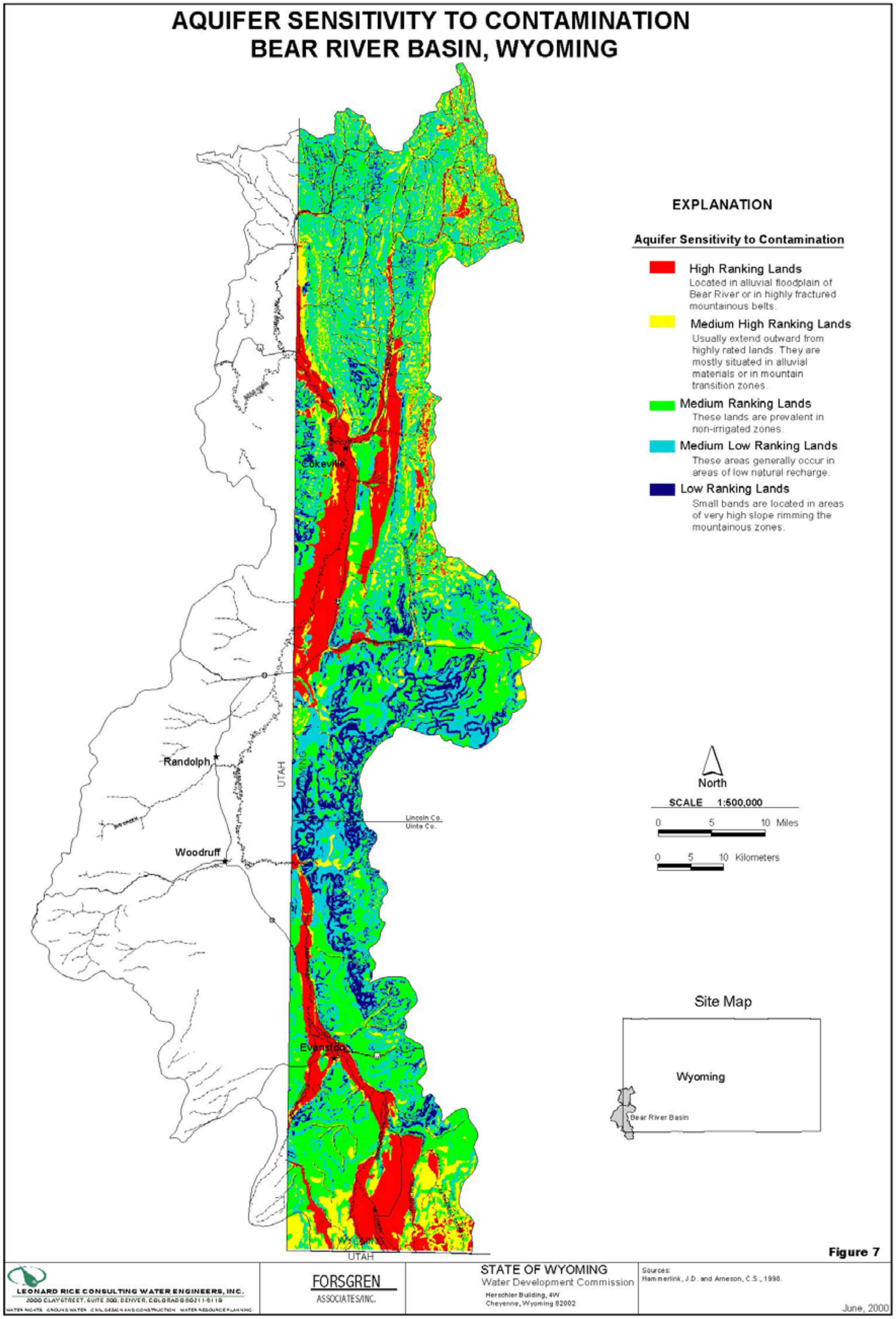

Figure 7: Aquifer Sensitivity to Contamination

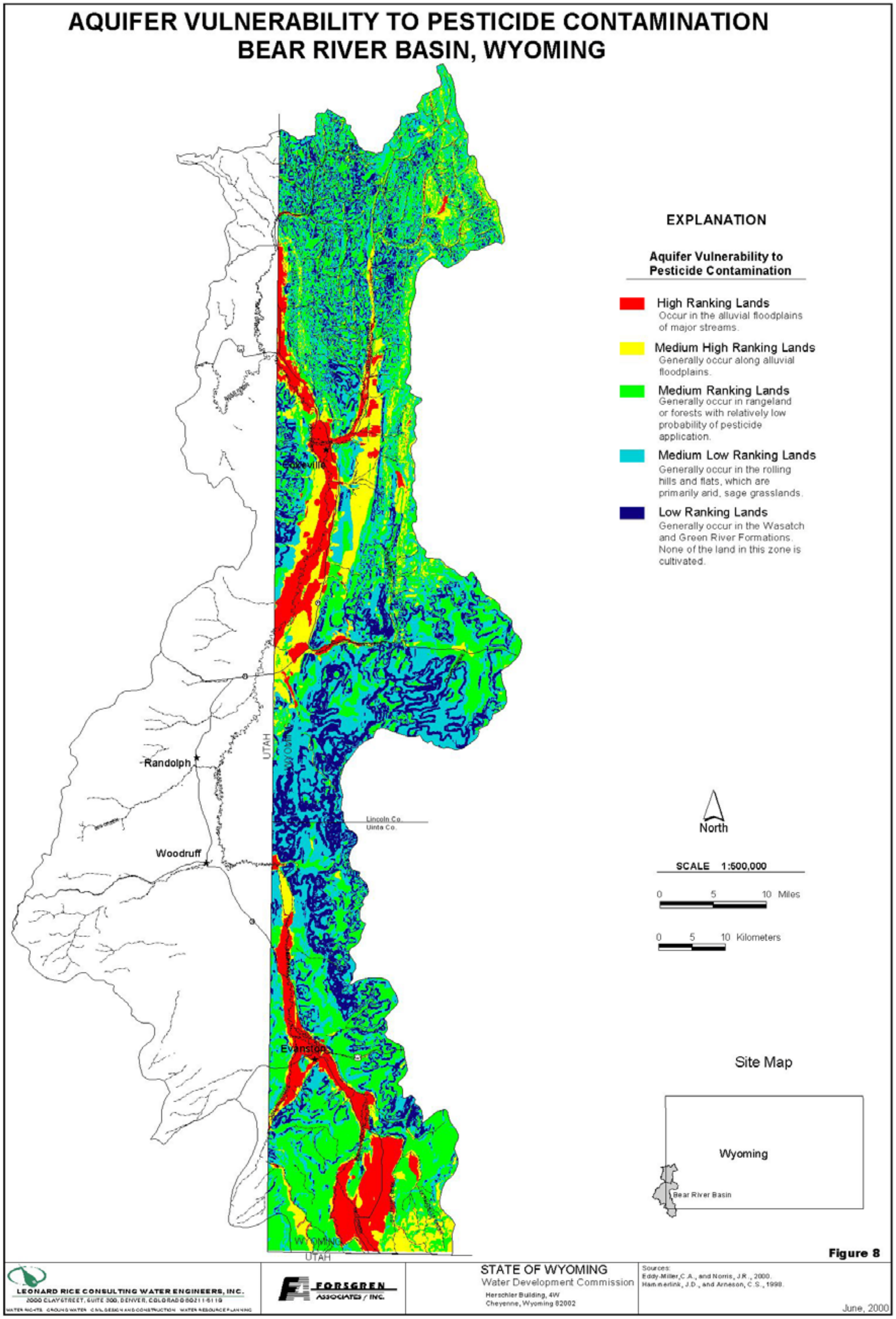

Figure 8: Aquifer Vulnerability to Pesticide Contamination

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APPENDIX A
GROUNDWATER AVAILABILITY

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GROUNDWATER AVAILABILITY

TO: Water Development Commission **DATE:** September 19, 2011

FROM: Keith Clary, P.G. **REFERENCE:** Bear River Basin Plan Update, 2011

SUBJECT: Groundwater Resources Investigation – Appendix A

Contents

1.0 Introduction

The Bear River Basin is located along the southwestern border of the State of Wyoming, with adjacent portions of the drainage basin located in Idaho and Utah. The Bear River Basin is an internal drainage on the North American continent that eventually drains in to the Great Salt Lake of Utah. The low-relief areas that are generally underlain by relatively flat-lying Cenozoic unconsolidated deposits and bedrock formations. The steeper mountain uplifts and ridges are commonly cored by the older Paleozoic and Mesozoic bedrock formations. Table A1 is a stratigraphic chart listing the geologic map units and corresponding aquifer classification in the

Bear River Basin of Wyoming (compiled primarily from the GIS units of the State of Wyoming Geologic Map 1:500,000-scale map). There are 34 GIS geologic units listed in Table A1.

In general, groundwater quality in the Bear River Basin decreases with increasing depths and with increasing distance from the outcrop/subcrop recharge areas. Additionally, permeability also generally decreases with depth. This is likely caused in part by compaction forces from increased lithostatic load and in part to infilling of open pore spaces by mineral cements. The groundwater quality of the aquifers and other hydrogeologic units within the Bear River Basin is highly variable, ranging from excellent to poor.

Table A1: Map Area Percentage in the Bear River Basin, Wyoming (from WSGS Data)

Unit	Map Area (percentage)	Map Area (square miles)
Surface water and ice	***0.26***	***4.0***
Volcanic rocks	***- 0 -***	***- 0 -***
Cenozoic Major Hydrogeologic Group	***60.72***	***925.5***
Quaternary Hydrogeologic Units	17.80	271.3
Upper Tertiary Hydrogeologic Units	6.90	105.2
Lower Tertiary Hydrogeologic Units	36.02	549.0
Mesozoic Major Hydrogeologic Group	***32.91***	***501.6***
Upper Cretaceous Hydrogeologic Units	1.14	17.3
Lower Cretaceous Hydrogeologic Units	17.78	271
Jurassic Hydrogeologic Units	10.57	161.1
Triassic Hydrogeologic Units	3.42	52.2
Paleozoic Major Hydrogeologic Group	***6.11***	***93.0***
Precambrian Major Hydrogeologic Group	***- 0 -***	***- 0 -***
Total Map Area (Wyoming only)	**100**	**1,524.1**

2.0 Major Hydrogeologic Groups

The hydrogeologic units are comprised of the various aquifers and confining units within the Wyoming Bear River Basin. These include unconsolidated sedimentary deposits and consolidated (lithified) bedrock formations ranging in age from Quaternary to Precambrian. The many hydrogeologic units vary widely in lithology and water-bearing properties. We describe the aquifers as occurring in four major hydrogeologic groups based on geologic time and the stratigraphic columns for the Basin areas.

We reevaluated and redefined the large regional aquifer systems in the Bear River Basin, including combining some of the separate units from the Appendix O – December 12, 2000 Ground Water Resource Investigation of Forsgren Associates, Inc. et al. (2001) (Figure 2 in that report). We grouped the geologic units located within the basin on the basis of the four geologic eras: the Cenozoic, Mesozoic, Paleozoic, and Precambrian, from youngest to oldest. Therefore, we have identified four major regional hydrogeologic groups in the Bear River Basin. The four Major Aquifer Groups or Major Hydrogeologic Groups are shown on Figure A1, and include, in descending geologic order:

- Cenozoic Major Hydrogeologic Group;
- Mesozoic Major Hydrogeologic Group;
- Paleozoic Major Hydrogeologic Group; and
- Precambrian Major Hydrogeologic Group.

This comprehensive major hydrogeologic group classification, which is based on the geologic eras, allows any geologic unit to be included in one (or more) of these four major groupings. This approach is applicable across the State of Wyoming, although there will be some discrepancies based on combinations of or geologic time-transgressive units. For example, combined units are mapped such as Paleozoic-Mesozoic rocks, and other formations cross time boundaries like Permian-Triassic or Pliocene-Pleistocene. In these cases, a geologic evaluation of the thickest portion of the formations was conducted to assign a combined or geologic time-transgressive unit to a hydrogeologic group corresponding to the majority of the geologic unit's thickness. As an example, if a Permian-Triassic formation had a thicker footage of its Permian section than the Triassic section of the formation, the formation was assigned to the Paleozoic Major Hydrogeologic Group.

The classification of the four Major Hydrogeologic Groups is also applicable to the geologic units of other adjoining states.

In general, the younger Major Hydrogeologic Groups overlie the older aquifer groups at depth within the basin, and the Paleozoic is exposed only in the outcrop areas of the mountain uplifts. The Precambrian Major Hydrogeologic Group is not exposed at the ground surface in the Bear River Basin and is not considered to be an aquifer in this basin. The Precambrian in this Basin acts as a regional, low-permeability, basal confining unit. The Precambrian formations underlie all three of the younger Major Hydrogeologic Groups at depth in the Bear River Basin.

We discuss these Major Hydrogeologic Groups and their aquifers in order from youngest to oldest, except for the Precambrian rock units. The Paleozoic formations generally underlie the Cenozoic and Mesozoic formations in most areas, except where the units are structurally deformed. There are important exceptions to this generalization because of the complexity of the geologic structures in the Overthrust Belt. In many areas of the Basin, the older Paleozoic and Mesozoic geologic formations are elevated in mountain uplifts above the younger Cenozoic formations.

3.0 General Discussion of Groundwater Resources

All of the water resources in the State of Wyoming are constitutionally the property of the state. These consist of all water in vapor, liquid, and solid phases; and include surface water, groundwater, precipitation (rain, sleet, and snow), snow fields, ice fields, glaciers, and water vapor in the atmosphere. The Wyoming State Engineer's Office (WSEO) regulates beneficial use of both surface water and groundwater. A WSEO permit is required to use state waters, including a groundwater use permit in the state for both water wells and springs. Wyoming's water is beneficially used for agriculture (crop irrigation and livestock watering), domestic supply (private household wells), public water system supply, lawn/garden watering, fish hatching/rearing, environmental purposes (groundwater remediation and monitoring), generating electricity, recreation, and many industrial purposes.

The water of the western United States is renewable, but often limited in supply. Annual precipitation is the ultimate source of both surface water and groundwater. Variations in the quantity and distribution of annual precipitation may limit available water supplies and create water shortages in areas of high demand. Population growth has increased demand and competition for Wyoming's water resources, both within the state and in downstream states.

The Wyoming Department of Environmental Quality, Water Quality Division (WDEQ-WQD) regulates both surface water and groundwater quality within the state to protect public health and the environment. WDEQ-WQD issues permits to regulate activity involving water resources. A permit is required to discharge water into state waters.

The Denver office of the U.S. Environmental Protection Agency (USEPA) Region 8 has primary control over (primacy) Wyoming's public drinking water supplies. Wyoming is the only state where USEPA has primacy over state drinking water systems. USEPA monitors water quality for the several hundred public water systems located Wyoming. Information on Wyoming's public drinking water systems is available from the USEPA Wyoming Drinking Water website (http://www.epa.gov/safewater/dwinfo/wy.htm).

In the Bear River Basin of Wyoming, groundwater resources occur within both the unconsolidated deposits and bedrock formations of the basin. Groundwater resources in the Bear River Basin include aquifers ranging in geologic age from Quaternary to Precambrian (Figures A1 and A2). Bear River Basin groundwater shows in a wide range of variability for both the quantity and quality available from the multiple geologic formations in the basin area.

In outcrop areas of the bedrock formations, shallow groundwater in the bedrock formations is typically unconfined. Deeper in the structural basin areas from the outcrop areas, groundwater is generally confined by low-permeability strata adjacent to the permeable aquifer beds (sandstone, coal, and limestone/dolomite beds). Confined (artesian) groundwater in some areas of the Bear River Basin flows at the surface from confined wells, where confining pressure is greater in pressure height than the ground surface elevation.

Within the Bear River Basin and on the flanks of the adjacent uplifts, most of the water-saturated portions of the geologic bedrock formations and unconsolidated deposits will yield groundwater to wells. This section addresses the quantity and quality of the groundwater available from these geologic units. Many of the low-permeability geologic units in the Bear River Basin yield very low quantities of low-quality groundwater, which may not be adequate or economically viable for the desired water use.

The aquifers are predominantly contained within in an interstratified sequence of high- and low-permeability sedimentary beds. Groundwater is present in the open spaces of the geologic formations and flow occurs through permeable, interconnected pathways under sufficient head pressure. The Bear River Basin aquifers are commonly heterogeneous and anisotropic in character on both local and regional scales. Groundwater flow occurring within the bedrock formations of the Bear River Basin is commonly structurally and stratigraphically controlled in portions of the structural basin areas and adjacent structural uplifts. The inferred regional groundwater flow patterns generally indicate groundwater flows from higher elevation areas towards the lower elevations of the Bear River drainage system.

Deep regional groundwater in the Bear River Basin formations flows predominantly through permeable formations and fractures from aquifer recharge areas, formational outcrops located along the margins of the structural basin areas; towards the structural axes of the structural basins; and down-gradient (downward in elevation). Discharge occurs along stream drainages as springs or as subcrop flow into overlying geologic units. The subcrop discharge of groundwater is generally into alluvium along stream valleys, and helps maintain base flow in some reaches of the streams.

Locally, groundwater is under unconfined (water table) conditions in formation outcrop areas along the margins of the Bear River Basin and in the shallow parts of outcrop areas in the basin. Shallow groundwater flow in the Bear River Basin is predominantly controlled by topography and stream drainage patterns. The regional groundwater flow also generally follows the ground surface topography and local stream drainages are superimposed on the structural basin areas.

An aquifer that may produce good quality, potable water at shallow depth (less than 1,000 ft deep) in the Bear River Basin may also produce petroleum (oil and conventional gas) from the same permeable zones deeper (greater than 5,000 ft deep) in the Basin.

In summary, local, topographically-controlled groundwater flow zones and outcrop areas are the primary areas of recharge to and discharge from the aquifers. Local groundwater flow, in areas where hills and uplands are above the local stream/river drainages in elevation, is dominated by these local topographic features. Local groundwater tends to flow downhill into nearby surface drainages. Complex surface water to groundwater interactions occur between permeable beds of bedrock, the unconsolidated deposits, and the surface water drainages, which are typically lined with alluvial deposits. The groundwater and surface water resources of the Bear River Basin of Wyoming are interconnected, as discharge of groundwater to the surface may occur from springs, subcrop discharge flow to overlying geologic units, and pumping wells.

At present, data on aquifer recharge rates, groundwater flow rates, aquifer discharge rates, degree of subsurface inter-aquifer mixing, and total groundwater quantities available for development in the Bear River Basin are sparse relative to the area and stratigraphic/structural complexity of the Basin. Future groundwater models for the stratigraphy/structure of the Basin and for water quality, quantity, and distribution will need to allow for updating as more data are collected in the future.

In conclusion, the groundwater resources of the Bear River Basin vary widely in occurrence, hydrogeologic characteristics, quantity, quality, and availability. In some parts of the basin, useable groundwater resources are difficult to nearly impossible to develop. In some areas of the basin, groundwater is the only reliable source of water supply available.

4.0 Geologic Setting: Structure

The Bear River Basin is located in an area of structural complexity called the Wyoming-Idaho-Utah Overthrust Belt, a fold-thrust belt stretching from Uinta County to Teton County in

Wyoming. The general structural orientation of the Overthrust Belt is north-south as a series of parallel folds (anticlinal and synclinal) and reverse/thrust/overthrust faults (Ahern et al., 1981). These older compressional structures have been overprinted by a set of younger extensional structures that also trend north-south (Ahern et al., 1981). The younger extensional structures are normal faults associated with Basin and Range-type pull apart (tensional stress) of the earth's crust in this region (Ahern et al., 1981).

The Overthrust Belt is a large fold-thrust complex located in southwestern Wyoming and adjacent areas of Idaho and Utah. It is a region of highly complex structural deformation of Paleozoic and Mesozoic formations: folding, reverse faulting, thrust faulting and overthrust faulting, and a later phase (beginning in the Late Tertiary) of overprinted normal faulting that has continued to the present day. The thrust sheets were generally transported eastward during the Sevier Orogeny (Early Cretaceous to Eocene). The north-south trending, parallel thrust faults of the Overthrust Belt are generally younger to the east.

The approximate thrust fault and thrust sheet sequence during the Sevier Orogeny (Early Cretaceous to Eocene; ~120 to ~50 million years) is modified from Link and DeGrey (2011):

- Paris-Willard Thrust Fault System (Early to Middle Cretaceous; 120-113 million years);
- Meade Thrust Fault System (Early to Late Cretaceous; 113-98 million years);
- Crawford Thrust Fault System (Late Cretaceous; 87-84 million years);
- Absaroka Thrust Fault System (Late Cretaceous; 84-74 million years);
- Hogsback/Darby Thrust Fault System (Paleocene; 63-57 million years); and
- Prospect Thrust Fault System (Eocene; 57-52 million years).

The Paris-Willard, Meade, Crawford, and Absaroka thrust fault systems are present in Idaho and Utah; and the Crawford, Absaroka, Hogsback/Darby, and Prospect are present eastward in Wyoming.   Each thrust sheet (hanging wall above the fault trace) ranges from about 10,000 to 20,000 ft thick (Dixon, 1982). The thrust sheets are relatively flat-lying with low-angle dips westward. A thrust ramp is present at the eastward part of the thrust sheet and exposure of the thrust fault at or near the ground surface.

The younger normal faults in the Basin include horst and graben structures and half-graben structures. Many of the normal faults are listric in character at depth (Constenius, 1996). Some of the normal faults reactivated movement on the older thrust/overthrust faults, but with the opposite motion. The normal fault reactivation often occurred along the ramps of the thrust/overthrust faults (Constenius, 1996). The hanging walls of the thrust/overthrust faults originally moved upwards and eastwards under the compressional stress regime of the Sevier Orogeny from Cretaceous to Eocene geologic time. Under the extensional stress regime of the later Basin and Range system from Oligocene to Quaternary geologic time, the hanging walls faulted and reactivated, moving downward and westwards (Constenius, 1996).

The geologic structures of the Bear River Basin predominantly determined the northward flow the Bear River in the Wyoming portion of the basin. Many of the margins of the Bear River Valley are structurally bound by listric normal faults which formed graben and half-graben structures (Constenius, 1996). These faulted and down-dropped river valley floors create the low topographic areas within the Bear River Basin. These structurally-lowered valleys helped determine the pathway for the northward flow of the Bear River. The Bear River flows through these geologic structures. Consequently, deposition of Quaternary unconsolidated deposits was concentrated in these structurally down-dropped valleys (graben and half-graben structures formed by listric normal faults).

The three major geologic maps showing the geologic units and structures in the Bear River Basin and referenced in this Appendix are shown on Figure A3 and include:

- <u>Northern Basin</u>: Cokeville 30-minute geologic quadrangle map (Rubey et al., 1980), scale 1:62,500.
- <u>Central Basin</u>: Kemmerer 30x60-minute geologic quadrangle map (M'Gonigle and Dover, 1993), scale 1:100,000.
- <u>Southern Basin</u>: Evanston 30x60-minute geologic quadrangle map (Dover and M'Gonigle, 1993), scale 1:100,000.

<u>Northern Basin (Cokeville 30-minute geologic quadrangle map)</u>

The major north-south trending, geologic faults in the southern part of the Cokeville quadrangle (Rubey et al., 1980) from west to east are:

- A normal fault bounds the western margin of the Bear River Valley and drops the valley downward in relation to the highlands located to the west of the valley;
- The Crawford thrust fault (associated Stoffer Ridge and Muddy Ridge faults) is located along the eastern margin of the Bear River Valley south of Cokeville and along the eastern flank of the Sublette Range north of Cokeville;
- Another normal fault bounds the eastern margin of the Bear River Valley and drops the valley downward in relation to the highlands east of the valley;
- A normal fault bounds the eastern margin of Sublette Flat and western flank of the Tunp Range; and
- The Tunp thrust fault is located along the eastern flank of the Tunp Range and western margin of the Hams Fork Plateau-Dempsey Basin.

In the Cokeville area, the Bear River Valley is defined by a graben structure with valley-fill consisting of alluvium, colluvium, terrace gravel, and alluvial fans deposits. The Fowkes Formation underlies the Quaternary valley-fill deposits in some areas and is exposed in outcrops along the Bear River Valley.

<u>Central Basin (Kemmerer 30x60-minute geologic quadrangle map)</u>

The major north-south trending, geologic faults and structures in the Kemmerer quadrangle (M'Gonigle and Dover, 1992) from west to east are:

- The Crawford thrust fault is located in the northwestern portion of the Kemmerer quadrangle and associated with the Crawford Mountains on the Wyoming-Utah border.

- A normal fault bounds the eastern margin of the Bear River Valley and drops the valley downward in relation to the highlands east of the valley in the northwestern portion of the Kemmerer quadrangle.
- The Tunp thrust fault is located along the eastern flank of the Tunp Range and western flank of Dempsey Ridge, trending eastward across Dempsey Ridge to the south, and located farther southwards along the western flank of the Bear River Divide in the western portion of the Kemmerer quadrangle.
- The Fossil Basin syncline structure underlies the Tertiary formations (Wasatch/Green River Formations) in the western half of the Kemmerer quadrangle.
- The Beaver Creek thrust fault is located to the east of Fossil Butte National Monument in the northern portion of the Kemmerer quadrangle.
- The Commissary thrust fault is located to the east of Fossil Butte National Monument in the northern portion of the Kemmerer quadrangle.
- The Absaroka thrust fault is located along the eastern margin of the Fossil Butte syncline structure and Commissary Ridge and west of Cumberland Flats.
- The Lazeart syncline structure is located on the footwall of the Absaroka thrust fault in the northern and southern portions of the Kemmerer quadrangle.
- Located farther east is the western margin of the Green River Structural Basin.

In the northwestern portion of the Kemmerer quadrangle, the Bear River Valley is located mostly north of Sage Junction. The Bear River Valley in this quadrangle is defined by a graben structure with valley-fill consisting of alluvium, colluvium, terrace gravel, and alluvial fans deposits. An older deposit in the Bear River Valley is the Fowkes Formation, which is exposed as outcrops along the western portion of the valley and underlies some of the younger Quaternary unconsolidated deposits.

Southern Basin (Evanston 30x60-minute geologic quadrangle map)

The major north-south trending, geologic faults and structures in the Evanston quadrangle (Dover and M'Gonigle, 1993) from west to east are:

- A normal fault bounds the eastern margin of the Bear River Valley and drops the valley downward in relation to the highlands east of the valley in the west-central portion of the Evanston quadrangle, which is near Evanston, Wyoming. This fault is generally interpreted as a listric normal fault.
- The Tunp thrust fault is located to the south and east of Evanston, Wyoming, is located around the eastern base of Medicine Butte, and trends to the northwest along the western flank of the Bear River Divide in the western portion of the Evanston quadrangle.
- The Fossil Basin syncline structure includes a thick sequence of Tertiary formations (Wasatch/Green River Formations) in the western half of the Kemmerer quadrangle.
- The Absaroka thrust fault is located along the eastern margin of the Fossil Butte syncline structure.
- The Ryckman Creek thrust fault is located in the north-central portion of the Evanston quadrangle.
- The Round Mountain thrust fault is located to the east of the Absaroka and Ryckman Creek thrust faults and west of Cumberland Flats.

- Lazeart syncline structure is located on the footwall of the Absaroka thrust fault in the northern and central portions of the Evanston quadrangle.
- Located farther east is the western margin of the Green River Structural Basin.

The folds and faults complicate the local geologic settings and generally require a site-specific hydrogeologic investigation to develop additional groundwater resources in the Bear River Basin. Many of the thrust and overthrust faults structurally offset geologic formations by thousands of feet to tens of thousands of feet. Some of the normal faults may have a few thousand feet of offset locally. The faults and associated fracture zones may act as either a barrier to, or a conduit for, groundwater flow. Because of the structural complexity of this area, moving a proposed well site a few feet away from another well site may result in drilling in a set of completely different geologic formations.

The groundwater resources of the Bear River Basin are predominantly controlled by the structural geology. In an undisturbed sequence, the Paleozoic formations underlie all younger geologic formations. However, in many areas of the Basin, the Paleozoic and Mesozoic units were uplifted on faults over and above younger formations and are now exposed in the mountain ridges of the Overthrust Belt. The Paleozoic and Mesozoic formations are the most structurally deformed geologic units in the Bear River Basin. The Tertiary and Quaternary formations are less deformed and relatively flat-lying.

During the Sevier Orogeny (mountain-building event) which formed the Overthrust Belt (fold-thrust), the Paleozoic and early Mesozoic sedimentary formations were compressed by a series of north-south trending overthrust and thrust fault systems. In general, the older thrust faults are located to the west and become progressively younger to the east. The older thrust sheets were transported eastward as the younger thrust sheets formed and actively were transported eastward towards the Green River structural basin.

The surrounding mountain uplifts of the Uinta Mountains, Wind River Range, Gros Ventre Range, and Teton Range flank the Overthrust Belt and these uplifts formed during the younger and somewhat concurrent Laramide Orogeny. The later stages of the Sevier Orogeny overlap in timing with the early development of the Laramide Orogeny (Late Cretaceous to Eocene-Oligocene).

The mountain uplifts of the Overthrust Belt were eroded and a blanket of Tertiary formations was unconformably deposited on top of the erosional surface developed on the older, deformed Paleozoic and Mesozoic formations. The attitude of the Paleozoic and Mesozoic formations may be nearly horizontal to nearly vertical and are overturned in some localities. The Tertiary formations are relatively flat-lying with low-angle dips.

The structural Fossil Basin (syncline structure) predominantly lies between the Tunp thrust fault system on the west and the Absaroka thrust fault system on the east and has accumulated a thick sequence of Tertiary sedimentary deposits of the Wasatch and Green River formations. The Fossil Basin syncline is predominantly located on the hanging wall of the Absaroka thrust fault and on the footwall of the Tunp thrust fault.

5.0 Aquifers and Major Hydrogeologic Groups

Groundwater resources are present in the unconsolidated sedimentary deposits and bedrock formations where these geologic units are sufficiently permeable and water-saturated. Groundwater resources may be developed in areas of the Basin where the groundwater is present in adequate quantities and qualities for the desired water use.

The three Major Hydrogeologic Groups exposed at the ground surface in the Bear River Basin are the Cenozoic, Mesozoic, and Paleozoic Major Hydrogeologic Groups. Each is discussed in the following sections.

5.1 Cenozoic Major Hydrogeologic Group

The Cenozoic Major Hydrogeologic Group consists of the water-saturated portions of the unconsolidated deposits and consolidated bedrock formations ranging in age from Quaternary (Holocene and Pleistocene Epochs) to Tertiary (Pliocene, Miocene, Oligocene, Eocene, and Paleocene Epochs). The Cenozoic Major Hydrogeologic Group is the most heavily used of the four Major Hydrogeologic Groups in the Bear River Basin. The Cenozoic Major Hydrogeologic Group is divided into the upper and younger Quaternary Geologic Units and the lower and older Tertiary Geologic Units.

The Quaternary geologic units in the Bear River Basin consist mostly of unconsolidated deposits: alluvial, landslide, eolian, lacustrine, glacial, gravel, and terrace deposits. Many of these Quaternary unconsolidated deposits are less than 50 ft thick in the Bear River Basin but some units may exceed 100 ft thick locally. Groundwater is yielded to wells from the water-saturated portions of the sand, gravelly sand, and gravel beds of these Quaternary deposits. The aquifers of the Cenozoic Major Hydrogeologic Group are the most commonly used aquifers for rural domestic and livestock watering uses in the Bear River Basin.

The Tertiary Geologic Units generally underlie the Quaternary Geologic Units. The Tertiary units are composed of sedimentary rocks which are the most abundant and widely used shallow aquifers in the Bear River Basin. These Tertiary units and the overlying Quaternary units comprise about 83 percent of the map area of the Wyoming Bear River Basin (Figures A-1 and A-2). The groundwater quality in these Tertiary units is highly variable, which reflects the highly complex stratigraphy and interfingering and intertonguing of the nonmarine Tertiary sedimentary rock units within the Bear River Basin. The Upper Tertiary Geologic Units yield water from the sandstone, conglomerate, and conglomeratic sandstone beds within the geologic units.

The Lower Tertiary Geologic Units are predominantly composed of the water-saturated portions of the Bridger Formation, Wasatch Formation, Wasatch Formation, Conglomerate of Sublette Range, Fort Union Formation, and Evanston Formation. These Paleocene-Eocene formations have a combined thickness averaging about 5,000-8,000 ft with a maximum thickness estimated as greater than 12,000 ft in the Bear River Basin of Wyoming.

The primary water-yielding beds in the Lower Tertiary Geologic Units are the sandstone, conglomeratic sandstone, conglomerate, and coal beds in these formations. The outcrop area of the Lower Tertiary Geologic Units is the largest within the Bear River Basin. Most of the existing water wells in the Bear River Basin yield water from the various inter-fingered members and tongues of the Green River and Wasatch formations and their lateral equivalent formations. The Fossil Basin structural syncline contains a large expanse of Lower Tertiary formations, mostly the Wasatch and Green River Formations.

5.11 Quaternary Geologic Units

Alluvial, alluvial fan, and terrace gravel deposits are present along the Bear River Valley and tributary drainages (Figure A-2). The Quaternary unconsolidated deposits unconformably overlie the older bedrock formations and are generally present in the valleys and lower elevation areas of the Bear River Basin. These Quaternary-age deposits are the source of shallow groundwater for many of the rural users in the Bear River Basin. The groundwater present within these unconsolidated deposits is generally unconfined.

Alluvial deposits and colluvium

The Quaternary alluvial deposits or alluvium is composed of interbedded, poorly to moderately-well sorted, unconsolidated, gravel, sand, and clay on floodplains and alluvial fans (Rubey et al., 1980).

Northern Basin (Cokeville quadrangle)

- C**olluvium (Qd)** consists of unconsolidated and generally unstratified, mixtures of very coarse to fine, angular to subangular rock debris, sand, and soil; includes slopewash and alluvial fans of tributary stream valleys in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Alluvium (Qa) (Upper Pleistocene? and Holocene)** is composed of unconsolidated, crudely to well stratified, mixtures of clay, silt, sand, and gravel deposited along present main streams, primarily as channel-fill and floodplain deposits; locally includes alluvial fan and terrace deposits, valley side colluvium or talus, and sediments deposited in small bogs, lakes, or deltas; gradational into other surficial deposits; locally exceeds 30 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).
- **Colluvium (Qc) (Pleistocene and Holocene)** is composed of unconsolidated and unstratified, angular debris mantling major stream valley sides, tributary stream valleys, and hill slopes; locally includes soil and gravel; variable thickness, commonly 3 ft or more thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Alluvium (Qa) (Upper Pleistocene? and Holocene)** is composed of unconsolidated, crudely to well stratified, mixtures of clay, silt, sand, and gravel deposited along major streams and tributary streams, primarily as channel-fill and floodplain deposits; locally includes alluvial fan and terrace deposits, valley side colluvium or talus, and sediments deposited in small bogs, lakes, or deltas;

gradational into other surficial deposits; locally more than 30 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

- **Colluvium (Qc) (Pleistocene and Holocene)** is composed of unconsolidated and unstratified, angular debris mantling major stream valley sides, tributary stream valleys, and hill slopes; locally includes soil and gravel; variable thickness, commonly 3 ft or more thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

In some areas of the Bear River Valley, the alluvial deposits are relatively thin (less than approximately 30 to 40 ft thick) and may yield only minimal amounts of water to wells of seasonally questionable water quality. In areas where the alluvial deposits are relatively thin (30 ft or less thick) and with shallow groundwater depths (10 ft or less) the water quality of shallow wells is suspect due to the susceptibility of bacterial or ammonia/nitrate contamination of the shallow groundwater from septic systems and livestock manure. These thin (less than about 30 ft thick) alluvial deposit areas include portions of the Bear River Valley in the vicinity of the Town of Bear River. Shallow groundwater quality in this area during the summer months may be very poor.

The alluvial deposits are up to 200 ft thick in the Bear River Basin and alluvial wells have reported yields ranging from 5 to nearly 2,000 gpm. Groundwater flow in the alluvial deposits is commonly towards or generally in a downstream direction paralleling the direction of the surface water flow in the river or streams. In some areas the water quality of alluvial wells is poor to fair.

Alluvial fan deposits

Alluvial fan deposits are common along the Bear River Valley in the area located to the north of the Town of Cokeville. Some upper portions of the alluvial fans are well drained of groundwater and groundwater is not present except at the deeper depths in the proximal and medial portions of the alluvial fan deposits.

Central Basin (Kemmerer quadrangle)

- **Alluvial fan deposits (Qf) (Upper Pleistocene? and Holocene)** is composed of unconsolidated, crudely stratified, alluvium and colluvium forming well defined fan-shaped deposits at mouths of tributary valleys; variable thickness, commonly 30 ft or more thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Alluvial fan deposits (Qf) (Upper Pleistocene? and Holocene)** is composed of unconsolidated, crudely stratified, alluvium and colluvium forming well defined fan-shaped deposits at mouths of tributary valleys; variable thickness, commonly 30 ft or more thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Playa lake and other lacustrine deposits

These Quaternary-age unconsolidated lacustrine deposits are only present in limited areas of the basin.

Windblown sand and loess deposits (eolian deposits)
These Quaternary-age unconsolidated eolian deposits are only present in limited areas of the basin.

Northern Basin (Cokeville quadrangle)

- **Loess deposits (Qlo) (Pleistocene and Holocene)** consist of light brown, unconsolidated, fine sand and silt; as much as 150 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Loess deposits (Qlo)** (Pleistocene and Holocene) is composed of poorly consolidated, wind-blown silt and fine-grained sand; locally forms dunes about 10 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Glacial deposits
These Pleistocene unconsolidated glacial deposits (Qg) are only present in limited areas of the basin. These areas are located in the highlands and mountain flanks of the northern and southern portions of the Bear River Basin. The southern deposits are associated with the northern flank of the Uinta Mountains uplift.

Northern Basin (Cokeville quadrangle)

- **Glacial deposits (Qm and Qmo) (Pleistocene)** consist of unconsolidated, unsorted, mixtures of rock fragments, silt, and clay; in tills and moraines of former mountain glaciers; as much as 200 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

Southern Basin (Evanston quadrangle)

- **Moraine (Qm) (Pleistocene)** is composed of unconsolidated, poorly sorted, bouldery glacial till having well defined lateral and terminal ridges and kettles; typically slumped; unknown thickness, probably at least 230 ft thick locally in the Evanston quadrangle (Dover and M'Gonigle, 1993).
- **Older moraine deposits (Qmo) (Pleistocene)** is composed of unconsolidated, poorly sorted, glacial till having subdued morphology in outcrop; much more extensively slumped and forested than the moraine (Qm) unknown thickness, probably at least 130 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Landslide deposits

Northern Basin (Cokeville quadrangle)

- **Landslide deposits (Qls) (Pleistocene and Holocene)** are composed of masses of older rock units that have moved downward and are partly broken and disaggregated in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Landslide deposits (Ql) (Pleistocene and Holocene)** is composed of slumps, landslides, and mudflows of soil and rock; includes unconsolidated, angular rock debris and large slump blocks that have moved or rotated downslope in mass under gravity, commonly as a result of removal of lateral support; locally more than 30 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Landslide deposits (Ql) (Pleistocene and Holocene)** is composed of slumps, landslides, and mudflows of soil and rock; includes unconsolidated, angular rock debris and large slump blocks that have moved or rotated downslope in mass under gravity, commonly as a result of removal of lateral support; locally more than 30 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Terrace gravel deposits

The Pliocene to Pleistocene terrace gravel deposits (Qt and QTg) are composed of unconsolidated mixtures of coarse gravel, sand, silt, and clay located 30 ft to more than 100 ft above local stream drainages; as much as 325 ft thick in western Wyoming and southeastern Idaho (Oriel and Platt, 1980). The terrace gravel deposits have at least one well with a reported yield 14 gpm (Forsgren Associates, Inc., GW Memo, 2001).

Northern Basin (Cokeville quadrangle)

- The **Pleistocene to Holocene terrace gravel deposits (Qt)** consist of unconsolidated, poorly to moderately sorted, partly dissected, mixtures of gravel, sand, and silt; present above the elevation of the present streams at heights of 15 to 40 ft, 100 to 150 ft, and 250 ft in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).
- The **Pleistocene to Pliocene(?) older gravel deposits (QTg)** are composed of unconsolidated and crudely stratified mixtures of pebble- to boulder-sized gravel, sand, silt, and clay; underlies bench located east of Smiths Fork; uncertain age; as much as 150 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980). East of the Town of Cokeville, the Sublette Flat area is underlain with a relatively thick and areally extensive terrace gravel deposit.
- **Terrace gravels and older alluvium (Qtg) (Pleistocene and Holocene)** is composed of unconsolidated mixtures of poorly to moderately sorted, silt, sand, and gravel occurring as partly dissected terraces at various levels (elevations) above the present-day stream drainages; mainly as two terraces along major streams, 15 to 40 ft and 100 to 150 ft above present steam levels; remnant of a higher terrace level at 250 ft above present streams in the Cokeville quadrangle (Rubey et al., 1980).
- **Older gravel (QTg) (Pliocene and Pleistocene)** is composed of unconsolidated mixtures of crudely stratified, pebble to boulder gravel, sand, silt, and clay; underlies bench east of Smiths Fork and exposed in the Sublette Flat area to the west of Tunp Range; age not determined; as much as 150 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Terrace deposits and gravel (Qtg) (Pleistocene and Holocene)** is composed of unconsolidated mixtures of sand, silt, and pebble, cobble, and boulder gravels occurring in numerous terraces or benches at various levels (elevations) above the present-day stream drainages; some terrace levels represent glacial outwash trains graded southward to moraines; other terrace levels represent redistributed older, higher level conglomerate and gravel deposits; variable thickness, but usually less than 16 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

- **Gravel deposits (Qg) (Pleistocene and Holocene)** is composed of unconsolidated gravel veneer or pavement commonly on pediment surfaces; includes lag concentrate from erosion of nearby formations; commonly forms prominent topographic benches; variable thickness, locally more than 16 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).
- **High-level terrace gravel deposits (QTg) (Pliocene and Pleistocene)** is composed of unconsolidated, cobble and boulder gravels occurring on terraces and pediments more than 245 ft above present stream drainages; the two terraces in the northeastern corner of the Kemmerer quadrangle south and west of the Green River may be erosional remnants of a high-level terrace, which now extends south from the Fort Bridger Airport to the southern part of the Evanston quadrangle; is more than 16 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Terrace deposits and gravel (Qtg) (Pleistocene and Holocene)** is composed of unconsolidated mixtures of sand, silt, and pebble, cobble, and boulder gravels occurring in numerous terraces or benches at various levels (elevations) above the present-day stream drainages; some terrace levels represent glacial outwash trains graded southward to moraines located in the Uinta Mountains, Utah; other terrace levels represent redistributed older, higher level conglomerate and gravel deposits; variable thickness, but is usually less than 16 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).
- **Gravel deposits (Qg) (Pleistocene and Holocene)** is composed of unconsolidated gravel veneer or pavement commonly on pediment surfaces; includes lag concentrate from erosion of nearby formations; commonly caps dissected pediment surfaces or pediment remnants; variable thickness, locally more than 16 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

5.12 Upper Tertiary Geologic Units

The Tertiary bedrock formations are composed of nonmarine (continental) mixtures of shale, siltstone, sandstone, conglomerate, lacustrine limestone, tuff, and other lithologies. These formations commonly interfinger with other formations and lithologies. The Upper Tertiary Geologic Units range in age from Miocene to Pliocene.

Salt Lake Formation

The Miocene to Pliocene Salt Lake Formation (Tsl) is composed of interbedded white, gray, and green tuff, calcareous siltstone, sandstone, and conglomerate, which grades laterally into red-weathering diamictite near exposures of older bedrock; up to about 23,000 ft thick near Preston, Idaho (Oriel and Platt, 1980). The Miocene Salt Lake Formation is present in some of the structurally down-dropped valley floors in the Bear

River Basin. The Salt Lake Formation generally exhibits low permeability, but may produce water from the sandstone and conglomerate and also from the fractures in the formation (Forsgren Associates, Inc., GW Memo, 2001).

Northern Basin (Cokeville quadrangle)

- **Salt Lake Formation (Tsl)** consists of pale red-gray, interbedded, poorly consolidated, tuffaceous, conglomerate, grit, sandstone, and siltstone with minor white rhyolitic volcanic ash beds; as much as 130 ft thick (Rubey et al., 1980).

Fowkes Formation

The Middle Eocene and Pliocene (?) Fowkes Formation (Tf) consists of interbedded light-colored tuffaceous sandstone and siltstone, which is locally conglomeratic; as much as 1,150 ft thick (Oriel and Platt, 1980). The Fowkes Formation yields groundwater to wells in areas where it is sufficiently permeable and saturated.

Northern Basin (Cokeville quadrangle)

- **Fowkes Formation (Tf)** consists of light colored, interbedded, tuffaceous, conglomerate, sandstone; upper Gooseberry Member (age uncertain: Eocene? or Pliocene?) and lower Sillem Member (Eocene) (Rubey et al., 1980).

Gooseberry Member *(Tfg) (Middle Eocene? or Pliocene?)* is composed of light colored, conglomerate and puddingstone containing heterogeneous pebbles and cobbles of quartzite, limestone, and volcanic rocks mixed into a matrix of white, silty, and tuffaceous limestone; thickens northward to 500 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Sillem Member *(Tfs) (Middle Eocene)* consists of gray to pale pink-gray, partly tuffaceous, interbedded mudstone, siltstone, and sandstone with interbeds or lenses of conglomerate containing medium to dark gray pebbles and cobbles of quartzite and chert; thickens northward to 650 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

Western part and northern Fossil Basin in the Kemmerer quadrangle:

- **Fowkes Formation (Tf) (Eocene to Pliocene) –** generally light-colored, partly tuffaceous mudstone, siltstone, and sandstone; locally contains ostracodal and gastropodal limestone; not present in the eastern part of the Kemmerer quadrangle; from 500 to 2,900 ft thick (M'Gonigle and Dover, 1992).

Gooseberry Member of Fowkes Formation *(Tfg) (Pliocene)* consists of indurated conglomerate containing pebbles and cobbles of quartzite, limestone, and volcanic rocks in a white silty matrix (Oriel and Tracy, 1970); unit may possibly represent the northern remnants of the middle Tertiary Norwood Tuff; as much as 200 ft thick (Dover and M'Gonigle, 1992).

Bulldog Hollow Member of Fowkes Formation (Tfb) (Middle Eocene) is composed of green-gray and green tuffaceous sandstone and siltstone and interbeds of ostracodal and gastropodal limestone; member contains late Bridgerian mammal fauna (Nelson, 1973); disseminated biotite and hornblende crystals are characteristic and locally abundant; Oriel and Tracey (1970) reported K-Ar age on hornblende of 47.7 +/- 1.5 million years ; recalculation using new constants (Dalrymple, 1979) gives a K-Ar age of 48.9 million years; Oriel and Tracey (1970) reported a thickness of about 200 ft in southwestern part of Sage 15-minute quadrangle, but unit may be as much as 2,300 ft thick farther south (Dover and M'Gonigle, 1992).

Sillem Member of Fowkes Formation (Tfs) (Middle Eocene) consists of pale pink, light tan, and gray, slightly tuffaceous mudstone, claystone, and sandstone containing conglomerate lenses and ostracodal or algal limestone and mudstone interbeds; basal contact with Wasatch Formation is gradational; Oriel and Tracey (1970) reported the thickness from 100 to 400 ft thick (Dover and M'Gonigle, 1992).

In the western part of the Kemmerer quadrangle and the northern part of the Fossil Basin: The basal Fowkes Formation lies unconformably on top of an erosional surface eroded into the top of the Wasatch Formation (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Fowkes Formation (Tf) (Eocene and Pliocene)** is composed of generally light colored, party tuffaceous mudstone, siltstone, and sandstone; locally contains ostracodal and gastropodal limestone interbeds; not present in the eastern part of the Evanston 30' x 60' quadrangle; 500 ft thick to as much as 2,900 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Bulldog Hollow Member (Tfb) (Middle Eocene) is generally green-gray and green tuffaceous sandstone and siltstone; interbedded ostracodal and gastropodal limestone; member contains late Bridgerian mammal fauna (Nelson, 1973); disseminated biotite and hornblende crystals locally abundant and characteristic of this member; K-Ar age date on hornblende of 47.7 +/- 1.5 million years. (Oriel and Tracey, 1970); recalculation of the K-Ar age date using the new constants of Dalrymple (1979) provides an age of 48.9 million years; as much as 2,300 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Sillem Member (Tfs) (Middle Eocene) consists of light pink, light tan, and gray, slightly tuffaceous mudstone, claystone, and sandstone containing conglomerate lenses and ostracodal and algal limestone and marlstone interbeds; basal contact with the underlying Wasatch Formation is gradational; Oriel and Tracey (1970) reported the thickness in the Fossil Basin ranges from 100 to 400 ft (Dover and M'Gonigle, 1993).

The Fowkes Formation generally exhibits low permeability, but may produce water from fractures in the formation (Forsgren Associates, Inc., GW Memo, 2001).

There are two wells (PCC#1 and PCC#2) constructed into the Fowkes Formation with reported total depths of 320 and 350 ft deep that are located near the mouth of Fowkes Canyon in the SW¼, NE¼, Section 32, T17N, R120W, Uinta County, Wyoming (TriHydro Corporation, 2003). The water-bearing sandstone and conglomeratic sandstone zones in these Fowkes wells reportedly range from 240 to 320 ft deep and with measured static water levels from 20.3 to 20.8 ft below ground surface (TriHydro Corporation, 2003). Based on a limited pumping test conducted in April 2002 at an 100 gpm discharge rate, the southern one of these two Fowkes wells has an estimated transmissivity of 1,100 gpm/ft, a hydraulic conductivity of 28.2 gpd/ft^2, a specific capacity of 0.63 gpm/ft, and a storage coefficient of 0.00024 (TriHydro Corporation, 2003).

The Fowkes Formation groundwater yielded by the southern Martin Ranch well is geochemically of the calcium-magnesium bicarbonate-type mixed with minor quantities of sodium-potassium chloride and calcium sulfate (TriHydro Corporation, 2003). The Fowkes water showed TDS concentrations ranging from 598 to 752 mg/L, which exceed the USEPA secondary drinking water standard of 500 mg/L for TDS, and also manganese detected at 0.15 mg/L which is three times higher than the USEPA secondary standard of 0.05 mg/L for manganese (TriHydro Corporation, 2003). In addition, the Fowkes water contains detectable radionuclide parameters/constituents below the standards for gross alpha at 5.3 pCi/L, gross beta at 3.9 pCi/L, and uranium at 0.0112 mg/L (TriHydro Corporation, 2003). The water also contains a high level of total iron at 2.92 mg/L, which exceeds the USEPA secondary standard (0.3 mg/L for iron) (TriHydro Corporation, 2003).

5.13 Lower Tertiary Geologic Units

The Lower Tertiary bedrock formations range in age from Paleocene to Oligocene.

<u>Bishop Conglomerate</u>

The Bishop Conglomerate is limited to some small exposures in area in the southeastern portion of the Bear River Basin. It may act as a local aquifer in the outcrop area of the formation where it is sufficiently water saturated and permeable for low-yielding wells (25 gpm or less).

<u>Southern Basin (Evanston quadrangle)</u>

- **Bishop Conglomerate (Tbi) (Oligocene)** consists of poorly consolidated, cobble and boulder conglomerate with well-rounded clasts of predominantly Precambrian quartzite from the Uinta Mountains, as well as Paleozoic sandstone, chert, limestone, and cherty limestone; sand and gravel matrix in the conglomerate; generally poorly sorted; locally completely indurated (consolidated), cemented with coarse-crystalline to sucrosic calcite; occurs in the southern part of the Evanston quadrangle as isolated caps thought to be isolated remnants of a formerly more extensive sheet which capped a pediment surface graded to the Uinta Mountains; commonly more than 130 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>Norwood Tuff</u>

<u>Southern Basin (Evanston quadrangle)</u>

- **Norwood Tuff (Tnc) (Eocene? and Oligocene)** is composed of white to light gray, moderately indurated (consolidated), tuffaceous and limey sandstone and siltstone containing gritty to pebbly lenses, disseminated cobbles and boulders, and scattered volcanic ash beds; contains well-rounded, purple, tan, and green, porphyritic and vesicular volcanic clasts similar in intermediate igneous composition and texture to rocks in the Keetley volcanic field to the south of the Evanston quadrangle; other clasts are mainly quartzite and limestone; commonly covered in outcrop by a veneer of lag gravel in which the coarser clasts from the Norwood Tuff are concentrated; contains unidentified mammal bone fragments; ash bed above basal conglomerate yields fission-track age from zircon of 34.4 +/- 1.3 million years; unit mapped may contain some of the Gooseberry Member of Fowkes Formation (Oriel and Tracey, 1970); mapped only in the Bear River area along western boundary of the Evanston quadrangle; local thickness at least 2,300 ft (Dover and M'Gonigle, 1993).

  <u>Basal conglomerate of Norwood Tuff</u> (Tnc) (Eocene?) consists of poorly consolidated cobble and boulder conglomerate with a white, tuffaceous and calcareous, sandstone matrix; characterized by abundant, well-rounded clasts of Oligocene age Keetley Volcanics; unknown thickness in the Evanston quadrangle (Dover and M'Gonigle, 1993).

The volcanic beds of the Norwood Tuff generally have low permeability, but may produce water from fractures in the formation (Forsgren Associates, Inc., GW Memo, 2001).

<u>Bridger Formation</u>

The Bridger Formation is limited to some small exposures in area in the eastern portion of the Bear River Basin. It may act as a local aquifer in the outcrop area of the formation where it is sufficiently water saturated and permeable for low-yielding wells (25 gpm or less).

<u>Central Basin (Kemmerer quadrangle)</u>

<u>Eastern part and western Green River Basin in the Kemmerer quadrangle</u>:

- **Bridger Formation (Tb) (Middle Eocene) –** Light to medium gray, green-gray, interbedded sequence of mudstone, claystone, siltstone, and sandstone; minor interbeds of light gray and green volcanic tuff, tan to light gray limestone and marlstone; thin beds of lignite and coal; pink to red colors sparsely developed;

only lower parts (Tbb and Tba), faunal zones B and A of Matthew (1909), are exposed in the Kemmerer quadrangle; nomenclature follows that of McGrew and Sullivan (1970, p. 68); boundaries of stratigraphic and biostratigraphic subdivisions have been placed at certain widespread limestone and marlstone interbeds or "white layers" (Sinclair, 1906; Matthew, 1909; Koenig, 1960; Bradley, 1964; McGrew and Sullivan, 1970); several widespread limestone layers have been numbered on the Kemmerer quadrangle geologic map; Middle Eocene are is interpreted based on vertebrate fossils and radiometric age dates; at least 650 ft thick in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>*Bridger B of Bridger Formation*</u> *(Tbb) (Middle Eocene)* is part of the "lower Bridger Formation" defined by "G" marker bed of McGrew and Sullivan (1970) (unit Tbg) at base; the top is not exposed in the Kemmerer quadrangle; limestone layers mapped in this member are numbered 5 and 4; about 325 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

5 limestone of Bridger B of Bridger Formation (Tbb-5) (Middle Eocene) consists of light to medium brown, platy limestone, from 1 to 3 ft thick; locally underlain by brown, slightly calcareous chert; forms bench and mesa cap in the southeastern corner of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

4 limestone of Bridger B of Bridger Formation (Tbb-4) (Middle Eocene) is composed of light brown-gray limestone, from 1 to 2 ft thick; locally platy to splintery, and locally contains brown, yellow-weathering chert; forms mesa cap east of Church Butte in southeastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

"G" marker bed of McGrew and Sullivan (1970) of Bridger B of Bridger Formation (Tbg) (Middle Eocene) consists of widespread, light brown to gray, platy to massive, ostracodal limestone; locally contains algal mounds as much as 3 ft high and 15 ft high; commonly forms a light tan caprock on mesas in outcrop; from 1 to 3 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>*Bridger A of Bridger Formation*</u> *(Tba) (Middle Eocene)* – Part of the "lower Bridger Formation" beneath the "G" marker bed of McGrew and Sullivan (1970) (unit Tbg); contains layers of white, lacustrine limestone numbered here from 3 to 1; include Whiskey Butte Bed of Sullivan (1980); unit split by Laney Member (Tglu) of Green River Formation; about 325 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

3 limestone of Bridger B of Bridger Formation (Tba-3) (Middle Eocene) consists of light gray to yellow-brown, ostracodal limestone; generally from 2 to 3 ft thick in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

2 limestone of Bridger B of Bridger Formation (Tba-2) (Middle Eocene) is composed of dusky yellow to light gray, yellow-weathering, platy limestone and papery marlstone; limestone commonly 2 ft thick, marlstone from 5 to 10 ft thick; exposed southeast of Opal Bench and east of Chrisman Bench in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

1 limestone of Bridger B of Bridger Formation (Tba-1) (Middle Eocene) consists of light gray, platy, ostracodal limestone and very light gray marlstone; locally contains high-spired gastropod fossils; forms minor benches in outcrop; generally from 4 to 5 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Limestone of Bridger B of Bridger Formation (Tba-ls) (Middle Eocene) is composed of unnamed local limestone beds in the lower part of the Bridger A unit (Tba) in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Green River Formation</u>

<u>Northern Basin (Cokeville quadrangle)</u>

- **Lower Eocene Green River Formation (Tg)** in the Cokeville 30-minute quadrangle includes:

  <u>Angelo Member of Green River Formation</u> (Tga) (Lower Eocene) consists of blue-white-weathering, calcareous shale, siltstone, and siliceous limestone, tan laminated limestone, and brown algal limestone; about 65 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

  <u>Fossil Butte Member of Green River Formation</u> (Tgf) (Lower Eocene) is composed of tan, brown, and gray limestone, marlstone, and gray siltstone; limestone is locally algal and gastropodal in part; as much as 200 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

<u>Central Basin (Kemmerer quadrangle)</u>

<u>Western part and northern Fossil Basin in the Kemmerer quadrangle</u>:

- **Green River Formation (Tg)** (Lower Eocene) consists of gray to tan limestone, gray to brown shale, and marlstone, oil shale, and tuff beds; formation varies for west to east across the map area; about 575 ft thick in eastern part and as much as

525 ft thick in the western part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Angelo Member of Green River Formation</u> (Tga) (Lower Eocene) consists of light gray to light tan, mainly white-weathering siliceous limestone, calcareous shale, and siltstone; includes minor tan laminated limestone, brown algal limestone, marlstone, sandstone, and brown organic-rich shale; calcareous beds interfinger with sandstone and shale beds of Wasatch Formation to the south and southwest; about 200 ft maximum thickness in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Fossil Butte Member of Green River Formation</u> (Tgfb) (Lower Eocene) is composed of light gray, tan, and light tan limestone, calcareous siltstone, marlstone, and shale, and brown, laminated carbonaceous shale and very thinly laminated ("papery") oil shale; tuffaceous interbeds are common; some calcareous beds rich in fossil-fish remains, algal, gastropodal, and ostracodal limestone beds occur mainly along the basin margins between Sillem Ridge and the Absaroka thrust fault; grades into and interfingers with light gray to light tan sandstone and pale red mudstone beds of the Wasatch Formation to the south and southwest; about 265 to 325 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Eastern part and western Green River Basin in the Kemmerer quadrangle</u>:

- **Green River Formation (Lower to Middle Eocene) in the Kemmerer quadrangle**

<u>Laney Member of Green River Formation (Tgl)</u> (Middle Eocene) consists of tan to brown, silty, algal limestone and ostracodal marlstone containing thin, light gray, fine- to coarse-grained sandstone interbeds; unit split by southward-thinning tongue of Bridger A unit (Tba), which includes Whiskey Butte Bed of Sullivan (1980); as much as 245 ft thick in eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Upper part of Laney Member of Green River Formation (Tglu) is located above the Whiskey Butte Bed of Sullivan (1980) and equivalent to the Cow Hollow Bed of Sullivan (1980); about 30 ft thick at the Hams Fork River in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower part of Laney Member of Green River Formation (Tgll) is located below the Whiskey Butte Bed of Sullivan (1980) and equivalent to the Craven Creek Bed of Sullivan (1980); about 115 ft thick at the Hams Fork River in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower part of Laney Member of Green River Formation (Tgls) is composed of light gray, silty, dolomitic or marly limestone; represents discontinuous lacustrine interbeds in the predominantly fluvial Wasatch Formation; generally less than 3 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Wilkins Peak Member of Green River Formation</u> (Tgw) (Middle Eocene) consists of light gray to tan, silty and sandy, gastropodal, ostracodal, and algal limestone and marlstone; light tan oil shale; medium- to coarse-grained sandstone interbeds; some siltstone and claystone interbeds; Oriel (1969) defined as the "middle tongue of Green River Formation;" member is divided into two parts to the north of the Hams Fork River; about 200 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Upper part of Wilkins Peak Member of Green River Formation (Tgwu) is composed of tan-weathering and generally more calcareous than the lower part of the Wilkins Peak Member; as much as 165 ft thick and thins to the south in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower part of Wilkins Peak Member of Green River Formation (Tgwl) consists of light gray-weathering, generally less calcareous than the upper part of the Wilkins Peak Member; contains oil shale; as much as 100 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Fontenelle Tongue of Green River Formation (Tgf)</u> (Lower Eocene) is composed of tan to light gray, gastropodal and ostracodal limestone, tan, laminated shale, brown oil shale, and light gray, medium- to coarse-grained, sandstone mainly in the upper part of the unit; as much as 130 ft thick in eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Middle part of Fontenelle Tongue of Green River Formation (Tgfs) consists of mainly tan shale and brown oil shale; as much as 50 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower part of Fontenelle Tongue of Green River Formation (Tgfl) – Mainly calcareous beds; as much as 50 ft thick in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Southern Basin (Evanston quadrangle)</u>

- **Green River Formation (Tg)** (Lower Eocene) consists of gray to tan limestone, gray to brown shale, marlstone, oil shale, and volcanic tuff beds; formation varies from west to east across the Evanston quadrangle; about 325 ft thick in the western part of the Evanston quadrangle and about 525 ft thick in the eastern part (Dover and M'Gonigle, 1993).

<u>Angelo Member of Green River Formation</u> *(Tga) (Lower Eocene)* is composed of light gray to light tan, white-weathering, siliceous limestone, calcareous shale, and siltstone; includes minor interbedded tan, laminated limestone, brown, algal limestone, marlstone, sandstone, and brown, organic shale; calcareous beds interfinger with sandstone and shale beds of the Wasatch Formation to the south and southwest; 130 ft maximum thickness in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>Fossil Butte Member of Green River Formation</u> *(Tgfb) (Lower Eocene)* consists of light gray, tan, and light tan limestone, calcareous siltstone, marlstone, and shale; brown, laminated carbonaceous shale, and very thinly, laminated or papery, oil shale; tuffaceous interbeds are common; some calcareous beds rich in fossil fish, algal, gastropodal, and ostracodal limestone beds are present mainly along the margins of the basin between Sillem Ridge and the Absaroka thrust fault; grades into and interfingers with the light gray to light tan, sandstone and light red mudstone beds of the Wasatch Formation to the south and southwest; about 200 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Wasatch Formation

The Lower Eocene Wasatch Formation (Tw and others) is composed of interbedded variegated red to gray mudstone; brown to gray, fine- to coarse-grained sandstone; conglomeratic lenses of quartzite, chert, and minor limestone pebbles; thins from the Wyoming Overthrust Belt to the eastward into the Green River structural basin and interfingers with the Lower Eocene Green River Formation; as much as 23,000 ft thick (Oriel and Platt, 1980).

The Wasatch Formation consists of variegated mudstone, claystone, siltstone, shale, sandstone, conglomeratic sandstone, and conglomerate. The Wasatch is a thick sequence of nonmarine sedimentary rock with named members of the formation in some areas. The Wasatch Formation and various members interfinger eastward with the members of the Green River Formation in the Fossil Basin (southern Overthrust Belt in Lincoln and Uinta counties) and Green River Basin.

The Town of Bear River obtains groundwater from the pebbly sandstone beds of the Eocene Wasatch Formation from the western highlands flanking the Bear River Valley. The groundwater flow in the Wasatch Formation in the area of the Town of Bear River is confined flow towards the east, which is down-gradient of the structural/depositional dip of the formation. The Wasatch bedrock in this area dips gently eastward.

<u>Northern Basin (Cokeville quadrangle)</u>

- **Paleocene to Lower Eocene Wasatch Formation (Tw)** in the Cokeville 30-minute quadrangle (Rubey et al., 1980) is composed of various members:

  <u>Tunp Member of Wasatch Formation</u> (Twt) (Lower Eocene) is a diamictite composed of unsorted, boulders and larger blocks of older rocks in a red mudstone matrix, the gravel clasts are matrix-supported; laterally equivalent to the upper part and other members of the Green River Formation in eastern Lincoln and western Sublette counties; as much as 400 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

  <u>Mudstone tongue of Wasatch Formation</u> (Twm) (Lower Eocene) consists of red and green mudstone, brown sandstone, and thin limestone interbeds; as much as 65 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

  <u>Main body of Wasatch Formation</u> (Tw) (Lower Eocene) is composed of red, maroon, and gray, variegated mudstone; brown, yellow, gray, and red, fine- to coarse-grained sandstone; lenses and beds of conglomerate containing pebble, cobble, and boulder gravel of quartzite, chert, and limestone; thin limestone interbeds, some pisolitic; conglomerate increases in thickness to the north where the main body cannot be discriminated from the lower member; as much as 1,650 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

  <u>Lower member of Wasatch Formation</u> (Twl) (Lower Eocene) consists of gray, brown, and red mudstone; gray carbonaceous claystone; brown and yellow-weathering, gray sandstone; red conglomerate containing black chert pebbles; hard, brown limestone; as much as 300 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

  <u>Basal conglomerate member of Wasatch Formation</u> (Twc) (Paleocene to Lower Eocene) is composed of mixtures of pebbles, cobbles, and boulders of older nearby rocks in a sandstone matrix; lower strata may be of Paleocene age; as much as 100 ft thick in the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

<u>Central Basin (Kemmerer quadrangle)</u>

<u>Western part and northern Fossil Basin in the Kemmerer quadrangle</u>:

- **Wasatch Formation (Tw) (Upper Paleocene to Lower and Middle Eocene)** consists of red, brown, green, yellow, and gray interbedded sequence of mudstone, fluvial sandstone, siltstone, and claystone; minor diamictite, conglomerate, grit, marlstone, and pisolitic limestone; the Wasatch Formation varies in lithology and thickness from west to east across the Kemmerer quadrangle; thins to the east from as much as 2,450 ft thick in the western part to about 850 ft thick in the eastern part to Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Main body of Wasatch Formation</u> *(Tw) (Lower to Middle Eocene)* – variegated, but mainly red, interbedded sequence of mudstone, fluvial sandstone, siltstone, and claystone with minor conglomerate and marlstone; at least 1,500 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Upper part (Tw2) (Lower to Middle Eocene) is above angular unconformity developed along the western margin of Fossil Basin near The Pinnacle; merges with unit Tws to the north and east; about 325 ft thick in Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower part (Tw1) (Lower Eocene) is mapped where unconformably overlain by unit Tw2 along the western margin of Fossil Basin; not differentiated from unit Tw elsewhere in the quadrangle; about 230 ft thick where mapped in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Limestone (- ls -) is composed of local, medium gray, thin limestone beds mapped as an individual bed in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Tunp Member of Wasatch Formation</u> *(Twt) (Lower to Middle Eocene)* consists of rubbly, locally derived diamictite in red mudstone matrix; blocks as much as 20 ft in diameter reported by Oriel and Tracy (1970); larger slide blocks locally; represents peripheral facies of Wasatch Formation found mainly along the northwestern margin of Fossil Basin; thickness varies locally and ranges from 100 to 500 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Bullpen Member of Wasatch Formation</u> *(Twb) (Lower to Middle Eocene)* is composed of variegated, red, gray, and green interbedded sequence of mudstone and gray and tan sandstone containing thin interbeds of granule conglomerate, gray and tan limestone, and light gray shale; about 400 ft thick at Elk Mountain (Oriel and Tracey, 1970) in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Mudstone tongue of Wasatch Formation</u> *(Twm) (Lower Eocene)* consists of green and red, brown, and red-brown mudstone and shale; derived from Tunp Member of Wasatch Formation and lies stratigraphically between the Angelo Member (Tga) and Fossil Butte Member (Tgfb) of the Green River Formation in the northern part of the Kemmerer quadrangle; pinches out to zero to the east and south; about 65 ft maximum thickness in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern mudstone tongue of Wasatch Formation *(Twms) (Lower Eocene)* is composed of red mudstone and shale with minor sandstone; derived from main body of Wasatch Formation (Tw) and lies stratigraphically between the Angelo Member (Tga) and Fossil Butte Member (Tgfb) of the Green River Formation in the southern part of the Kemmerer quadrangle; pinches out to zero to the north and east and merges into unit Tw south of quadrangle; does not merge with unit Twm to the north; about 50 ft maximum thickness in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Sandstone unit of Wasatch Formation *(Twss) (Lower Eocene)* consists of very light tan to gray sandstone, locally present above sandstone tongue (Tws) of Wasatch Formation; about 50 ft maximum thickness in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Sandstone tongue of Wasatch Formation *(Tws) (Lower Eocene)* is composed of tan to brown, crossbedded, medium- to coarse-grained sandstone; overlies angular unconformity localized along the western margin of Fossil Basin near The Pinnacle and merges with the basal part of unit Tw2; pinches out to zero to the north and along the eastern margin of Fossil Basin; about 80 ft maximum thickness in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Calcareous member of Wasatch Formation *(Twgf) (Lower Eocene)* consists of light gray to tan, crossbedded sandstone and shale unit containing 1.5 to 3 ft thick, light gray limestone beds similar to those typically present in the Green River Formation; merges with the Fossil Butte Member (Tgfb) of Green River Formation to the north and east, and merges with the lower part of Wasatch Formation (Tw) to the south in the Evanston 30' x 60' quadrangle; about 265 ft thick along the southwestern margin of Fossil Basin in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Lower member of Wasatch Formation *(Twl) (Lower Eocene)* is composed of gray, brown, and red mudstone and sandstone, carbonaceous claystone, and some algal and pisolitic limestone; locally conformable with overlying main body (Tw) of Wasatch Formation; as much as325 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Basal conglomerate member of Wasatch Formation *(Twc) (Upper Paleocene to Lower Eocene)* consists of conglomeratic sandstone containing clasts from Nugget Sandstone; may include some Paleocene strata (Oriel and Tracey, 1970); local thickness ranges from 3 to 325 ft or greater in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Eastern part and western Green River Basin in the Kemmerer quadrangle</u>:

- **Wasatch Formation (Tw) (Lower to Middle Eocene)** is composed of red, brown, green, yellow, and gray interbedded sequence of mudstone, fluvial sandstone, siltstone, and claystone; minor diamictite, conglomerate, grit, marlstone, and pisolitic limestone; the Wasatch Formation varies in lithology and thickness from west to east across the Kemmerer quadrangle; thins to the east from as much as 2,450 ft thick in the western part to about 850 ft thick in the eastern part to Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Upper member of Wasatch Formation</u> (Twu) (Lower to Middle Eocene) is composed of green, gray, brown, and locally red, interbedded sequence of siltstone and fine- to coarse-grained sandstone, locally conglomeratic sandstone; includes Desertion Point tongue of Sullivan (1980); thickens southward from about 165 ft near the Hams Fork River in the eastern Kemmerer quadrangle to at least 720 ft to the south in the Evanston quadrangle (M'Gonigle and Dover, 1992).

Marker bed in the upper member of Wasatch Formation (Twum) consists of a local marker unit (bed) of light gray sandstone and shale in unit Twu; about 3 ft thick in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>New Fork Tongue of Wasatch Formation</u> (Twn) (Lower Eocene) consists of green mudstone, light gray marlstone, and light gray to brown, locally crossbedded, medium- to coarse-grained sandstone; about 120 ft thick at Slate Creek; thins to the south and gradually pinches out to zero thickness south of Little Round Mountain in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Sandstone beds of Wasatch Formation</u> (Twsb) (Lower Eocene) is composed of gray, brown, and red, interbedded, lenticular, siltstone and sandstone beds and stringers occurring within units of the Green River Formation; as much as 100 ft thick locally in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>La Barge Member of Wasatch Formation</u> (Twlb) (Lower Eocene) consists of red, purple, brown, tan, light yellow, variegated and mottled mudstone; minor interbedded tan, gray, and red sandstone, which is locally conglomeratic; a few marlstone and limestone lenses are present (Lawrence, 1963); La Barge Member has been dated as Lost Cabin age and possibly Lysite age, which is not as old as Gray Bull age (earliest Wasatchian continental mammal age) that has been established for beds in the Wasatch Formation in the Fossil Basin area (Oriel and Tracey, 1970); as much as 300 ft in exposed thickness in the eastern in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Basal conglomerate of Wasatch Formation (Twco) (Lower Eocene) is composed of brown to red, interbedded sequence of mudstone, sandstone, and cobble conglomerate; exposed mainly in the Slate Creek area, where the largest diameter gravel clasts are locally derived; interfingers with the La Barge Member of the Wasatch Formation; contacts are gradational; about 165 ft in maximum thickness in the eastern Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Wasatch Formation (Tw) (Upper Paleocene? to Lower Eocene to Middle Eocene)** consists of red, brown, green, yellow, and gray interbedded sequence of mudstone, fluvial sandstone, siltstone, and claystone; minor diamictite, conglomerate, grit, mudstone, and pisolitic limestone; formation varies from west to east in Evanston quadrangle with various members and lithologic changes; as much as 1,050 ft thick in the western part of the Evanston quadrangle and about 1,015 ft thick in the eastern part (Dover and M'Gonigle, 1993).

Main body of Wasatch Formation (Tw) (Lower to Middle Eocene) is composed of variegated, but mainly red, interbedded sequence of mudstone, fluvial sandstone, siltstone, claystone, conglomerate, and marlstone; at least 1,050 ft thick in the western part of the Evanston 30' x 60' quadrangle, west of and above the Absaroka thrust fault (Dover and M'Gonigle, 1993).

Upper part of main body of Wasatch Formation (Tw_2) (Lower to Middle Eocene) is above an angular unconformity developed along the western margin of the Fossil Basin; merges to the south and west with the main body of the Wasatch Formation; about 460 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Lower part of main body of Wasatch Formation (Tw_1) (Lower Eocene) is mapped where unconformably overlain by the upper part (unit Tw_2) along the western margin of the Fossil Basin; merges with the main body of the Wasatch Formation elsewhere; about 460 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Slumped masses of Wasatch Formation (Tws) are mapped only along the southern boundary of the Evanston quadrangle; thickness variable; locally includes all of main body of the Wasatch Formation (Dover and M'Gonigle, 1993).

Southern mudstone tongue of main body of Wasatch Formation (Twms) (Lower Eocene) consists of red mudstone, shale, and minor sandstone; derived mainly from the main body of the Wasatch Formation and lies stratigraphically between the Angelo (Tga) and Fossil Butte (Tgfb) Members of the Green River Formation in the southern part of the Evanston quadrangle; pinches out to the north in the Kemmerer quadrangle and to the east; merges into the main body of the Wasatch Formation south of the Evanston quadrangle; does not merge with unit Twm to the north in the Kemmerer quadrangle; 130 ft maximum thickness (Dover and M'Gonigle, 1993).

Calcareous member of main body of Wasatch Formation (Twgf) (Lower Eocene) consists of light gray to tan, crossbedded sandstone and shale member containing from 1.5 to 3 ft thick interbeds of light gray limestone, which are similar to the Green River Formation; merges with the Fossil Butte Member (Tgfb) of Green River Formation to the north and east; merges with the lower part of the Wasatch Formation to the south; as much as 260 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Fossil Basin and westernmost portions of the Green River Structural Basin
(Wasatch and Green River Formations)
The Wasatch Formation is a stratified aquifer with multiple water-bearing zones within the formation. Locally, some Wasatch wells completed into deep sandstone beds flow water to the surface under artesian pressure; Wasatch sandstone and conglomeratic sandstone wells reportedly yield from 10 to 1,300 gpm (Forsgren Associates, Inc., GW Memo, 2001).

The Town of Bear River, Deer Mountain #6 Well (WSEO #P142000W test well and #P146167W for municipal well) is constructed into the Wasatch Formation with a total depth 570 ft deep and the well is located in the SE¼, SW¼, Section 2, T16N, R121W, Uinta County, Wyoming (TriHydro Corporation, 2003). The primary water-bearing sandstone and conglomeratic sandstone zones were screened from 272 to 313 ft and from 502 to 521 ft deep in this well and with a measured static water level at 47 ft below ground surface (TriHydro Coporation, 2003). Based on pumping tests conducted during April 2002 at 100 gpm constant-rate discharge, the well has an estimated transmissivity of 800 gpm/ft, a hydraulic conductivity of 32 gpd/ft^2, and a specific capacity of 0.7 gpm/ft at 100 gpm pumping rate (TriHydro Corporation, 2003).

Groundwater from the Wasatch Formation is yielded by the River Deer Mountain #6 Well for the Town of Bear River is geochemically of the calcium-magnesium bicarbonate-type mixed with minor quantities of sodium-potassium chloride and calcium sulfate (TriHydro Corporation, 2003). The Deer Mountain #6 water showed total dissolved solids (TDS) concentrations ranging from 390 to 406 milligrams per liter (mg/L) (TriHydro Corporation, 2003). This water contains radon at a detected level of 380 picoCuries per liter (pCi/L) and iron at 0.82 mg/L, which both exceeded the USEPA drinking water standards (300 pCi/L for radon and 0.3 mg/L for iron) (TriHydro Corporation, 2003).

Conglomerate on Sublette Range

The Paleocene (?) to Lower Eocene (?) Conglomerate on Sublette Range (Tsr) is only exposed in several small outcrop areas in the Sublette Range, which is located to the northwest of the Town of Cokeville (T25N-T26N, R118W-R119W, Lincoln County, Wyoming). The Conglomerate on the Sublette Range may act as a local aquifer in the outcrop area of the formation, where it is sufficiently water saturated and permeable for low-yielding wells (25 gpm or less).

Northern Basin (Cokeville quadrangle)

- **Conglomerate on Sublette Range (Tsr)** consists of predominantly white, pink, dark gray, well-rounded, crudely stratified, pebble to boulder gravel composed of quartzite and gray chert; mixtures with silt and sand; age and stratigraphic relationships to the Evanston and Wasatch formations are uncertain; as much as 600 ft thick in the Cokeville 30-minute quadrangle, Wyoming (Oriel and Platt, 1980; Rubey et al., 1980).

Evanston Formation

The Upper Cretaceous to Paleocene Evanston Formation (KTe or Te) is composed of interbedded gray siltstone, sparse red sandstone, and minor lignite/coal beds; about 820 ft thick (Oriel and Platt, 1980). The coal beds of the formation were mined in the area north of Evanston, along the eastern margin of the Bear River Valley and adjacent to the abandoned old mining town of Almy. The vacant site of the Town of Almy was located about three miles north of Evanston. At least one well is completed into the Evanston Formation with a reported yield of 1 gpm (Forsgren Associates, Inc., GW Memo, 2001).

Northern Basin (Cokeville quadrangle)

- The Upper Cretaceous to Paleocene Evanston Formation in the Cokeville 30-minute quadrangle includes:

Main body of Evanston Formation (TKe) (Upper Cretaceous to Paleocene) consists mainly of light gray siltstone; unit is not exposed but is present in the subsurface in the southern portion of the Cokeville quadrangle, Wyoming (Rubey et al., 1980).

Hams Fork Conglomerate Member of Evanston Formation (Keh) (Upper Cretaceous) is composed of pebble to boulder conglomerate containing well rounded, pebble, cobble and boulder gravel of quartzite, chert, and limestone; gray and brown sandstone; gray mudstone; about 1,000 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Lower member of Evanston Formation (Kel) (Upper Cretaceous) consists of gray, brown, and black shale; gray, green, yellow, and brown siltstone; thin- to massively-bedded, fine- to coarse-grained sandstone; thin coal beds; locally contains gray quartzite and brown and black chert-pebble conglomerate at base of member; as much as 800 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

<u>Central Basin (Kemmerer quadrangle)</u>

<u>Western part and northern Fossil Basin in the Kemmerer quadrangle</u>:

- **Upper part (Paleocene) of Evanston Formation (KTe) (Upper Cretaceous to Lower, Middle, and Upper Paleocene)** (M'Gonigle and Dover, 1992).

<u>Upper part of Evanston Formation</u> (Te) (Middle to Upper Paleocene) consists of gray claystone and siltstone containing minor interbeds of tan sandstone, carbonaceous claystone, and coal and a prominent zone of boulder conglomerate beds; lies with a major unconformity on pre-Tertiary rock formations, including Hams Fork Conglomerate Member of Evanston Formation (Keh) elsewhere; Middle to Late Paleocene age based on palynomorphs and vertebrate fossils; locally as much as 1,000 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Main body of the upper part of Evanston Formation</u> (Tem) (Middle to Upper Paleocene) is composed of interbedded gray, carbonaceous, claystone and siltstone with tan sandstone; gritty and coaly interbeds locally present; mapped only in the Little Muddy Creek area along the Absaroka thrust fault; age determination based on palynomorphs; 650 ft maximum thickness in the western part of the Kemmerer quadrangle and Fossil Basin area (M'Gonigle and Dover, 1992).

<u>Conglomerate unit of the upper part of Evanston Formation</u> (Tec) (Middle? Paleocene) consists of interbedded, poorly consolidated, boulder and cobble conglomerate containing well-rounded clasts composed mainly of quartzite; lithologically identical to and probably derived from the Hams Fork Conglomerate Member (unit Keh); mapped only in the Little Muddy Creek area along the Absaroka thrust fault; age indicated by stratigraphic position; estimated 165 ft of maximum thickness in the western part of the Kemmerer quadrangle and Fossil Basin area (M'Gonigle and Dover, 1992).

<u>Lower unit of the upper part of Evanston Formation</u> (Tel) (Upper Lower? To Middle Paleocene) is composed of interbedded gray, carbonaceous, claystone and siltstone; not distinguishable from unit Tem without intervening conglomerate of unit Tec; mapped only in the Little Muddy Creek area along Absaroka thrust fault; age determination based on palynomorphs; about 165 ft in maximum thickness in the western part of the Kemmerer quadrangle and Fossil Basin area (M'Gonigle and Dover, 1992).

<u>Western part and northern Fossil Basin in the Kemmerer quadrangle</u>:

- **Lower part of Evanston Formation (KTe) (Upper Cretaceous to Upper Paleocene)**

<u>*Hams Fork Conglomerate Member of Evanston Formation*</u> *(Keh) (Upper Cretaceous)* consists of poorly to moderately well consolidated, cobble and boulder conglomerate beds containing a matrix of gritty sandstone and siltstone interbedded with sandstone and mudstone; well-rounded clasts are composed of quartzite, chert, and limestone and average about 6 inches in diameter, but are up to about 1.5 ft in diameter; forms conspicuous hogbacks in outcrop, but is generally poorly exposed; bedding commonly marked by trains of loose boulders; concordant and folded with underlying Adaville Formation in the Lazeart syncline fold; palynomorphs, leaves, and vertebrate fossils indicate a Late Cretaceous age; about 1,000 ft thick to the east (below) and west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>*Lower member of Evanston Formation*</u> *(Kel) (Upper Cretaceous)* consists of medium to dark gray, carbonaceous mudstone, siltstone, and sandstone; only present in the northern part of the Kemmerer quadrangle and to the east of Naughton Reservoir; about 400 ft thick to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>***Eastern part and east (below) the Absaroka thrust fault in the Kemmerer quadrangle***</u>***:***

- **Lower part of Evanston Formation (KTe) (Upper Cretaceous to Upper Paleocene)**

<u>*Hams Fork Conglomerate Member of Evanston Formation*</u> *(Keh) (Upper Cretaceous)* is composed of poorly to moderately well consolidated, cobble and boulder conglomerate beds containing a matrix of gritty sandstone and siltstone interbedded with sandstone and mudstone; well-rounded clasts are composed of quartzite, chert, and limestone and average about 6 inches in diameter, but are up to about 1.5 ft in diameter; forms conspicuous hogbacks in outcrop, but is generally poorly exposed; bedding commonly marked by trains of loose boulders; concordant and folded with underlying Adaville Formation in the Lazeart syncline fold; palynomorphs, leaves, and vertebrate fossils indicate a Late Cretaceous age; about 1,000 ft thick to the east (below) and west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>**Southern Basin (Evanston quadrangle)**</u>

- **Upper part (Paleocene) of Evanston Formation (Te) (Upper Cretaceous to Paleocene)**

<u>*Upper unit of the upper part of Evanston Formation*</u> *(Te)* (Middle to Upper Paleocene) consists of gray claystone and siltstone containing minor tan

sandstone, carbonaceous claystone, and coal interbeds; a prominent zone of boulder conglomerate beds; lies with an angular unconformity on pre-Tertiary bedrock formations, including the Hams Fork Conglomerate Member (Keh) of the Evanston Formation along the Absaroka thrust fault; may be disconformable on Hams Fork Member elsewhere; Middle to Late Paleocene age based on palymorphs and vertebrate fossils; as much as 1,000 ft thick locally in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>*Main body of the upper part of Evanston Formation*</u> *(Tem)* (Middle to Upper Paleocene) is composed of gray, carbonaceous claystone and siltstone with interbedded tan sandstone; gritty and coaly interbeds are locally present; mapped only in a small area along the Absaroka thrust fault at the north edge of the Evanston quadrangle; age based on palymorphs; 650 ft maximum thickness in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>*Conglomerate unit of the upper part of Evanston Formation*</u> *(Tec)* (Middle? Paleocene) consists of poorly consolidated, cobble and boulder conglomerate containing well-rounded clasts mainly of quartzite; lithologically identical and probably derived from the Hams Fork Conglomerate Member (Teh); mapped only in the Shortleff Creek-Clear Creek area along the Absaroka thrust fault; age indicated by stratigraphic position; estimated 165 ft maximum thickness in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>*Lower unit of the upper part of Evanston Formation*</u> *(Tel) (upper Lower? to Middle Paleocene)* is composed of gray, carbonaceous claystone and siltstone; not distinguishable from unit Tem without intervening conglomerate of unit Tec; mapped only in the Little Muddy Creek area along the Absaroka thrust fault; age based on palymorphs; about 165 ft maximum thickness in the Evanston quadrangle (Dover and M'Gonigle, 1993).

- **Lower part (Upper Cretaceous) of Evanston Formation (Te) (Upper Cretaceous to Paleocene)**

<u>*Hams Fork Conglomerate member of lower part of Evanston Formation*</u> *(Teh) (Upper Cretaceous)* consists of poorly to moderately-well consolidated, cobble and boulder conglomerate beds containing gritty sandstone and siltstone matrix interstratified with sandstone and mudstone beds; clasts of quartzite, chert, and limestone are well rounded and average about 6 inches in diameter, but range to about 2 inches in diameter; forms conspicuous hogbacks, but is generally poorly exposed; bedding commonly marked by trains of loose boulder gravel; palynomorphs, fossil

leaves, and vertebrate fossils all indicate an Late Cretaceous age (Dover and M'Gonigle, 1993).

5.2 Mesozoic Major Hydrogeologic Group

The Mesozoic Major Hydrogeologic Group (Figure A-1) consists of the water-saturated portions of the consolidated bedrock formations of Cretaceous, Jurassic, and Triassic age. The Mesozoic Major Hydrogeologic Group is the second most used of the four major aquifer groups within the Bear River Basin, after the Cenozoic Major Hydrogeologic Group. The Upper Cretaceous formations are exposed in the Overthrust Belt structures. The outcrop exposures of the Lower Cretaceous, Jurassic, and Triassic bedrock formations are limited to the uplifted hill and mountain ranges of the Bear River Basin (Figure A-1). The Mesozoic formations have a combined thickness averaging about 12,000 ft with a maximum thickness estimated at 29,000 ft in the Wyoming Bear River Basin. These Mesozoic aquifers yield groundwater within or close to the formation outcrop areas that are shown on Figures A-1 and A-2.

The Cretaceous age formations are divided into the Upper Cretaceous and Lower Cretaceous Geologic Units. The Mesozoic Major Hydrogeologic Group yields water mostly from the siltstone, sandstone, conglomeratic sandstone, and conglomerate beds:

- In the Upper Cretaceous age Adaville Formation, Blind Bull Formation, and Frontier Formation;
- In the Lower Cretaceous age Sage Junction Formation, Quealy Formation, Cokeville Formation, Thomas Fork Formation, Smiths Formation, Bear River Formation, and Gannett Group;
- In the Jurassic age Stump Formation, Preuss Sandstone (Redbeds), and Nugget Sandstone; and
- In the Triassic age Ankareh Formation, Woodside Shale, and Dinwoody Formation.

Groundwater is also yielded from some thin carbonate (limestone and dolomite) beds present in the Twin Creek Limestone, Thaynes Limestone, and Dinwoody Formation in the Bear River Basin.

The Mesozoic Major Hydrogeologic Group also includes the Upper and Lower Cretaceous Geologic Units, regionally extensive, thick marine shale confining units of the Upper Cretaceous Hilliard Shale and the Lower Cretaceous Aspen Shale. The low-permeability, Cretaceous-age shale confining units separate the aquifer units which are interbedded above and/or below the confining units.

The hydrogeologic units of the Mesozoic Major Hydrogeologic Group are composed of the Upper Cretaceous, Lower Cretaceous, Jurassic, and Triassic Geologic Units, in descending order. The Mesozoic formations are predominantly composed of shale, siltstone, and fine-grained sandstone with minor quantities of interbedded conglomerate and limestone. These sedimentary lithologies were deposited in a mixed sequence of marine and continental (nonmarine) environments.

5.21 Upper Cretaceous Geologic Units

Adaville Formation

The Upper Cretaceous Adaville Formation (Kav) consists of brown-weathering, gray sandstone, siltstone, and carbonaceous shale; conglomeratic in the upper part of the formation and coal beds in the lower part; as much as 2,100 ft thick (Oriel and Platt, 1980). The Adaville Formation yields small quantities of water from the sandstone beds in the formation (especially the basal sandstone) and one well reportedly yields 20 gpm (Forsgren Associates, Inc., GW Memo, 2001).

Northern Basin (Cokeville quadrangle)

- **Adaville Formation (Kav)** consists of yellow- to brown-weathering, carbonaceous clay, siltstone, and thin- to massively-bedded, fine- to coarse-grained sandstone; thin beds of pebble conglomerate in the upper part of the formation; numerous, mineable coal beds are present in the middle and lower parts of the formation; up to 2,100 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Adaville Formation (Kav)** consists of interbedded, mainly nonmarine, gray, brown, and tan shale and siltstone; brown to gray, locally bioturbated, platy to crossbedded, medium- to fine-grained sandstone; carbonaceous shale; numerous coal beds averaging about 16 ft thick, but as much as 115 ft thick; palynomorph analysis indicates an Early Campanian age; about 2,000 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The Adaville Formation is not exposed to the west (above) the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992), where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies directly on the Lower Cretaceous Sage Junction Formation.

Lazeart Sandstone Member of Adaville Formation *(Kal) (Upper Cretaceous)* is composed of very light gray, yellow-brown, and tan, fine- to medium-grained, lithic "salt and pepper" sandstone; forms thick cliffs in outcrop; interbedded brown-gray shale and coal in slopes between sandstone cliffs in outcrop; sandstone beds contain marine fossils and bedding interpreted as progradational beach sequences that overlap to the south; about 590 ft thick in the southern portion of Kemmerer quadrangle (to the east (below) of the Absaroka thrust fault) and thins markedly and locally pinches out to zero thickness north of the Hams Fork River in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Adaville Formation (Kav)** consists of gray, brown, and tan, interbedded, mainly nonmarine shale and siltstone; brown to gray, locally bioturbated, platy to crossbedded, medium- to fine-grained sandstone; carbonaceous shale; numerous coal beds averaging about 16 ft thick, but as much as 115 ft thick; palynomorph analysis indicates an Early Campanian age; about 2,200 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>Lazeart Sandstone Member of Adaville Formation</u> (Kal) (Upper Cretaceous) consists of very light gray, yellow-brown, and tan, fine- to medium-grained, lithic "salt and pepper" sandstone; forms thick cliffs in outcrop; interbedded brown-gray shale and coal in slopes between sandstone cliffs in outcrop; sandstone beds contain marine fossils and bedding interpreted as progradational beach sequences that overlap to the south in the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>Hilliard Shale</u>

The Upper Cretaceous Hilliard Shale (Kh) is composed of interbedded dark gray to tan claystone, siltstone, and sandy shale; increasing quantities of tan sandstone to the northward and westward; about 5,600 ft thick in the Preston 1° x 2° quadrangle (Oriel and Platt, 1980). The Hilliard Shale underlies the Adaville Formation and overlies the Frontier Formation in the southern Overthrust Belt and western Green River structural basin. East of the Overthrust Belt and westernmost Green River structural basin, the Hilliard Shale is the stratigraphic equivalent to the Baxter Shale, Steele Shale, and Niobrara Formation in Sweetwater and Carbon counties, Wyoming.

The Hilliard Shale yields small quantities of water from the sandstone beds in the formation (Forsgren Associates, Inc., GW Memo, 2001). The Hilliard Shale is not an important aquifer in western Uinta County (Robinove and Berry, 1963) but may yield useable quantities of moderate quality groundwater to wells in outcrop areas. Shallow groundwater may be available in the sandstone beds or fractured shale beds of the formation. Groundwater is yielded from the sandstone beds of the formation and groundwater flow is generally as porous flow through intergranular permeability.

<u>Northern Basin (Cokeville quadrangle)</u>

- **Hilliard Shale (Kh)** has a total thickness of about 5,575 ft thick and is composed of three members (one formal and two informal):

<u>Upper shale member of Hilliard Shale</u> (Khu) (Upper Cretaceous) consists of dark gray to tan claystone, siltstone, and thin beds of fine- to coarse-grained sandstone in the Cokeville quadrangle (Rubey et al., 1980).

<u>Shurtliff Sandstone Member of Hilliard Shale</u> (Khs) (Upper Cretaceous) is composed of white to light gray, fine- to coarse-grained sandstone; chert-bearing grit and conglomerate increases northward; locally contains abundant large oyster shell fossils in the Cokeville quadrangle (Rubey et al., 1980).

<u>Lower shale member of Hilliard Shale</u> (Khl) (Upper Cretaceous) consists of dark gray to tan claystone, siltstone, and sandy shale in the Cokeville quadrangle (Rubey et al., 1980).

<u>Central Basin (Kemmerer quadrangle)</u>

- **Hilliard Shale (Kh)** consists of dark olive-gray, marine shale, siltstone, and sandy shale, which contains thin interbeds of tan to light gray, sandstone and limestone, especially in the upper part of the formation; palymorphs indicate a Santonian and Coniacian age; poorly exposed in outcrops; 5,900 ft estimated minimum thickness to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The Hilliard Shale is not exposed to the west (above) the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992), where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies directly on top of the Lower Cretaceous Sage Junction Formation.

<u>Hinshaw Member of Smith (1965) of Hilliard Shale</u> (Khh) (Upper Cretaceous) – interbedded marine shale and sandstone sequence in the upper part of the Hilliard Shale; shale and sandstone interbeds from 1 to 33 ft thick; is a transitional sequence from shale beds of main body of Hilliard Shale into the overlying Lazeart Sandstone Member of the Adaville Formation; sandstone units are gray to tan, fine-grained, lithic "salt and pepper" sandstone beds with feldspar and chert grains; locally with burrowing; sedimentary structures in the sandstone include hummocky bedding, large-scale ball and pillow structures, some trough crossbedding; bedding is indistinct (vague) and generally from 0.7 to 1.6 ft thick; sandstone beds have sharp basal contacts; approximately from 850 to 1,000 ft in total member thickness to the east (below) of the Absaroka thrust fault in the Kemmerer 30' x 60' quadrangle (M'Gonigle and Dover, 1992).

<u>Shurtliff Sandstone Member of the Hilliard Shale</u> (Khs) (Upper Cretaceous) – A ledge-forming, gray to light tan, fine-grained to gritty sandstone containing abundant fossil oyster shells in the middle part of the Hilliard Shale; about 1,000 ft thick in the northern part of and to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle; intertongues with the main body of Hilliard Shale and pinches out to zero thickness to the southwest of Frontier, Wyoming (M'Gonigle and Dover, 1992). The Shurtliff Sandstone Member of the Hilliard Shale near Kemmerer is considered to be a southward-extending tongue of the Blind Bull Formation into the Hilliard Shale (Rubey, 1973b).

<u>Conglomerate member of Little Muddy Creek of Royse et al. (1975) of the Hilliard Shale</u> (Khc) (Upper Cretaceous) – A coarse boulder conglomerate and interbedded sandstone that grades abruptly upward and downward and intertongue laterally with the typical Hilliard Shale; contains well-rounded boulders as much as 6 ft in diameter composed of Paleozoic and Mesozoic rocks exposed in the upper plate (hanging wall) of the Absaroka thrust fault; vertical succession in clast composition represents an inverted succession of source beds according to Royse et al.

(1975); sparse palynomorphs indicate a Santonian and Coniacian age; about 2,000 ft maximum thickness to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992)

Southern Basin (Evanston quadrangle)

- **Hilliard Shale (Kh)** consists of dark olive-gray, marine shale, siltstone, and sandy shale, which contains thin interbeds of tan to light gray, sandstone and limestone, especially in the upper part of the formation; palymorphs indicate a Santonian and Coniacian age; poorly exposed in outcrops; 5,900 ft estimated minimum thickness in the quadrangle (Dover and M'Gonigle, 1993).

Hinshaw Member of Smith (1965) of Hilliard Shale (Khh) (Upper Cretaceous) **–** interbedded marine shale and sandstone sequence in the upper part of the Hilliard Shale; is a transitional sequence from shale beds of main body of Hilliard Shale into the overlying Lazeart Sandstone Member of the Adaville Formation; from 1-ft to 30-ft thick, gray to tan, fine-grained, lithic "salt and pepper" sandstone beds with feldspar and chert grains; locally with burrowing; sedimentary structures in the sandstone include hummocky bedding, large-scale ball and pillow structures, some trough crossbedding; bedding is indistinct and generally from 0.7 to 1.6 ft thick; sandstone beds have sharp basal contacts; member is not identified south of Section 17, T15N, R118W, Uinta County; approximately from 850 to 1,000 ft in total member thickness in the Evanston 30' x 60' quadrangle (Dover and M'Gonigle, 1993).

Blind Bull Formation

The Upper Cretaceous Blind Bull Formation (Kbb) is present in the northern portion of the Bear River Basin and is a lateral stratigraphic equivalent to part of the Hilliard Shale in the southern portion of the Bear River Basin. The Blind Bull Formation consists of partly conglomeratic sandstone, siltstone, claystone, coal, and bentonite (Rubey, 1973b). The Hilliard Shale is located in the eastern and southern parts of the Overthrust Belt and this shale unit becomes increasingly sandy to the northward and northwestward to laterally grade into the Blind Bull Formation; exceeds 5,000 ft thick in some areas (Rubey, 1973b) to as much as 9,200 ft thick in the Cokeville quadrangle (Rubey et al., 1980). The Shurtliff Sandstone Member of the Hilliard Shale near Kemmerer is considered to be a southward-extending tongue of the Blind Bull Formation from the northern Overthrust Belt (Rubey, 1973b).

- **Blind Bull Formation (Kbb)** consists of interbedded, gray to tan, conglomeratic sandstone, siltstone, claystone, coal, and bentonite; as much as 9,200 ft thick (Oriel and Platt, 1980). The Blind Bull Formation yields small quantities of water from the conglomeratic sandstone and sandstone beds in the formation (Forsgren Associates, Inc., GW Memo, 2001).

Northern Basin (Cokeville quadrangle)

- **Blind Bull Formation (Kbb)** consists of gray, brown, and black shale; gray, green, yellow, and brown siltstone; white, gray, yellow, green, and brown, fine- to coarse-grained sandstone and pebble conglomerate; includes thin beds of bentonite and impure coal; up to 9,200 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Frontier Formation

The Upper Cretaceous Frontier Formation (Kf) is composed of interbedded white to brown sandstone and dark gray shale with beds of abundant oyster fossils are present in the upper part of the formation and coal and lignite beds in the lower part; approximately 2,600 ft thick (Oriel and Platt, 1980). The Frontier Formation is capable of yielding moderate quantities of water from the sandstone beds (Forsgren Associates, Inc., GW Memo, 2001). The Frontier Formation is classified as a minor aquifer in the State of Wyoming (WWC Engineering, Inc., 2007). Groundwater is yielded from the sandstone beds of the formation and groundwater flow is generally as porous flow through intergranular permeability.

Northern Basin (Cokeville quadrangle)

- **Frontier Formation (Kf)** consists of interbedded sandstone, siltstone, shale, and coal; about 2,600 ft in total thickness in the Cokeville quadrangle (Rubey et al., 1980); and includes the following geologic mapping units:

Upper part of Frontier Formation (Kfu) (Upper Cretaceous) consists of tan sandstone and some lignitic shale; abundant oyster shell fossils; forms hogbacks in outcrop (Rubey et al., 1980).

Middle part of Frontier Formation (Kfm) (Upper Cretaceous) consists of white to light gray, ridge-forming sandstone in upper part; dark gray shale, coal, and tan sandstone in lower half of unit (Rubey et al., 1980).

Upper and middle parts undifferentiated of Frontier Formation (Kfum) (Upper Cretaceous) (Rubey et al., 1980).

Lower part of Frontier Formation (Kfl) (Upper Cretaceous) consists of dark gray shale, tan siltstone, white and brown sandstone; a few thin beds of lignite and porcellanite (silicified volcanic ash bed); low resistance to erosion (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Frontier Formation (Kf)** consists of an interbedded marine and nonmarine sequence of sandstone, siltstone, and carbonaceous shale containing interbeds of coal and, locally, porcellanite and conglomerate; palynomorphs and molluscan fossils indicate an early Coniacian to Cenomanian age; mapped in the Little Muddy Creek area to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle; about 2,200 ft in maximum thickness in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The Frontier Formation is not exposed to the west (above) the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992), where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies directly on the Lower Cretaceous Sage Junction Formation.

<u>Dry Hollow Member of Hale (1960) of Frontier Formation</u> (Kfd) (Upper Cretaceous) consists of gray, green-gray, and tan, nonmarine shale and siltstone with minor tan to brown, platy to crossbedded, locally bioturbated, thin, fine- to medium-grained sandstone and thin coal interbeds; the uppermost sandstone bed exceeds 10 ft in thickness and contains marine fauna fossils in the upper part and directly is underlain by the Kemmerer coal zone; palynomorphs indicate an early Coniacian to late Turonian age; about from 325 to 425 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Conglomerate of the Dry Hollow Member of Hale (1960) of Frontier Formation (Kfdc) (Upper Cretaceous) consists of pebble conglomerate locally developed in the lower part of the Dry Hollow Member; locally forms channels cutting into the top of the Oyster Ridge Sandstone Member; about from 3 to 10 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992993).

<u>Oyster Ridge Sandstone Member of Frontier Formation</u> (Kfo) (Upper Cretaceous) consists of light tan to white, parallel-bedded to crossbedded, fine- to medium-grained sandstone; interbedded with some minor brown shale beds; cliff former in outcrop; bedding and fossil fauna are interpreted as deposition in a marine shoreline depositional environment; minor channeling in the upper part; about from 50 to 200 ft thick to the east (below) of the Absaroka thrust fault in Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Allen Hollow Member of Hale (1960) of Frontier Formation</u> (Kfa) (Upper Cretaceous) consists of dark gray to green-brown, marine shale; sandstone and siltstone beds in the upper part; *Collignoniceras woolgari* fossils indicate a Middle Turonian age; mostly covered in outcrop; about 300 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Coalville Member of Hale (1960) of Frontier Formation</u> (Kfc) (Upper Cretaceous) consists of dark green-gray shale and tan, flaggy to crossbedded and ripple-marked, bioturbated, fine-grained sandstone; contains brackish-water to marine fossil fauna of early Turonian age;

about from 80 to 150 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Chalk Creek Member of Hale (1960) of Frontier Formation (Kfcc) (Upper Cretaceous) – consists of gray, green-gray, and brown, mostly nonmarine shale, bentonitic shale, tuff and tuffaceous sandstone, carbonaceous shale, coal, and tan, platy to crossbedded, locally bioturbated, fine- to coarse-grained sandstone; basal part of member interfingers with the top of the Aspen Shale (Ka) near Cumberland Gap in southernmost Lincoln County; molluscan fossils and stratigraphic position indicate a Cenomanian age; about from 1,000 to 1,400 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Frontier Formation (Kf)** consists of interbedded marine and nonmarine sequences of sandstone, siltstone, and carbonaceous shale containing interbeds of coal and locally, porcellanite and conglomerate beds; palymorphs and molluscan fossils indicate an early Coniacian and Cenomanian age; mapped in the Little Muddy Creek area, Uinta County; 2,200 ft maximum thickness in the quadrangle (Dover and M'Gonigle, 1993).

Dry Hollow Member of Hale (1960) of Frontier Formation (Kfd) (Upper Cretaceous) consists of gray, green-gray, and tan, nonmarine shale and siltstone with minor tan to brown, platy to crossbedded, locally bioturbated, thin, fine- to medium-grained sandstone and thin coal interbeds; the uppermost sandstone bed exceeds 10 ft in thickness and contains marine fauna fossils in the upper part and directly is underlain by the Kemmerer coal zone; palynomorphs indicate an early Coniacian to late Turonian age; about from 325 to 425 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Conglomerate of the Dry Hollow Member of Hale (1960) of Frontier Formation (Kfdc) (Upper Cretaceous) consists of pebble conglomerate locally developed in the lower part of the Dry Hollow Member; locally forms channels cutting into the top of the Oyster Ridge Sandstone Member; about from 33 to 65 ft thick along the eastern flank of the Lazeart syncline structure and thinner to the west in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Oyster Ridge Sandstone Member of Frontier Formation (Kfo) (Upper Cretaceous) consists of light tan to white, parallel-bedded to crossbedded, fine- to medium-grained sandstone; interbedded with some minor brown shale beds; cliff former in outcrop; bedding and fossil fauna are interpreted as deposition in a marine shoreline depositional environment;

about from 80 to 115 ft thick in Evanston quadrangle (Dover and M'Gonigle, 1993).

Allen Hollow Member of Hale (1960) of Frontier Formation (Kfa) (Upper Cretaceous) consists of dark gray to green-brown, marine shale; sandstone and siltstone beds in the upper part; *Collignoniceras woolgari* fossils indicate a Middle Turonian age; mostly covered in outcrop; about 300 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Coalville Member of Hale (1960) of Frontier Formation (Kfc) (Upper Cretaceous) consists of dark green-gray shale and tan, flaggy to crossbedded and ripple-marked, bioturbated, fine-grained sandstone; contains brackish-water to marine fossil fauna of early Turonian age; from 80 to 150 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Chalk Creek Member of Hale (1960) of Frontier Formation (Kfcc) (Upper Cretaceous) consists of gray, green-gray, and brown, mostly nonmarine shale, bentonitic shale, tuff and tuffaceous sandstone, carbonaceous shale, coal, and tan, platy to crossbedded, locally bioturbated, fine- to coarse-grained sandstone; basal part of member interfingers with the top of the Aspen Shale (Ka) near Cumberland Gap in southernmost Lincoln County; molluscan fossils and stratigraphic position indicate a Cenomanian age; from 1,000 to 1,300 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

5.22 Lower Cretaceous Geologic Units

The Lower Cretaceous bedrock formations associated with the Absaroka thrust fault system of the Overthrust Belt in the Bear River Basin includes the following:

Western part	***Eastern part***
Frontier Formation	**Frontier Formation**
Sage Junction Formation	**Aspen Shale**
Quealy Formation	**Aspen Shale**
Cokeville Formation	**lower Aspen Shale/upper Bear River Formation**
Thomas Fork Formation	**Bear River Formation**
Smiths Formation	**Bear River Formation**
Gannett Group	**Gannett Group**

The Lower Cretaceous bedrock formations were deposited in a variety of sedimentary environments ranging from marine to non-marine including rivers, floodplains, and coal beds. Many of these geologic units contain interfingering and interbedded sedimentary rock beds.

Aspen Shale

The Lower Cretaceous Aspen Shale (Ka) is composed of interbedded light to dark gray siltstone and claystone with minor quartz-rich sandstone and porcellanite; and thins southward from 2,000 to 1,100 ft thick (Oriel and Platt, 1980). To the eastward in Wyoming, the Upper Cretaceous Mowry Shale is a lateral equivalent to the Aspen Shale.

Northern Basin (Cokeville quadrangle)

- **Aspen Shale (Ka)** consists of interbedded, gray siltstone, claystone, quartzitic and cherty sandstone, and light gray, white, and pink porcellanite (silicified volcanic ash); includes some beds of black fissile shale and bentonite; porcellanites in the lower part form prominent, silvery-gray hogbacks in outcrop; in the northeastern corner of the quadrangle, some beds are present that are transitional from the Aspen Shale to the lower part of the Blind Bull Formation; thins to the south from 2,000 to 1,100 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle) and Southern Basin (Evanston quadrangle)

- **Aspen Shale (Ka)** consists of interbedded dark to light gray, silvery-weathering, marine shale, siltstone, siliceous sandstone, and porcellanite; porcellanite beds form prominent gray ridges in outcrop; contains abundant fish scales; palynmorphs and molluscan fossils indicate an Albian and Cenomanian age; estimated to be from 800 to 1,200 ft thick in these two quadrangles (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

The Aspen Shale is classified as a marginal aquifer in the State of Wyoming (WWC Engineering, Inc., 2007). Groundwater is yielded from the sandstone beds of the formation and groundwater flow is generally as porous flow through intergranular permeability. The Aspen Shale is probably not an aquifer in the Uinta County area (Robinove and Berry, 1963).

Bear River Formation

The Lower Cretaceous Bear River Formation (Kbr) consists of interbedded, black shale, brown fine-grained sandstone, and minor interbedded fossiliferous limestone and bentonite; and thins eastward from 1,800 to 1,400 ft thick (Oriel and Platt, 1980).

Northern Basin (Cokeville quadrangle)

- **Bear River Formation (Kbr)** consists of interbedded black fissile shale; resistant, olive-brown, fine-grained sandstone; and dark gray, highly fossiliferous limestone; some beds are light gray to dark gray and bentonitic to porcellanitic; other beds are heavily iron stained; thins to the south from 1,800 to 1,400 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle) and
Southern Basin (Evanston quadrangle)

- **Bear River Formation (Kbr)** consists of interbedded dark gray carbonaceous shale; tan to olive-tan, fine-grained sandstone; and very fossiliferous (gastropod *Pyrgulifera* and pelecypod) limestone; poorly exposed and forms slopes mantled with gastropod and pelecypod shells; palynmorphs and shelly fossils indicate an Albian age; estimated to be from 650 to 1,300 ft thick in these two quadrangles (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Groundwater is yielded from the sandstone beds of the formation and groundwater flow is generally as porous flow through intergranular permeability. The Bear River Formation may yield small quantities (25 gpm or less) of moderate to poor quality groundwater to wells in the Uinta County area (Robinove and Berry, 1963).

Lateral equivalents to the Bear River Formation and Aspen Shale in the Cokeville to Kemmerer area of the Wyoming Overthrust Belt

The stratigraphic nomenclature change between the western and eastern Lower Cretaceous formations occurs at the Absaroka thrust fault in the Wyoming Overthrust Belt (Rubey, 1973b). The formations located above and to the west of the Absaroka thrust, including the hanging wall of the fault, are the western formations (Smiths, Thomas Fork, Cokeville, Quealy, and Sage Junction). The formations located below and to the east of the Absaroka thrust, including the footwall of the fault, are the eastern formations (Bear River and Aspen).

Sage Junction Formation

The Lower Cretaceous Sage Junction Formation (Ksj) exceeds 3,000 ft thick and is composed predominantly of gray and tan siltstone, sandstone, and quartzite with minor quantities of porcellanite, limestone, conglomerate, and some coal beds (Rubey, 1973b). The formation is a lateral western equivalent to part of the Aspen Shale. The uppermost several hundred feet of the Sage Junction Formation may be equivalent in age to the lower part of the Upper Cretaceous Frontier Formation (Rubey, 1973b).

Northern Basin (Cokeville quadrangle)

- **Sage Junction Formation (Ksj)** consists of interbedded porcellaneous and sandy, detrital, sequence containing light gray, tan, gray-red mudstone and claystone; light gray and tan siltstone and very fine- to medium-grained sandstone and quartzite; pebble conglomerate and numerous thin beds of white, gray, and green to pink procellanite; up to at least 3,300 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Sage Junction Formation (Ksj)** is composed of interbedded, light gray, siltstone and mudstone containing tan sandstone and quartzite interbeds; thin interbeds of variegated porcellanite are common; locally contains thin beds of grit and brown to gray, fossiliferous limestone; some coal beds are present in the lower part of the formation; Rubey (1973) reported Early Cretaceous leaf and invertebrate fauna fossils; minimum thickness of at least 3,375 ft thick to the west (above) of the Absaroka thrust fault and in the northwestern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992). To the west (above) the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992), the Upper Cretaceous lower member of the Evanston Formation exposures unconformably overly directly on top of the Sage Junction Formation.

Southern Basin (Evanston quadrangle)

- **Sage Junction Formation (Ksj)** consists of interbedded, light gray, siltstone and mudstone containing tan sandstone and quartzite interbeds; thin interbeds of variegated porcellanite are common; locally contains thin beds of grit and brown to gray, fossiliferous limestone; some coal beds in the lower part of the formation; Early Cretaceous leaf and invertebrate fauna fossils; uncertain thickness but at least 650 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Quealy Formation

The Lower Cretaceous Quealy Formation (Kq) is approximately 1,000 ft thick in the area northeast of Cokeville (latitude 42° 30' North) and consists of red and variegated pastel-tinted mudstone and minor interbedded pink, gray, and tan sandstone (Rubey, 1973b). The formation thins southward and is absent to the east and south of the Town of Cokeville (Rubey, 1973b). The Quealy Formation thins eastward from Idaho into Wyoming from 1,100 to 500 ft thick (Oriel and Platt, 1980). The Quealy Formation is the western stratigraphic equivalent to the middle to lower portion of the Aspen Shale (Rubey, 1973b).

In general, the underlying Cokeville Formation thickens to the south. South of the latitude of Cokeville, where the Quealy Formation is absent, the Sage Junction Formation lies directly on top of the Cokeville Formation (Rubey, 1973b).

Northern Basin (Cokeville quadrangle)

- **Quealy Formation (Kq)** consists of interbedded red and variegated mudstone and pink, gray, and tan sandstone; thins to the east from 1,100 to 500 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle) and
Southern Basin (Evanston quadrangle)

- **Quealy Formation (Kq)** is either not present or was not identified as a mappable geologic unit (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Cokeville Formation

The Lower Cretaceous Cokeville Formation (Kck) is approximately 1,600 ft thick near Cokeville and is composed of gray to tan fossiliferous sandstone, sandy siltstone, and light to dark gray claystone/mudstone; with minor fossiliferous tan limestone; light gray, tan, and pink porcellanite; bentonite; and a few coal beds (Rubey, 1973b). The few coal beds are located in the upper portion of the Cokeville; these coal beds were mined about one half-mile west of Sage (Rubey, 1973b).

The type section of the Cokeville Formation is exposed east of Cokeville Butte (Section 36, T25N, R119W, Lincoln County, Wyoming) where the formation is about 1,609 ft thick (Rubey, 1973b). In the area of Sage, the Cokeville Formation becomes thicker and ranges from 1,900 to 2,500 ft thick (Rubey, 1973b). In general, the Cokeville Formation thickens to the south. The Cokeville Formation thickens southeastward from Idaho into Wyoming from 850 to 3,000 ft thick (Oriel and Platt, 1980).

The upper part of the Cokeville Formation is the western stratigraphic equivalent to the lower portion of the Aspen Shale and the lower Cokeville is the western equivalent to the upper Bear River Formation (Rubey, 1973b).

Northern Basin (Cokeville quadrangle)

- **Cokeville Formation (Kck)** consists of interbedded, light gray and tan, thin-bedded, medium-grained sandstone and sandy siltstone' light to dark gray shale; highly fossiliferous (gastropods), tan and gray limestone and calcareous concretions; some interbeds of porcellanite, bentonite, and coal beds; thickens to the southeast from 900 to 3,000 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Cokeville Formation (Kc)** is composed of an interbedded sequence of dark gray, carbonaceous, shaly mudstone and siltstone, tan-weathering sandstone, and highly fossiliferous, gray to tan limestone and coquina containing gastropod (*Pyrgulifera*) and pelecypod fossils, which are also characteristic of the Bear River Formation (unit Kbr); a few coal beds are present in the upper part of the formation; Rubey (1973) reported the thickness in the northwestern part of the Kemmerer quadrangle from 1,900 to 2,500 ft to the west (above) the Absaroka thrust fault, but thins to the south; there is a maximum thickness of 1,300 ft in the Evanston quadrangle, which is located to the south of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Cokeville Formation (Kck)** consists of an interbedded sequence of dark gray, carbonaceous, shaly mudstone and siltstone, tan-weathering sandstone, and gray to tan, highly fossiliferous limestone and coquina containing the gastropod (*Pyrgulifera*) and pelecypod fossils, which are also characteristic of the Bear River Formation (Kbr); a few coal beds are present in the upper part of the Cokeville Formation; from 1,900 to 2,500 ft thick reported by Rubey (1973) in the Kemmerer quadrangle, but thins to the south to no more than 1,300 ft thick in the southern part of the Evanston quadrangle (Dover and M'Gonigle, 1993).

Thomas Fork Formation

The Lower Cretaceous Thomas Fork Formation (Ktf) is approximately 1,000 ft thick and consists of variegated, banded, red, purple, brown, and green mudstone; and minor interbedded gray to tan sandstone (Rubey, 1973b). In part, the sandstone is conglomeratic with pebbles up to 4 inches in diameter and the mudstone contains gray to brown limestone nodules up to several inches in diameter (Rubey, 1973b).

The type section of the formation is exposed along the Thomas Fork (Sections 25-26, T28N, R119W, Lincoln County, Wyoming) where the formation is about 1,090 ft thick (Rubey, 1973b). The formation thickens northward to about 2,000 ft thick in the southwestern part of Star Valley and thins southward to approximately 350 ft thick in the Sage area (Rubey, 1973b). The Thomas Fork Formation thins southeastward from Idaho into Wyoming from 1,750 to 400 ft thick (Oriel and Platt, 1980).

The Town of Cokeville developed their groundwater supply from the thin, fractured, fine-grained sandstone beds of the Lower Cretaceous Thomas Fork Formation along Spring Creek Valley. The Town of Cokeville wells were constructed to replace the Town's springs as a water supply and the wells tap the same source of groundwater as the older springs. The two Cokeville municipal water-supply wells (Cokeville #2 and Cokeville #3 wells) yield from 400 to 700 gpm to the Town's public drinking water system. The Town of Cokeville wells are constructed to depths of approximately 141 and 174 ft.

Northern Basin (Cokeville quadrangle)

- **Thomas Fork Formation (Ktf)** consists of interbedded black fissile shale; resistant, olive-brown, fine-grained sandstone; and dark gray, highly fossiliferous limestone; some beds are light gray to dark gray and bentonitic to porcellanitic; other beds are heavily iron stained; thins to the south from 1,800 to 1,400 ft thick (Rubey et al., 1980).

- The Thomas Fork Formation yields groundwater to the two Town of Cokeville water-supply wells through fractured sandstone beds. Groundwater infiltrates in the Sublette Flat area downward through the shallow terrace gravel deposits into sandstone subcrops of the Thomas Fork Formation. Groundwater flow through the confined sandstone beds is down-gradient through a synclinal fold underlying a portion of Sublette Flat to discharge as outcrop/subcrop springs located along the Spring Creek Valley.

- The spring discharge areas from the Thomas Fork Formation in Spring Creek Valley are lower in elevation than the subcrops of the same formation under Sublette Flat. The difference in groundwater elevation provides the head pressure to drive groundwater flow through the confined sandstone beds of the Thomas Fork Formation. The fractured sandstone bedrock formed during the active compressional folding and faulting phase of the Overthrust Belt from Upper Cretaceous to Tertiary.

Central Basin (Kemmerer quadrangle)

- **Thomas Fork Formation (Ktf)** is composed of interbedded light red and red-brown mudstone and gray, tan and light tan sandstone and gritty sandstone; contains calcareous zones (unit Ktfl); about 325 ft thick in the Sage 15-minute quadrangle (Rubey et al., 1975), which is located to the west (above) of the

Absaroka thrust fault in the Kemmerer quadrangle; the Thomas Fork Formation thickens southward from 325 ft to at least 1,300 ft in the Evanston 30’ x 60’ quadrangle (M’Gonigle and Dover, 1992).

<u>*Limestone in the Thomas Fork Formation*</u> *(Ktfl)* – Poorly exposed calcareous zones mantled by lavender or gray limestone nodules averaging from 20 to 30 mm in diameter; about from 3 to 6 ft thick to the west (above) the Absaroka thrust fault in the Kemmerer quadrangle (M’Gonigle and Dover, 1992).

<u>Southern Basin (Evanston quadrangle)</u>

- **Thomas Fork Formation (Ktf)** consists of interbedded, light red and red-brown, mudstone and gray, tan, and light tan, sandstone and gritty sandstone; outcrops are typically mantled by poorly exposed zones of lavender or gray limestone nodules averaging from 0.8 to 1.2 inches (20 to 30 mm) in diameter; merges to the south with and is lithologically indistinguishable from the upper part of the Lower Cretaceous Kelvin Formation in northeastern Utah; thickens to the south from about 325 ft in the Sage 15-minute quadrangle (western half of the Kemmerer 30’ x 60’ quadrangle) to at least 1,300 ft thick in the Evanston quadrangle (Dover and M’Gonigle, 1993).

<u>Smiths Formation</u>

The Lower Cretaceous Smiths Formation (Ks) is approximately 750 ft thick along Smiths Fork located to the northeast of the Town of Cokeville and is composed of ferruginous black shale and interbedded tan, quartz-rich, very fine-grained sandstone (Rubey, 1973b). The black shale and tan sandstone lithologies are interbedded throughout the formation, but the upper member is mainly tan sandstone and the lower member is dominantly black shale (Rubey, 1973b).

The type section is exposed along the Smiths Fork (Section 27, T29N, R118W, Lincoln County, Wyoming) where the formation is about 700 to 755 ft thick (Rubey, 1973b). The Smiths Formation thins southward to only about 300 to 400 ft thick near the Sage and Kemmerer areas. The Smiths Formation thickens eastward from Idaho into Wyoming from 300 to 850 ft thick (Oriel and Platt, 1980).

<u>Northern Basin (Cokeville quadrangle)</u>

- **Smiths Formation (Ks)** consists of interbedded tan, quartz-rich, fine-grained sandstone in upper part and ferruginous black shale in the lower part; about 850 ft maximum thickness; thins to the west and south from 850 to 300 ft thick (Rubey et al., 1980). In the Cokeville quadrangle, the unit Kss is the upper sandstone part of Smiths Formation and unit Ksb is the lower shale part of Smiths Formation.

<u>Central Basin (Kemmerer quadrangle)</u>

- **Smiths Formation (Ks)** is composed mainly of light olive-brown to tan, fine-grained sandstone or quartzite; locally containing black carbonaceous shale at the base; from 300 to 400 ft thick in the Sage 15-minute quadrangle (Rubey et al.,

1975) located to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle; apparently thins southward to from 115 to 200 ft thick in the Evanston quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Smiths Formation (Ks)** consists mainly of interbedded light olive-brown to tan, fine-grained sandstone or quartzite; locally containing black carbonaceous shale at the base of the formation; appears to thin to the south from 300 to 400 ft in the Kemmerer quadrangle to from 115 to 200 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Gannett Group

The Lower Cretaceous Gannett Group (Kg) is composed of red sandy mudstone, sandstone, and chert-pebble conglomerate; includes some thin limestone and dark gray shale in the upper part and is more conglomeratic in the lower part; and thins eastward from Idaho into Wyoming from approximately 3,000 to 800 ft thick (Oriel and Platt, 1980). The Gannett Group in the Cokeville area of Lincoln County thins southeastward from 2,900 to 790 ft thick (Rubey et al., 1980). In some areas, the Gannett Group is geologically mapped as separate formations or sets of formations. The Gannett Group was described in detail by Eyer (1969) and Furer (1970). Within Uinta County, the Gannett Group is probably capable of yielding only small quantities of groundwater to wells (Robinove and Berry, 1963).

The Gannett Group is composed of five stratigraphic formations, which are in descending order from top to bottom:

- Smoot Formation;
- Draney Limestone;
- Bechler Conglomerate;
- Peterson Limestone; and
- Ephraim Conglomerate.

These five formations of the stratigraphic group are described as:

Smoot Formation **–** This upper formation was described as the unnamed upper redbed member until named by Eyer (1969); composed of interbedded red mudstone and siltstone (Oriel and Platt, 1980). The Smoot Formation is absent in some local areas and is a total of approximately 200 ft thick when combined with the underlying Draney Limestone (Oriel and Platt, 1980).

Draney Limestone **–** This unit consists of dark to medium gray limestone, weathering light gray, very fine-crystalline to aphanitic limestone interbedded with dark gray calcareous shale and siltstone; approximately 200 ft in combined thickness with the overlying Smoot Formation (Oriel and Platt, 1980; Rubey et al., 1980).

***Bechler Conglomerate* –** This formation is composed of red, red-gray, purple, and purple-gray, calcareous mudstone and siltstone, which becomes increasingly sandstone and chert-pebble conglomerate towards the west; a few thin limestone interbeds locally; approximately 1,300 ft thick (Oriel and Platt, 1980; Rubey et al., 1980).

***Peterson Limestone* –** This unit consists of light to medium gray and pastel-colored, wreathing very light gray, very fine-crystalline limestone and pastel-colored calcareous mudstone; about 230 ft thick (Oriel and Platt, 1980; Rubey et al., 1980).

***Ephraim Conglomerate* –** This basal formation of the Gannett Group is composed of brick-red, red, orange-red, and maroon mudstone and siltstone; light gray, red, tan, and brown, crossbedded, coarse-grained calcareous to quartzitic sandstone; red to brown, chert-pebble conglomerate; thins eastward from Idaho into Wyoming from approximately 3,300 to 490 ft thick (Oriel and Platt, 1980; Rubey et al., 1980).

Northern Basin (Cokeville quadrangle)

- **Gannett Group (Kg)** thins to the southeast from 2,900 to 800 ft thick (Rubey et al., 1980) and includes:

Upper unnamed member [Smoot Formation] of Gannett Group (Kr) consists of red mudstone and siltstone; absent locally (Rubey et al., 1980).

Draney Limestone of Gannett Group (Kd) is composed of dark to medium gray, weathers light gray, very fine-crystalline limestone; includes dark gray, calcareous siltstone (Rubey et al., 1980).

Bechler Conglomerate of Gannett Group (Kb) consists of purple-gray to red-gray, calcareous, sandy mudstone and siltstone; some interbedded thin limestone; unit becomes increasingly sandy and conglomeratic to the west in the Cokeville quadrangle (Rubey et al., 1980).

Peterson Limestone of Gannett Group (Kp) is composed of light to medium gray and pastel-colored, weathers light gray, very fine-crystalline limestone in the Cokeville quadrangle (Rubey et al., 1980).

Ephraim Conglomerate of Gannett Group (Ke) is composed of a prominent unit of brick-red to orange-red, sandy siltstone and claystone; light gray, red, and brown, crossbedded, coarse-grained, calcareous to quartzitic sandstone; minor light gray to tan nodular limestone in the Cokeville quadrangle (Rubey et al., 1980).

<u>Central Basin (Kemmerer quadrangle)</u>

- **Gannett Formation (Kg)** is composed of brick-red, orange-brown, and maroon, interbedded, mudstone, siltstone, and sandstone; locally, contains a few limestone beds in the upper part and chert-pebble conglomerate beds in the lower part of the unit; as much as 2,100 ft thick to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

  <u>Limestone interbeds in Gannett Group</u> (Kgl) – Prominent gray, pink, or lavender, nodular limestone interbeds in the upper part of the Gannett Group; beds are about 3 ft thick; better developed in the northern part of the Kemmerer quadrangle and located to the west (above) the Absaroka thrust fault (M'Gonigle and Dover, 1992).

  <u>Conglomerate beds in Gannett Group</u> (Kgc) – Locally thick, chert-pebble conglomerate or grit beds are present in the lower part of the Gannett Group; conglomerate is more abundant to the west (above) of the Absaroka thrust fault; beds are about 3 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

  <u>Ephraim Conglomerate of the Gannett Group</u> (Kge) – Interbedded red, sandy mudstone, red to tan coarse- to fine-grained sandstone, and massive conglomerate containing gray to black chert pebbles; mapped in the western and northwestern part of the Kemmerer quadrangle and located to the west (above) the Absaroka thrust fault (M'Gonigle and Dover, 1992). This is the basal formation of the Gannett Group.

- **Gannett Group (Kg)** is composed of brick red, orange-brown, and maroon, interbedded mudstone, siltstone, and sandstone; contains a few gray, pink, and lavender, nodular limestone interbeds in the middle and upper parts of the formation; locally contains a few, chert-pebble conglomerate beds in the lower part of the formation; limestone beds are better developed in the northern part of the Kemmerer quadrangle; as much as 2,100 ft thick to the west (above) of the Absaroka thrust fault and thins eastward to about 650 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

<u>Southern Basin (Evanston quadrangle)</u>

- **Gannett Formation (Kg)** is composed of brick-red, orange-brown, and maroon, interbedded, mudstone, siltstone, and sandstone; locally, contains a few chert-pebble conglomerate beds in the lower part of the unit; limestone beds are better developed in the northern part of the Evanston quadrangle; about 650 ft thick in the quadrangle (Dover and M'Gonigle, 1993).

  <u>Limestone interbeds in Gannett Group</u> (Kgl) – Prominent gray, pink, or lavender, nodular limestone interbeds in the middle and upper part of the Gannett

Group; beds are about 3 ft thick; better developed in the northern part of the Evanston quadrangle (Dover and M'Gonigle, 1993).

<u>*Conglomerate beds in Gannett Group*</u> *(Kgc)* – Locally thick, chert-pebble conglomerate or grit beds are present in the lower part of the Gannett Group; conglomerate is more abundant to the west of the Absaroka thrust fault; beds are about 3 ft thick in the Evanston quadrangle (Dover and M'Gonigle, 1993).

5.23 Jurassic Geologic Units

The Jurassic bedrock formations are predominantly sedimentary rock units that were deposited in marine environments to non-marine (sand-rich desert or coastal beach) environments for the Nugget Sandstone. Groundwater is yielded from sandstone, siltstone, and limestone beds that are sufficiently water saturated and permeable.

<u>**Stump Formation**</u>

The Middle to Upper Jurassic Stump Formation (Js) is composed of interbedded light to dark green, green-gray, glauconitic, fine-grained sandstone, siltstone, and limestone; thins eastward from Idaho into Wyoming from 330 to 165 ft thick (Oriel and Platt, 1980; Rubey et al., 1980). In the Cokeville area of Lincoln County, the Stump Formation thins eastward from 300 to 150 ft thick (Rubey et al., 1980).

Pipiringos and Imlay (1979) divided the Stump Formation into two members:

- Upper Jurassic Redwater Member of the Stump Formation; and
- Middle Jurassic Curtis Member of the Stump Formation.

The Stump Formation ranges in thickness from 92 ft to at least 400 ft in the Overthrust Belt area and thins irregularly to the north and east from the thickest section in southeastern Idaho (Pipiringos and Imlay, 1979). The upper member of the Stump is similar to the silty to sandy facies of the Redwater Member of the Sundance Formation eastward in Wyoming and the lower member of the Stump resembles the Curtis Formation in the San Rafael Swell area of central Utah (Pipiringos and Imlay, 1979).

<u>*Redwater Member (upper) of the Stump Formation*</u> is composed of two lithologic units: upper unit is gray, green-gray, nearly white, glauconitic, thin- to thick-bedded, crossbedded sandstone with minor interbeds of sandy siltstone, clayey siltstone, and oolitic, sandy limestone, and which locally contains chert pebbles, belemnite fossils, and ammonite fossils; lower unit is yellow-gray to brown, glauconitic siltstone and claystone, which is locally finely sandy and contains belemnite fossils (Pipiringos and Imlay, 1979).

<u>*Curtis Member (lower) of the Stump Formation*</u> consists of two lithologic units: upper unit is mainly green-gray to olive-green, soft, flaky to fissile claystone with minor thin interbeds of sandstone and oolitic, fossiliferous

limestone; lower unit is mostly green-gray to brown-gray, glauconitic, thin- to thick-bedded, ripple-marked to low-angle crossbedded, fine- to very fine-grained sandstone (some silty and medium-grained sandstone) (Pipiringos and Imlay, 1979).

East of Evanston (Section 18, T15N, R118W), Wyoming, the Stump Formation has a total thickness of 288 ft, which includes 49 ft of the upper Redwater Member and 239 ft of the lower Curtis Member (Pipiringos and Imlay, 1979). At La Barge Creek (Section 17, T27N, R115W) in Sublette County, Wyoming, the Stump Formation has a total thickness of only 92 ft, which includes 56 ft of the upper Redwater Member and 36 ft of the lower Curtis Member (Pipiringos and Imlay, 1979).

The sandstone beds of the Stump Formation may possibly yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963).

Northern Basin (Cokeville quadrangle)

- **Stump Formation (Js)** is composed of light to dark green, glauconitic, fine-grained sandstone, limestone, siltstone, and claystone interbedded; thins to the east from 300 to 150 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Stump Formation (Jsp)** is composed of interbedded, green-gray, glauconitic sandstone, siltstone, and limestone; from 1,640 to 1,965 ft in combined thickness with the underlying Preuss Formation to the west (above) of the Absaroka thrust fault and from 100 to 165 ft in thickness for the Stump alone to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The combined thickness of Preuss and Stump formations to the east (below) of the Absaroka thrust fault ranges from 500 to 560 ft in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Stump Formation (Jsp)** consists of green-gray, glauconitic, sandstone, siltstone, and limestone; at least 500 ft thick in total estimated thickness combined with the underlying Preuss Formation in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Preuss Formation (Preuss Redbeds)

In outcrop and shallow groundwater areas, the bedded halite (rock salt) in the lower portion of the Preuss Formation (Imlay, 1952) has been removed from the formation by dissolution and water transport. These evaporite dissolution beds in the lower Preuss Formation may contain breccias zones and collapse structures which may enhance permeability for groundwater flow in conduits/fractures. Imlay (1952) reported a single 29-ft thick salt bed and aggregate thickness of 96 ft of salt beds penetrating while drilling 456 ft of the Preuss Formation in a borehole located along the Wyoming-Idaho border in the lower part of the Preuss Formation. The location of that borehole was not identified in the report (Imlay, 1952).

The Middle Jurassic Preuss Formation (Preuss Redbeds) may yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963). In subsurface areas where bedded halite (rock salt) or other evaporite minerals are present within the formation, the groundwater quality would be considered unusable without treatment because the TDS level is in excess of 10,000 mg/L. In the areas with bedded rock salt contained in the Preuss Formation, the groundwater is of the sodium chloride-type.

Northern Basin (Cokeville quadrangle)

- **Preuss Formation (Preuss Redbeds) (Jp)** (Middle Jurassic) consists of interbedded purple, maroon, dull red, purple-gray, and red-gray, siltstone, sandy siltstone, silty claystone, and claystone with minor interbedded halite (rock salt), alum, and gypsum locally present in irregular zones; includes beds of red, gray, and tan, fine-grained sandstone; thin-bedded and regular bedded; thins eastward from Idaho into Wyoming from 1,640 to 360 ft thick (Oriel and Platt, 1980). In the Cokeville area of Lincoln County, the Preuss Formation thins eastward from 1,600 to 380 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Preuss Formation (Preuss Redbeds) (Jsp)** is composed of thinly interbedded, dark red-brown to purple-red, siltstone, mudstone, and sandstone; green-gray, glauconitic sandstone, siltstone, and limestone; from 1,640 to 1,965 ft in combined thickness with the underlying Preuss Formation to the west (above) of the Absaroka thrust fault (in the western part of the Sage 15-minute quadrangle) and 400 ft in estimated thickness for the Preuss alone to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The Preuss Formation contains salt at depth in the subsurface near Salt Creek in the southwestern portion of the Kemmerer quadrangle (M'Gonigle and Dover, 1992). The combined thickness of Preuss and Stump formations to the east (below) of the Absaroka thrust fault ranges from 500 to 560 ft in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Preuss Formation (Preuss Redbeds) (Jsp)** is composed of dark red-brown, thinly interbedded, siltstone, mudstone, and sandstone; contains salt in the subsurface near Salt Creek in the west-central part of the quadrangle; at least 500 ft thick in total estimated thickness combined with the underlying Preuss Formation in the Evanston quadrangle (Dover and M'Gonigle, 1993).

Twin Creek Formation

The Middle Jurassic Twin Creek Limestone (Jt) consists of green-gray argillaceous (shaly) limestone and calcareous siltstone; and thins eastward from Idaho into Wyoming from over 3,300 ft to about 1,000 ft thick (Oriel and Platt, 1980). Imlay (1967) reported that the formation thins eastward from 2,720 ft thick near Idaho Falls, Idaho, to 665 ft thick in northwestern Wyoming, and from 2,850 ft thick near Salt Lake City to 440 ft thick in the Uinta Mountains, Utah.

The Twin Creek Limestone was deposited in a Jurassic seaway marine environment and pelecypod fossils including *Gryphaea* are present in the formation (Imlay, 1967). Imlay (1967) defined and described seven (7) members of the Twin Creek Formation in the Overthrust Belt of Wyoming-Idaho-Utah, including the basal Gypsum Spring Member. These members are, from youngest (top) to oldest (bottom):

- Giraffe Creek Member
- Leeds Creek Member
- Watton Canyon Member
- Boundary Ridge Member
- Rich Member
- Sliderock Member
- Gypsum Spring Member

These seven members of the Twin Creek Limestone in the Overthrust Belt area are described below:

Giraffe Creek Member of Twin Creek Limestone is composed of yellow-gray, green-gray, and pink-gray silty to sandy, ripple-marked, thin-bedded limestone and sandstone with minor thick interbeds of oolitic sandy limestone; becomes more sandy and glauconitic to the west; grades upward (10 ft or less) into the red, soft siltstone at the base of the Preuss Formation; thins eastward and northward from 295 to 25 ft thick (Imlay, 1967).

Leeds Creek Member of Twin Creek Limestone consists of light gray, dense, shaly, soft limestone, which weathers into slender splinters; contains minor interbeds of oolitic silty or sandy, ripple-marked limestone; becomes increasingly clayey to the northeast in Idaho and Wyoming and to the south in Utah; it is the least resistant lithology in the Twin Creek Limestone and commonly forms valleys where exposed; the member grades upward into the harder, silty to sandy, basal limestone of the overlying member; thins eastward from 1,600 to 260 ft thick (Imlay, 1967).

Watton Canyon Member of Twin Creek Limestone is composed of gray, compact, dense, brittle, medium- to thin-bedded limestone, which forms prominent cliffs and ridges; the basal unit of the member is generally massive and oolitic; some oolitic limestone interbeds occur throughout the member; the upper part of the member grades upwards into the shaly, soft basal limestone of the overlying member; contains pelecypod fossils; thins eastward from 400 to 60 ft thick (Imlay, 1967).

Boundary Ridge Member of Twin Creek Limestone consists of red, green, and yellow, soft siltstone with interbedded silty to sandy or oolitic limestone;

the member grades eastward into red, gypsiferous, soft siltstone and claystone; the member grades westward into cliff-forming, oolitic to dense limestone with minor interbedded red siltstone; this member is overlain by a sharp contact with the cliff-forming, basal limestone of the Watton Canyon Member; thins eastward from 285 to 30 ft thick (Imlay, 1967).

Rich Member of Twin Creek Limestone is composed of gray, splintery, shaly limestone which is very soft at the base of the member; becomes increasingly clayey to the north; the upper few feet of the Rich Member grade upward into the basal hard sandy limestone or red, soft siltstone of the Boundary Ridge Member; contains pelecypod and cephalopod fossils; thins eastward from 500 to 40 ft thick (Imlay, 1967).

Sliderock Member of Twin Creek Limestone consists of gray-black, medium- to thin-bedded limestone; in Wyoming, the basal beds are oolitic; in Idaho, the basal beds are sandy, glauconitic, crossbedded, and pebbly; in Utah, the basal beds are sandy and oolitic; this member generally forms a low ridge between the adjacent members; contains pelecypod and cephalopod fossils; thins eastward from 285 to 20 ft thick (Imlay, 1967).

Gypsum Spring Member of Twin Creek Limestone is composed of red to yellow, soft siltstone and claystone, which is interbedded with brecciated, vuggy, or chert-bearing limestone; in Wyoming a basal unit of brecciated limestone grades eastward into thick, massive gypsum deposits; the chert-bearing limestone thickens westward from a few feet thick in Wyoming to a thick, cliff-forming unit in Idaho; locally, the top bed is a green tuff; thins eastward irregularly from 400 to 12 ft thick (Imlay, 1967). In areas of Wyoming located to the east of the Bear River Basin, the Gypsum Spring Formation is a distinct, mapable, stratigraphic unit.

Northern Basin (Cokeville quadrangle)

- **Twin Creek Formation (Jt)** consists of dark gray, thin-bedded, argillaceous, and partly sandy limestone and calcareous siltstone, and beds of more massive, oolitic limestone; thin-bedded limestone and siltstone and siltstone, weathers light gray and forms conspicuous slopes in outcrop; thins to the east from 2,550 to 1,000 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Twin Creek Limestone (Jt)** is composed of dark to light gray, light yellow-gray-weathering, thin-bedded limestone and calcareous siltstone containing minor brown mudstone; includes as much as 100 ft thick of an interbedded basal unit of red-weathering, limestone breccia, yellow to light tan sandstone, siltstone, and red, silty mudstone (Rubey et al., 1975); as much as 2,900 ft thick to the west (above) of the Absaroka thrust fault and about from 800 to 1,000 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

The Twin Creek Limestone may yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963). Groundwater from the Gypsum Spring Member should be avoided at depths and in areas where gypsum deposits are present in the member because of the potential for a high calcium-sulfate and TDS content of the groundwater. In the structurally deformed areas of the Overthrust Belt, the permeability and well yield of the Twin Creek Limestone may be greatly increased by groundwater fracture-flow through the formation.

Nugget Sandstone

The Triassic(?) to Jurassic Nugget Sandstone (JTRn) is composed of tan to pink, crossbedded, well-sorted quartz-rich sandstone; and ranges from approximately 1,000 to 600 ft thick (Oriel and Platt, 1980). The Nugget Sandstone is considered of possibly Triassic to Jurassic in age. The lower portion of the formation may be Triassic but the lack of diagnostic fossils in the sandstone has made the age of the formation questionable. The Nugget Sandstone has been interpreted as deposited as an eolian (wind-blown) sand dune sequence from a desert or a beach environment.

In some areas of the Overthrust Belt, the upper portion of the Nugget Sandstone exhibits calcite (calcium carbonate) cement with slightly increased permeability and the lower portion of the formation has siliceous (quartz) cement with decreased permeability. This dual cementation feature of the Nugget Sandstone has been observed in an oilfield production well located to the northeast of Evanston in Uinta County, Wyoming.

Northern Basin (Cokeville quadrangle)

- **Nugget Sandstone (JTRn)** consists of light tan to pink-tan, massive, crossbedded, quartzitic and slightly calcareous, fine- to medium-grained sandstone; forms prominent ridges and mountain crests in outcrop; thins to the east from 1,000 to 600 ft thick in the Cokeville quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Nugget Sandstone (JTRn)** is composed of tan, pink, and white, well sorted, medium-bedded to massive, locally crossbedded, fine- to medium-grained, quartz-rich sandstone; commonly has a dark gray-black, manganese oxide (desert varnish) staining on weathered outcrops of formation; forms characteristic dark brown blocky talus slopes in outcrop; as much as 1,475 ft thick to the west (above) of the Absaroka thrust fault and about 650 ft thick to the east (below) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

The Nugget Sandstone will possibly yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963).

5.24 Triassic Geologic Units

The Triassic bedrock formations include interfingering sequences of redbeds and marine limestone lithologies that reach their maximum thickness in the Fort Hall Indian

Reservation area of southeastern Idaho (Kummel, 1954). The Triassic Ankareh Formation, Thaynes Limestone, and Woodside Formation were defined from exposures near Park City, Utah (Boutwell, 1907; Kummel, 1954). East of the Overthrust Belt in western Wyoming, the three Triassic formations (Ankareh, Thaynes, and Woodside) grade laterally into the Triassic Chugwater Group (Formation). The Chugwater Group overlies the Dinwoody Formation in the Green River and Wind River Basins.

Ankareh Formation

The Upper Triassic Ankareh Formation (TRa) consists of red and maroon shale and pale purple limestone with minor white to red fine-grained quartz-rich sandstone; and thickens eastward from Idaho into Wyoming from approximately 460 to 920 ft thick (Oriel and Platt, 1980). To the east in central Wyoming, the Ankareh Formation is the stratigraphic equivalent of the upper portion of the Red Peak Member, Alcova Limestone Member, unnamed redbeds of interbedded siltstone and sandstone, and Popo Agie Member of the Chugwater Formation/Group (Kummel, 1954).

The Lower to Upper Triassic Ankareh Formation in Wyoming is predominantly composed of red shale, with minor interbedded red or light tan sandstone or thin, gray limestone locally; the sandstone bed may correlate westward to the Timothy Sandstone Member of the Thaynes Limestone and the limestone may correlate westward to the Portneuf Limestone Member of the Thaynes Limestone; the redbeds present below the thin limestone or sandstone in the Ankareh may correlate westward to the Lanes Tongue of the Ankareh Formation; 775 ft thick at Swift Creek in the Salt River Range, Wyoming; 850 ft thick at the headwaters of Middle Piney Creek in the Wyoming Range, Wyoming; about 650 ft thick at Muddy Creek in Lincoln County, Wyoming (Kummel, 1954).

Central Basin (Kemmerer quadrangle)

- **Ankareh Formation or Ankareh Redbeds (TRa)** is composed of red to maroon, brightly colored, interbedded sequence of calcareous sandstone or quartzite, siltstone, and mudstone; locally contains minor limestone; about 740 ft thick to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

The Ankareh Formation will probably yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963).

Thaynes Limestone

The Lower Triassic Thaynes Limestone (TRt) is composed of gray limestone and brown-weathering, gray, calcareous siltstone with abundant dark gray shale and limestone abundant in the lower part of the formation; and thins eastward from Idaho into Wyoming from approximately 1,640 to 985 ft thick (Oriel and Platt, 1980). Kummel (1954) defined several members of the Thaynes and an interfingering Ankareh Formation member:

Timothy Sandstone Member of Thaynes Limestone is the uppermost lithologic member of the Thaynes Limestone and is missing at Cokeville and at Spring Canyon in Sublette Ridge, Wyoming; this member is 125 ft thick and consists of red siltstone, shale, and sandstone at Hot Springs along Indian Creek in southeastern Idaho and rapidly thins eastward into Wyoming; the unit is present in the Grays Range of Wyoming (Kummel, 1954).

Portneuf Limestone Member of Thaynes Limestone consists of olive-gray, massive limestone and olive-light tan calcareous siltstone; 12.5 ft thick at Cokeville Canyon and at Spring Canyon in Sublette Ridge, Wyoming, and is present in the Cumberland Gap area south of Kemmerer, Wyoming (Kummel, 1954).

Lanes Tongue of Ankareh Formation is composed of red, interbedded shale and siltstone; 200 ft thick at Cokeville Canyon and 645 ft thick at Spring Canyon in Sublette Ridge, Wyoming (Kummel, 1954). This redbeds member is similar to the overlying Ankareh Formation (Kummel, 1954).

Upper calcareous siltstone member of Thaynes Limestone consists of light tan, thin- to massively-bedded, silty limestone and calcareous siltstone; about 1,000 ft thick at Spring Canyon in Sublette Ridge, Wyoming (Kummel, 1954).

Middle shale member of Thaynes Limestone is composed of black shale and shaly limestone; contains cephalopod, ammonite, and pelecypod fossils; about 50 ft thick at Cokeville, Wyoming (Kummel, 1954).

Middle limestone member of Thaynes Limestone consists of gray, massive, fine-crystalline limestone; contains brachiopod and pelecypod fossils; about 90 ft thick at Cokeville, Wyoming (Kummel, 1954).

Lower shale member of Thaynes Limestone is composed of dark gray, silty limestone; about 107 ft thick at Cokeville, Wyoming (Kummel, 1954).

Lower limestone member of Thaynes Limestone consists of gray-blue to gray, weathers gray, massive limestone containing cephalopod fossils; about 50 ft thick at Spring Canyon in Sublette Ridge, Wyoming (Kummel, 1954).

Central Basin (Kemmerer quadrangle)

- **Thaynes Limestone (TRt)** is composed of mainly light brown-gray-weathering, interbedded silty limestone and calcareous siltstone in the upper part; green-gray, brown-weathering, calcareous siltstone and minor silty claystone and limestone interbedded in the lower part; from 700 to 1,300 ft thick to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M’Gonigle and Dover, 1992).

The Thaynes Limestone may yield moderate quantities of water from the limestone beds in locations where the formation is fractured (Forsgren Associates, Inc., GW Memo, 2001). Wells reportedly yield from 12 to 150 gpm (Forsgren Associates, Inc., GW

Memo, 2001). The Thaynes Limestone will probably yield small quantities of groundwater to wells in western Uinta County (Robinove and Berry, 1963).

Woodside Formation

The Lower Triassic Woodside Formation (TRw) consists of interbedded red siltstone and shale with minor sandstone and gray limestone interbeds; thickens eastward from Idaho into Wyoming from approximately 395 ft to 590 ft thick (Oriel and Platt, 1980). The Woodside Formation overlies the Dinwoody Formation and is overlain by the Thaynes Limestone in the Bear River Basin.

The Woodside Formation is composed of maroon and red, shaly siltstone and interbedded red shale; formation is 800 ft thick at Hot Springs, Idaho, on the east side of the Bear Lake Valley; Idaho; about 390 ft thick at Montpelier Canyon, Idaho and consists of about one-half redbeds; 490 ft thick at Cokeville in Sublette Range and 565 ft thick at Turner Canyon, Wyoming; 695 ft thick at North Piney Creek and 680 ft thick at Martin Creek in the Wyoming Range, Wyoming; eastwards into central Wyoming, the upper Woodside Formation is stratigraphically equivalent to the Red Peak Member of the Chugwater Formation/Group (Kummel, 1954).

Central Basin (Kemmerer quadrangle)

- **Woodside Formation (TRw)** is composed of mainly interbedded red siltstone and claystone containing some thin interbeds of red sandstone and gray limestone; non-resistant to weathering in outcrop areas; about 650 ft thick to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

The Woodside Formation will probably yield small quantities of groundwater to wells in Uinta County (Robinove and Berry, 1963).

Dinwoody Formation

The Lower Triassic Dinwoody Formation (TRd) is composed of gray limestone and olive-green to green-brown siltstone; thins eastward from Idaho into Wyoming from approximately 1,640 ft to 245 ft thick (Oriel and Platt, 1980).

The 50- to 175-foot thick, basal unit of the Dinwoody Formation is composed of light tan to tan, silty limestone and calcareous siltstone; the 25- to 350-foot thick, middle unit consists of interbedded, gray silty limestone, gray crystalline limestone, and olive-light tan to gray shale beds; the 100- to 300-foot thick, upper unit is composed of interbedded, tan, calcareous siltstone, gray silty limestone, gray crystalline limestone, and a few shale beds; the basal and middle units thin eastward from the Overthrust Belt to zero thickness in Wyoming; total formation thickness is 545 ft at Cokeville in the Sublette Ridge and 180 ft along Muddy Creek in Lincoln County, Wyoming (Kummel, 1954).

Central Basin (Kemmerer quadrangle)

- **Dinwoody Formation (TRd)** is composed of green-gray, thin-bedded, interbedded calcareous siltstone and silty limestone; estimated thickness from 100 to 500 ft to the west (above) of the Absaroka thrust fault in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

The Dinwoody Formation is probably not an aquifer in the Uinta County area (Robinove and Berry, 1963).

5.3 Paleozoic Major Hydrogeologic Group

The Paleozoic Major Hydrogeologic Group (Figure A-1) is the third most used of the four Major Hydrogeologic Groups and consists of the water-saturated portions of the bedrock formations of Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian ages. In the Bear River Basin, these Paleozoic formations have a combined thickness averaging about 5,000 ft with a maximum thickness estimated at 9,800 ft. The Paleozoic formations generally thicken towards the west in the Bear River Basin.

As shown in Figure A-1, the outcrop exposures of the Paleozoic bedrock formations are limited to small areas located along the Crawford thrust fault system in the western portion of the Basin; along the Tunp thrust fault system east of Cokeville; and along the northeastern portion of the Bear River Basin. The Paleozoic Major Hydrogeologic Group is accessible in or very close to these outcrop areas. The Paleozoic aquifers produce water from the carbonate (limestone and dolomite) and sandstone beds within the geologic units. Structurally controlled, fracture permeability within the Paleozoic formations is usually required for siting and construction of a high yielding well.

The hydrogeologic units of the Paleozoic Major Aquifer Group, underlie the Mesozoic and Cenozoic Major Aquifer Groups, except in areas where structural deformation has uplifted and exposed the Paleozoic formations in the mountains and highlands of the Overthrust Belt. In descending order by age, the Paleozoic Major Aquifer Group consists of the Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian formations.

The Paleozoic formations are predominantly composed of limestone, dolostone (dolomite), shale, and sandstone. These sedimentary lithologies were predominantly deposited in marine environments. The Paleozoic hydrogeologic units are generally exposed in the mountains and highlands of the Bear River Basin. The highly complex structural features of the Overthrust Belt require site-specific geologic and hydrogeologic investigation to develop groundwater resources from the Mesozoic and Paleozoic hydrogeologic units. Where structurally deformed by folding and faulting in the Overthrust Belt, the Paleozoic aquifers may have their bedrock permeability of the sandstone, limestone, and dolostone (dolomite) beds enhanced by fracture or conduit flow.

<u>Phosphoria Formation and related rocks</u>

The Lower Permian Phosphoria Formation (Pp) consists of an upper part of dark to light gray chert and shale; a lower part of brown-weathering dark phosphatic shale and limestone; and thins eastward from Idaho into Wyoming from approximately 360 ft to 230 ft thick (Oriel and Platt, 1980).

<u>Northern Basin (Cokeville quadrangle)</u>

- **Phosphoria Formation (Pp)** thins to the north from 360 to 260 ft thick (Rubey et al., 1980) and includes:

Rex Chert Member of Phosphoria Formation is composed of dark gray siltstone, black, thin-bedded chert and limestone, and a few thin beds of phosphate rock in the upper part; resistant ledges of gray, cherty, dolomitic limestone and some bedded chert in the middle and lower part of the member; unit as mapped includes Franson Tongue of Park City Formation, Retort Phosphatic Shale and Tosi Chert Member of the Phosphoria Formation (Rubey et al., 1980).

Meade Peak Phosphatic Shale Member of Phosphoria Formation consists of dark gray, non-resistant, and brown phosphatic siltstone and cherty siltstone, gray dolomite, several blue beds of phosphorite, and one bed of vanadiferous carbonaceous siltstone; as mapped includes lower chert member of Phosphoria Formation (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Phosphoria Formation (Pp)** is composed of dark gray siltstone, thin-bedded black chert and limestone, and a few thin beds of phosphate rock; resistant ledges of gray cherty dolomitic limestone and bedded chert in the upper part of the formation; dark, non-resistant, phosphatic siltstone, gray dolostone (dolomite), and dark cherty siltstone; includes several beds of phosphate rock and vanadium-bearing, carbonaceous siltstone in the lower part of the formation; about 425 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Phosphoria Formation (Pp) and related rocks** are not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Phosphoria Formation is present in the subsurface of the Evanston quadrangle.

The Phosphoria Formation yields small quantities of water from the sandstone beds in the formation and where fractured, the formation may yield moderate quantities and one Phosphoria well has a reported yield of 200 gpm (Forsgren Associates, Inc., GW Memo, 2001). The Phosphoria Formation is probably not an aquifer in Uinta County (Robinove and Berry, 1963).

Wells Formation

The Middle to Upper Pennsylvanian to Lower Permian Wells Formation (PIPw) is composed of interbedded gray limestone and pale yellow calcareous sandstone with minor gray dolomite beds; the lower part of the formation is cherty; thins eastward from Idaho into Wyoming from about 2,000 ft to 600 ft thick (Oriel and Platt, 1980). The Wells Formation is capable of yielding moderate to large quantities of water with one well having a reported yield of 200 gpm (Forsgren Associates, Inc., GW Memo, 2001). The groundwater possibilities of the Wells Formation in Uinta County are unknown (Robinove and Berry, 1963).

Northern Basin (Cokeville quadrangle)

- **Wells Formation (PIPw)** consists of white-tan, fine-grained quartzite and sandstone; alternating beds of gray, dolomitic limestone and hard siltstone in the upper part; a few thin calcareous beds in the middle and lower part; forms bold ridges and mountain crests in outcrop; includes a tongue of the lower part of the Park City Formation at top of the unit; thins to the east from 1,100 to 600 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Wells Formation (PIPw)** is composed of interbedded quartzite, siltstone, and limestone or dolostone (dolomite) in the upper part of the formation; mainly white to light tan, well sorted, fine-grained quartzite and sandstone in the lower part of the formation; ranges from 600 to 1,000 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Limestone of Wells Formation (PIPwl) (Lower Permian) is composed of gray limestone in the upper part of the Wells Formation; mapped as a separate unit only in the Sage and Kemmerer 15-minute quadrangles by Rubey et al. (1975); about 260 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Wells Formation (PIPw)** is not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Wells Formation is present in the subsurface of the Evanston quadrangle.

Tensleep Sandstone

The Tensleep Sandstone (Weber Sandstone lateral equivalent) is a Pennsylvanian-Permian formation composed mostly of sandstone with interbedded carbonate units (limestone and/or dolostone (dolomite)). The Tensleep Sandstone is not mapped as a geologic unit nor exposed at the ground surface within the Cokeville, Evanston, and Kemmerer quadrangles (Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Amsden Formation

The Upper Mississippian to Pennsylvanian Amsden Formation (IPMa) is composed of red and gray cherty limestone and yellow siltstone, sandstone, and conglomerate; thins eastward from Idaho into Wyoming from 560 ft to 330 ft thick across the Overthrust Belt (Oriel and Platt, 1980). The Amsden overlies the Madison Limestone and is overlain by the Tensleep Sandstone (Mallory, 1967). The Amsden Formation has the following members in some areas:

Ranchester Limestone Member (Lower Pennsylvanian; Mallory, 1967)

Horseshoe Shale Member (Upper Mississippian to Lower Pennsylvanian; Mallory, 1967)

Darwin Sandstone Limestone Member (Upper Mississippian; Mallory, 1967)

Northern Basin (Cokeville quadrangle)

- **Amsden Formation (IPMa)** consists of interbedded, gray, red, and black, cherty limestone; fine-grained quartzite and sandstone; red and yellow siltstone, limestone breccia, quartz-rich conglomerate, and pisolitic iron oxide; gray, cherty limestone is most abundant in the upper part; sandstone and quartzite is more common in the lower part; thickens to the south from 360 to 560 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Amsden Formation (IPMa)** (Upper Mississippian to Pennsylvanian) is composed of interbedded gray, red, black, and brown, cherty limestone and limestone breccia, light tan sandstone and quartzite, and variegated red, yellow, and green siltstone and claystone; Rubey et al. (1975) reports the formation thickness ranges from 150 ft in the western part to 400 ft in the eastern part of the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Amsden Formation (IPMa)** is not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Amsden Formation is present in the subsurface of the Evanston quadrangle.

Madison Limestone

The Lower to Upper Mississippian Madison Limestone (Mm) consists of an upper part of light gray, massive limestone and a lower part of dark gray, thin-bedded limestone; ranges from about 1,000 ft to over 1,800 ft thick (Oriel and Platt, 1980). The Madison Limestone is a thick sequence of carbonate deposition (limestone and dolostone (dolomite)). The Madison Limestone is classified as a major aquifer where it has enhanced permeability by fracturing or solution conduits.

Northern Basin (Cokeville quadrangle)

- **Madison Limestone (Mm)** consists of light gray, massive, resistant, coarse-crystalline limestone alternating with interbedded, dark gray, thin-bedded, less resistant, fine-crystalline limestone; the hard massive limestone dominates the upper part; the softer thin-bedded limestone is more common in the lower part; thins to the east from 1,800 to 1,000 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle) and
Southern Basin (Evanston quadrangle)

- **Madison Limestone (Mm)** is not mapped as a geologic unit nor exposed at the ground surface in the Kemmerer and Evanston quadrangles (Dover and M'Gonigle, 1993; M'Gonigle and Dover, 1992). However, the Madison Limestone is present in the subsurface of these two quadrangles.

Darby Formation

The Upper Devonian to Lower Mississippian Darby Formation (unit MDd) consists of an upper part of black, yellow, and red sandstone and siltstone and a lower part of dark gray dolomite and dolomitic limestone; approximately 460 ft thick (Oriel and Platt, 1980).

Northern Basin (Cokeville quadrangle)

- **Darby Formation (MDd)** consists of dark gray, light tan to dark brown-weathering, massive, to medium-bedded, fetid dolostone (dolomite); interbeds of black, yellow, and red, calcareous, sandy siltstone in the upper part; about 450 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Darby Formation (MDd)** (Upper Devonian to Lower Mississippian) is composed of dark gray, fetid dolostone (dolomite) and gray dolostone (dolomite) containing interbeds of variegated black, yellow, and red, calcareous siltstone; about 885 ft thick in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Darby Formation (MDd)** is not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Darby Formation is present in the subsurface of the Evanston quadrangle.

Laketown Dolomite

The Middle to Upper Silurian Laketown Dolomite is composed of medium to light gray, white-weathering, fine-crystalline, thick-bedded dolomite; thins eastward from Idaho into Wyoming from approximately 1,300 to 1,000 ft thick (Oriel and Platt, 1980). The Laketown Dolomite is exposed on the northeastern flank of the Crawford Mountains in southwestern Lincoln County, Wyoming, near the Utah border. It is generally absent from the remainder of the State of Wyoming. This absence is due either to the non-deposition during the Silurian or later erosion which removed almost all of the Silurian formations within the State of Wyoming. The Laketown Dolomite is not considered to be a usable aquifer in the Bear River Basin due to the limited regional extent and thickness.

Bighorn Dolomite

The Upper Ordovician Bighorn Dolomite (Ob) consists of light gray massive dolomite; thins eastward from Idaho into Wyoming from 820 to 400 ft thick (Oriel and Platt, 1980). The Bighorn Dolomite is considered to be a minor aquifer in the Bear River Basin.

Northern Basin (Cokeville quadrangle)

- **Bighorn Dolomite (Ob)** consists of light gray, massive, very fine-crystalline, dolostone (dolomite); some dark gray dolostone (dolomite) in the upper part; forms prominent ridges and mountain crests in outcrop; thins southeastward from 800 to 400 ft thick (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Bighorn Dolomite (Ob)** is composed of mottled light to dark gray, resistant, massive dolostone (dolomite); about 600 ft thick in the southwestern corner of the Sage 15-minute quadrangle in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Bighorn Dolomite (Ob)** is not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Bighorn Dolomite is present in the subsurface of the Evanston quadrangle.
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Gallatin Limestone

The Upper Cambrian Gallatin Limestone (Cgl) consists of gray and tan, mottled limestone; about 400 ft thick (Oriel and Platt, 1980).

Northern Basin (Cokeville quadrangle)

- **Gallatin Limestone (Cgl)** consists of mottled gray and tan limestone; dolomitic and massive in the upper part; more calcitic in the middle and lower part; about 400 ft thick in the quadrangle (Rubey et al., 1980).

Central Basin (Kemmerer quadrangle)

- **Gallatin Limestone (Cg)** is composed of interbedded, mottled yellow and tan, thin-bedded to massive, dolostone (dolomite) and limestone; about 230 ft thick of an incompletely exposed section located in the southwestern corner of the Sage 15-minute quadrangle in the Kemmerer quadrangle (M'Gonigle and Dover, 1992).

Southern Basin (Evanston quadrangle)

- **Gallatin Limestone (Cgl)** is not mapped as a geologic unit nor exposed at the ground surface in the Evanston quadrangle (Dover and M'Gonigle, 1993). However, the Gallatin Limestone is present in the subsurface of the Evanston quadrangle.

Gros Ventre Formation (Gros Ventre Group)

The Middle to Upper Cambrian Gros Ventre Formation (Gros Ventre Group) (Cgv) is composed of gray and tan, oolitic in part, limestone with green-gray micaceous shale in the middle of the formation; thins eastward from Idaho into Wyoming from 1,300 to 650 ft thick (Oriel and Platt, 1980). Generally, the shale members or beds of this Cambrian unit act as low permeability confining units (aquitards). The Gros Ventre Formation is not mapped as a geologic unit nor exposed at the ground surface in the Cokeville, Kemmerer, and Evanston quadrangles (Rubey et al., 1980; Dover and M'Gonigle, 1993; M'Gonigle and Dover, 1992). However, the Gros Ventre Formation is present in the subsurface of the three quadrangles.

Flathead Sandstone

The Lower Cambrian Flathead Sandstone (Cf) in the Wyoming Overthrust Belt is composed of white to pink, fine-grained sandstone and some lenses of coarse-grained sandstone; the upper part includes some green silty shale interbeds and the lower part is conglomeratic (Lines and Glass, 1975). The Flathead Sandstone ranges from 175 to 200 ft thick in the northern Overthrust Belt (Teton Pass area in Teton County, Wyoming) (Schroeder, 1969).

The Flathead Sandstone is not mapped as a geologic unit nor exposed at the ground surface in the Cokeville, Kemmerer, and Evanston, and Kemmerer quadrangles (Rubey et al., 1980; Dover and M'Gonigle, 1993; M'Gonigle and Dover, 1992). However, the Flathead Sandstone is present in the subsurface of the three quadrangles. The sandstone beds of the Middle Cambrian Flathead Sandstone have generally low permeability due to high level of cementation present the sand-sized grains in the rock. The cementation has reduced the intergranular porosity of the sandstone to about from 0 to 15 percent. Where fractured, the permeability of the sandstone may be greatly enhanced.

5.4 Precambrian Major Hydrogeologic Group

The Precambrian Major Hydrogeolgoic Group consists of bedrock formations ranging in age from Proterozoic to Archean. The hydrogeologic units of the Precambrian Major Hydrogeologic

Group are not exposed at the ground surface within the Bear River Basin but the Precambrian formations underlie the younger geologic formations at deeper depths. The Precambrian rocks are upper crustal rocks and they are generally considered to be the basement rocks. The Precambrian rocks are composed mainly of quartzite with minor quantities of schist and gneiss.

The Precambrian bedrock formations are not considered to be an aquifer in the Bear River Basin of Wyoming and this aquifer group is not used in this Basin but is used in other areas of the State of Wyoming. Within the Bear River Basin, the deep Precambrian basement rock units act as a regional, underlying low-permeability confining unit (aquitard). Precambrian bedrock formations are exposed at the ground surface in adjacent portions of the Bear River Basin located in southeastern Idaho and northern Utah and also exposed in the adjacent Snake-Salt and Green River Basins of Wyoming.

6.0 Definitions

- ***Aquifer*** **–** A formation, group of formations, or part of a formation that contains sufficient water-saturated high-permeable material to yield significant quantities of water to wells and springs (modified from Lohman et al., 1972).

- ***Aquifer system*** **–** A heterogeneous body of intercalated high-permeable and low-permeable material that functions regionally as a water-yielding hydrologic unit; it comprises two or more high-permeable aquifers separated at least locally by a low-permeable confining unit that impedes groundwater movement but does not greatly affect the regional hydraulic continuity of the system (modified from Poland et al., 1972).

- ***Confining unit*** **–** A formation, group of formations, or part of a formation that is defined as a body of low-permeability material stratigraphically adjacent to an aquifer. In nature, however, the hydraulic conductivity of the confining unit may range from nearly zero to some value distinctly lower than that of an aquifer. Its conductivity relative to that of the aquifer it confines is specified or indicated by a suitable modifier such as slightly permeable or moderately permeable (modified from Lohman et al., 1972).

In this report, we use the terms ***aquifer***, ***water-bearing bed***, and ***water-bearing unit*** as they are currently accepted for use by the USGS. In hydrogeologic use, an individual water-bearing bed or unit is generally considered to be thinner and less areally extensive than an aquifer. We also use the terms ***confining unit*** or ***confining bed*** because they are in current use by the USGS. ***Aquitard*** is also an older synonym for confining unit, but the common hydrogeologic use of the older term ***aquitard*** is declining.

The aquifers and four Major Hydrogeologic Groups are generally anisotropic because of interbedded low-permeability confining beds or confining units (shale, claystone, mudstone, bentonite beds) present within the aquifer systems. Groundwater flow rates through permeable aquifers and confining units range from very high to very low. A high flow rate through a gravel-rich, high-permeability deposit may exceed 100 centimeters per second (cm/s) (3.3 ft per second (fps) or 2.9 x 10^5 ft per day (ft/day)). A low flow rate within a clay-rich, low-permeability deposit may be less than 10^{-9} cm/s (3.3 x 10^{-11} fps or 2.9 x 10^{-7} ft/day). Thus, flow rates vary over 11 to 12 orders of magnitude. The rate of water flow through an aquifer may be several orders of magnitude faster than the flow rate through an adjacent aquitard or confining bed/unit.

Confining units are conventionally considered to be impermeable to groundwater flow, but in reality, most confining units seep water at low to very low flow rates. ***Confined aquifers*** are overlain and underlain by confining units which limit groundwater flow out of the aquifer. Confined aquifers are under the confining pressure or artesian pressure. The terms ***semi-confined*** or ***semi-confining unit*** are appropriate for beds or formations with sufficient seepage from, or through, the confining unit to an adjacent aquifer.

Unconfined aquifers are water-saturated parts of geologic units wherein groundwater is under atmospheric pressure. The commonly used term "***water table***" is the same as the geohydrologic terms "***groundwater surface***" or "***potentiometric surface***." The term water table implies a flat, horizontal groundwater surface, but the actual groundwater (potentiometric) surface is generally tilted or contoured like a topographic land surface.

The slope of the groundwater surface is defined as the ***hydraulic gradient***; it has both direction and magnitude. Hydraulic gradient is commonly expressed in feet of elevation change per foot of horizontal distance (ft/ft). The direction of slope from high to low elevation indicates the potential direction of groundwater flow, provided permeable interconnected pathways exist to allow such groundwater movement. Steep hydraulic gradients are common in low-permeability geologic units, low-angle to nearly flat hydraulic gradients for high-permeability units.

Perched groundwater or a ***perched aquifer*** refers to groundwater lying on top of a confining bed; it is the same concept as ponded (trapped) groundwater. Perched groundwater is located above the deeper aquifers that may be either unconfined or confined. Perched groundwater is generally unconfined and is hydrologically separated from the deeper aquifers by an underlying confining bed. The saturated thickness of perched groundwater may range from a few inches to more than 10 ft.

Groundwater flows in aquifers as porous flow, conduit flow, fracture flow, or a combination of these three flow types.

- ***Porous flow*** **–** water moving through interconnected, open, intergranular or intercrystalline pore spaces within a rock unit (conglomerate, sandstone, siltstone, limestone, or dolomite bedrock; or unconsolidated mixture containing loose gravel, sand, silt, and clay). The size of the sediment grains or mineral crystals is a factor in flow rate through pore spaces. Larger open pore spaces between larger grains/crystals generally have greater flow due to less friction, the result of lower grain surface-area-to-volume ratios. In a mixed deposit with clay to gravel grain sizes, increased amounts of fine-grained matrix in the pore spaces reduces the permeability and flow rate.

- ***Conduit flow*** **–** water moving through large discrete open spaces (such as pathways, pipes, cavities, channels, caves, or karstic zones) within a rock unit (limestone or dolomite). Conduits may form by the dissolution of soluble minerals in a rock unit or by subsurface sediment transport (piping) through a loosely consolidated formation.

- ***Fracture flow*** **–** water moving through interconnected breaks within a geologic unit. The breaks are created by structural deformation (folding, faulting, jointing in rocks, cleating in coal, across or along bedding planes) or physiochemical alteration (bedrock weathering or soil formation).

Groundwater flow is generally driven by gravity from areas of higher pressure (greater hydraulic head, higher elevation) to areas of lower pressure (lesser hydraulic head, lower elevation). However, groundwater flow directions as inferred from potentiometric surface maps will only occur if permeable pathways actually exist to allow the water to flow in the subsurface.

Pumping water from a well generally introduces man-induced groundwater flow toward the well. During pumping, the water level in the pumping well deepens, correspondingly lowering the aquifer water pressure locally in the aquifer(s) surrounding the well (zone of influence). After the pumping stops, the water level in the well rises back approximately to a static (non-pumping) level. The rate of water-level decline or rise in a well during pumping or non-pumping periods of time provide data useful for determining the hydrologic properties of the well and aquifer system.

Groundwater flow to a pumping well may be either laminar or turbulent. Most natural and man-induced groundwater flow is laminar: along a relatively straight path through the aquifer and into the well. There are a few examples of turbulent flow in nature, where groundwater cascades and roils through a subsurface bedrock formation or an unconsolidated deposit. Wells may be subject to man-induced turbulent flow when they are pumped at higher discharge rates than the maximum rate at which an aquifer will yield laminar-flowing water to the well. During turbulent flow, sediment may be mobilized within the aquifer and enter the pumping well, causing pebbly, sandy, silty, clayey, or muddy (highly turbid) water to be produced from the pump. In a pumping coal-bed well, turbulent flow may yield abundant coal fines in the produced water.

Other groundwater-related definitions include:

- ***Water table*** **–** an old term; is the groundwater surface within an unconfined aquifer under atmospheric pressure. In popular usage, the water table is the first occurrence of unconfined or confined groundwater encountered below the ground surface; technically, this may be inaccurate.

- ***Potentiometric surface*** **–** a theoretical and conceptual surface that represents the static head pressure of groundwater and replaces the older terms include piezometric surface and water table. A synonym is the groundwater surface. The potentiometric surface is expressed in terms of elevation in feet above mean sea level (ft-msl).

- ***Static head*** **or** ***static water level*** **–** the level of water in a well when the well and surrounding wells are not being pumped and the groundwater in the aquifer is at rest. Static head or level is commonly expressed in feet, either depth below measuring point or depth below ground surface. Also, the static head or level may be converted to elevation in feet above mean sea level (ft-msl).

- ***Drawdown* –** the lowering of the groundwater (potentiometric) surface by the actions of man (well(s) pumping) or by natural means (seasonal variations, annual variations, drought) from a higher groundwater-level datum. Drawdown is expressed in feet of water-level change. A rise in a groundwater level is the opposite of drawdown.

- ***Gaining stream* –** a stream, or reach (part) of a stream, in which the discharge of groundwater from the geologic unit(s) underlying (or adjacent to) the stream adds to the surface water flow of the stream.

- ***Losing stream* –** a stream, or reach (part) of a stream, in which the surface water leaks into the geologic unit(s) underlying (or adjacent to) the stream to recharge the groundwater and decreasing the surface water flow of the stream.

- ***Well yield* –** a measure of the rate of groundwater discharged (pumped or flowing) from a well and is expressed in gallons per minute (gpm).

- ***Porosity* –** the proportion of open-space volume (pores, pipes, conduits, voids, or fractures through which water can move) with respect to the total volume of an earth material (soil, unconsolidated deposit, or bedrock), expressed as percentage.

- ***Permeability* –** a measure of the amount of water flowing through the interconnected open spaces of an aquifer or aquitard and is expressed in gallons per day per square foot (gpd/ft^2).

- ***Specific capacity* –** the pumping discharge rate of a well divided by the number of feet of drawdown of the water level measured in the well during pumping, and is expressed in gallons per minute per foot of drawdown (gpm/ft).

- ***Specific yield* –** defined as the drainable porosity, and is reported as a proportion (percent) of the water volume that will drain under gravity from a total volume of earth material (alluvium). Specific yield is calculated only for unconfined aquifers, such as alluvial deposits.

- ***Transmissivity* –** the rate at which groundwater of the prevailing kinematic viscosity is moving through a unit width of the water-saturated portion of the aquifer under a unit hydraulic gradient and is expressed in gallons per day per foot (gpd/ft).

- ***Total dissolved solids (TDS)* –** a measure of the maximum concentration of dissolved chemical species (mineral salts). TDS is generally expressed as either milligrams per liter (mg/l) or parts per million (ppm).
- ***Geochemical water type* –** an expression of the dominant cations and anions dissolved in the groundwater.

The availability of a groundwater resource depends on the quantity, quality, and depth of the water, and on its intended use. These factors also determine the cost of developing the resource; if the groundwater cannot be developed economically, the resource will not be used. Groundwater quality depends primarily on the natural geochemistry of the water, the result of a variety of geologic factors; and in addition, groundwater may be contaminated or impaired by human activity.

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Figures (for Appendix A)

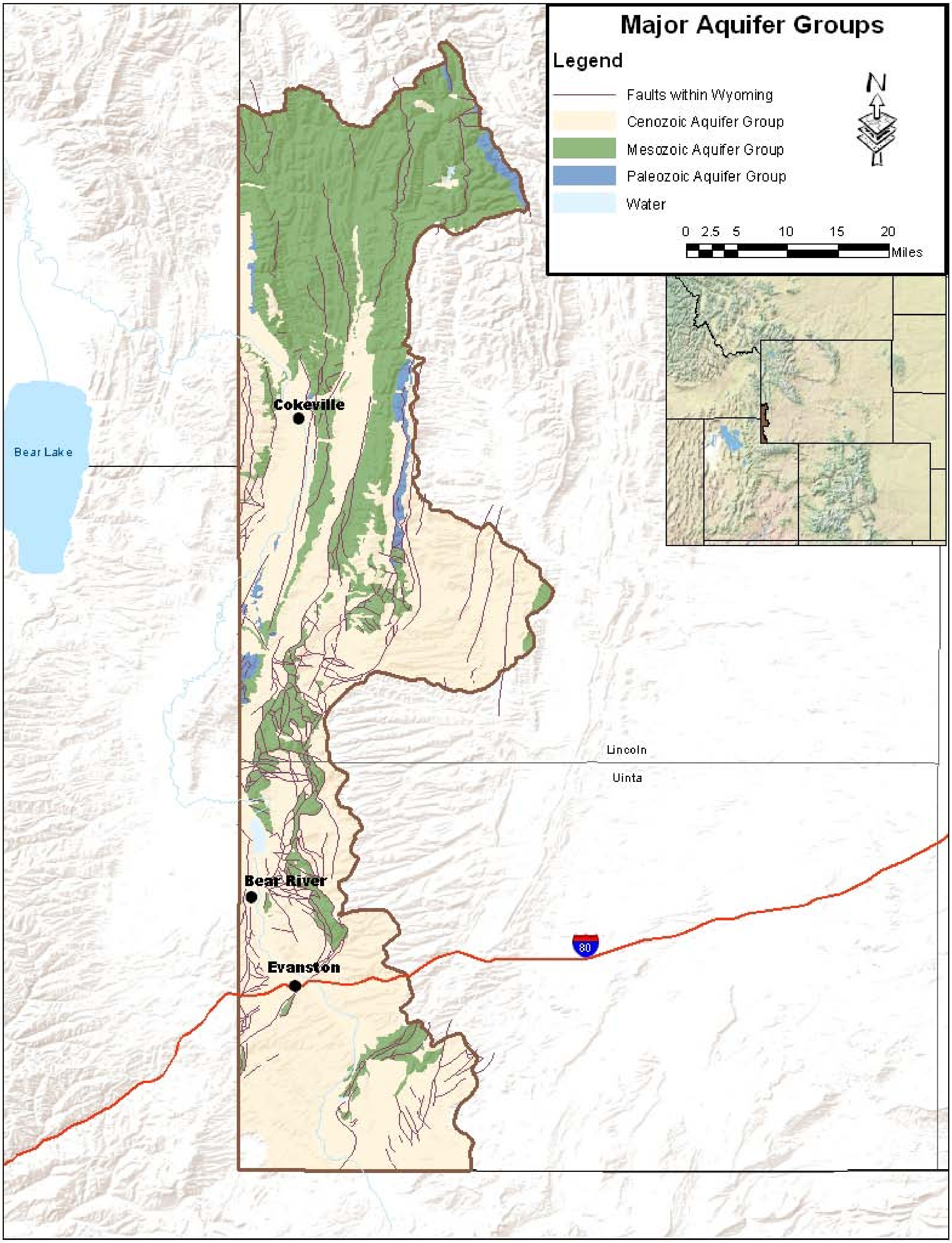

Figure A1: Major Aquifer Groups

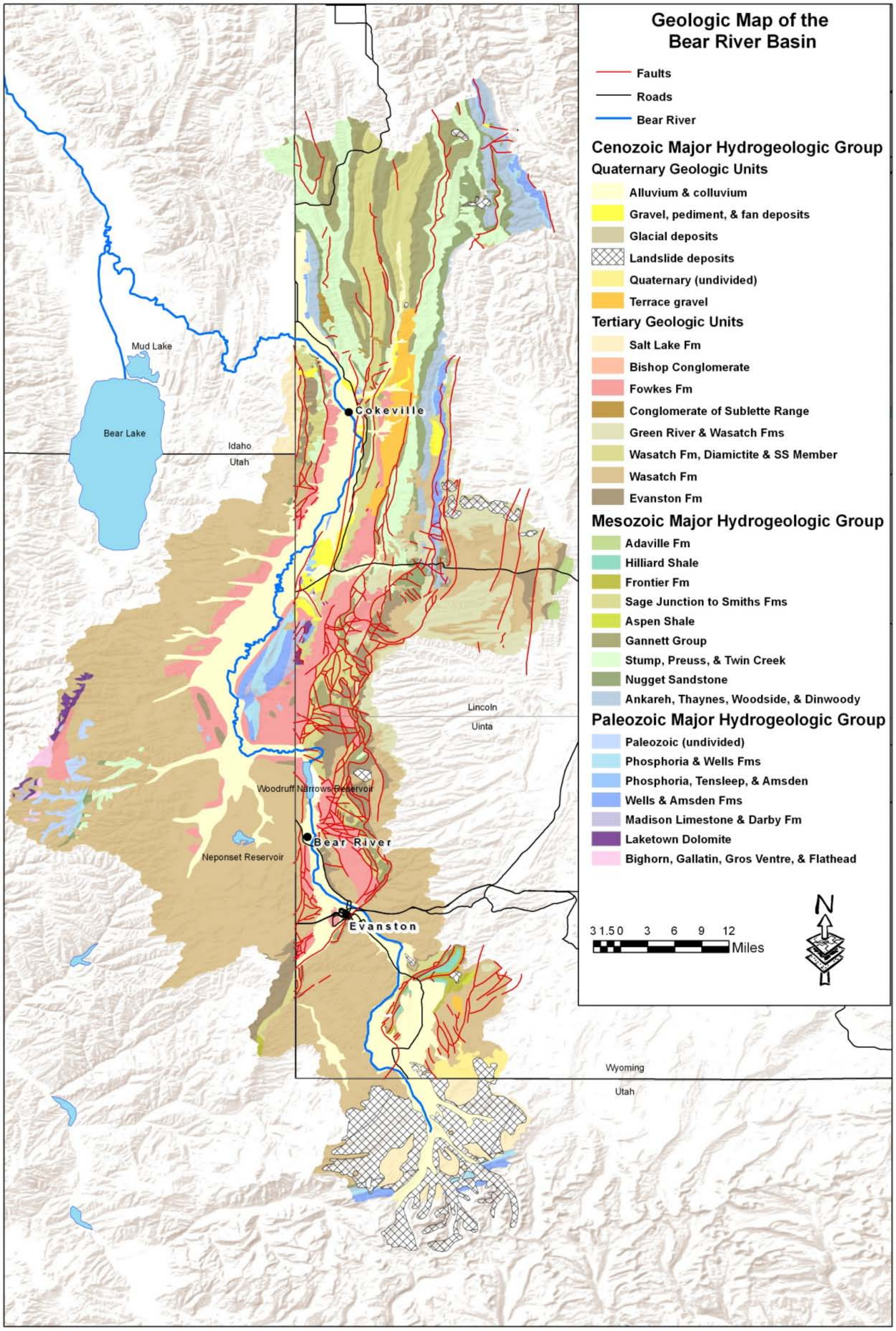

Figure A2: Geologic Map

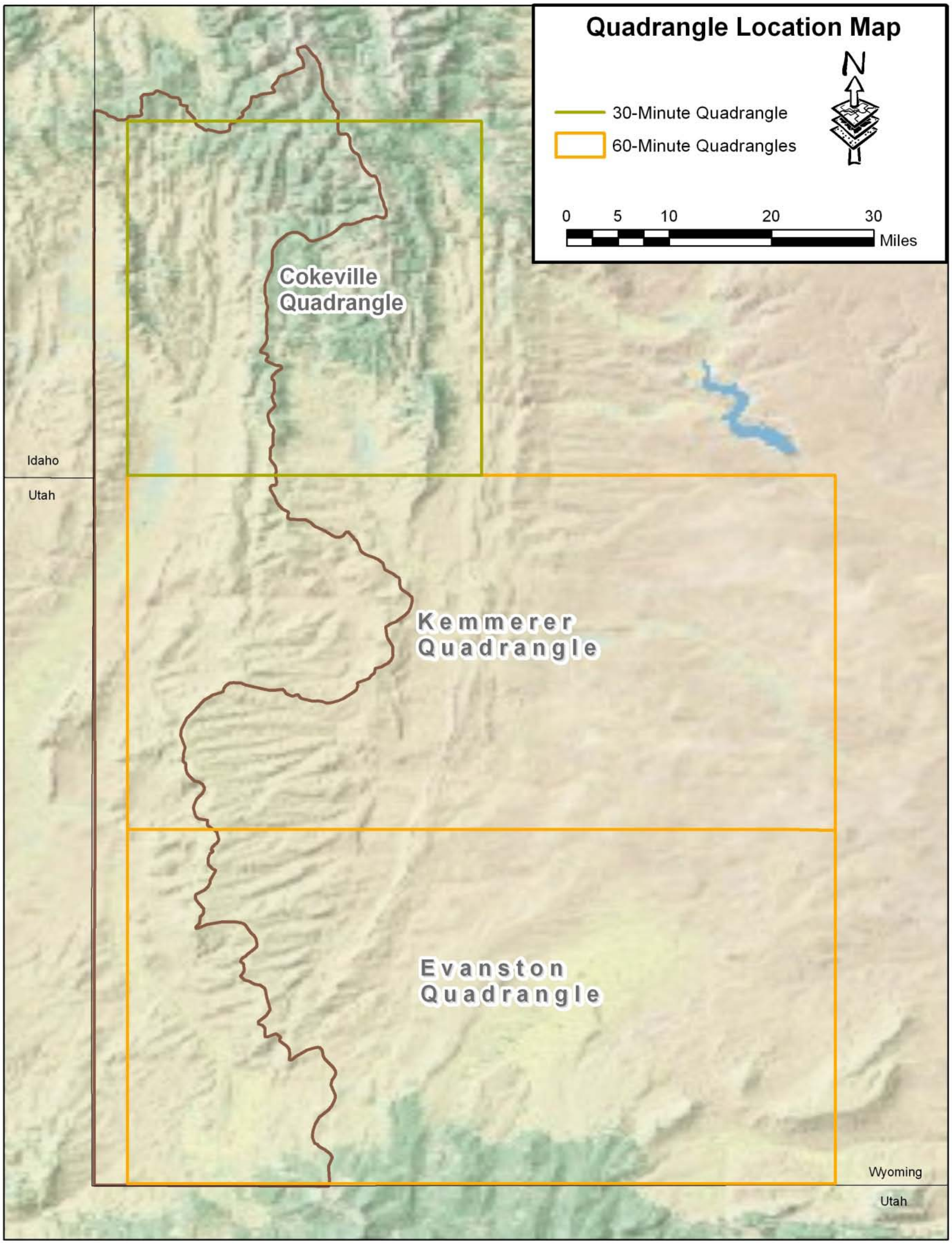

Figure A3: Quadrangle Location Map

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