Chapter 7

Physical and chemical characteristics of hydrogeologic units in the Bear River Basin

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In this report, previously published data describing the physical characteristics of hydrogeologic units (aquifers and confining units) are presented on a map (**Pl. 3**) and summarized in tabular format (**Pl. 4**). The original sources of the data used to construct the summary are listed (see the bottom of **Pl. 4**). Physical characteristics are summarized to provide a broad summary of hydrogeologic unit characteristics and include spring discharge, well yields, specific capacity, transmissivity, porosity, hydraulic conductivity, and storage (storativity/storage coefficient). Individual data values and corresponding interpretation were utilized and summarized as presented in the original reports—no reinterpretation of existing hydraulic data was conducted for this study. For example, values of transmissivity derived from aquifer tests were used as published in the original reports, and no reanalysis of previously published aquifer tests was conducted.

7.1 Bear River Basin

The physical and chemical characteristics of hydrogeologic units of Cenozoic, Mesozoic, Paleozoic, and Precambrian age in the Bear River Basin (Bear River Basin) are described in this section of the report. Hydrogeologic units of the Bear River Basin are identified on **Plate 5**. Most geologic descriptions were modified from Clarey (2011).

7.2 Cenozoic hydrogeologic units

Hydrogeologic units of Cenozoic (Quaternary and Tertiary) age are described in this section the report. Cenozoic hydrogeologic units are composed of both unconsolidated deposits such as sand and gravel (primarily of Quaternary age) and consolidated sediments (bedrock of Tertiary age) such as sandstone and conglomerate. Compared with aquifers of Mesozoic, Paleozoic, and Precambrian age, Cenozoic aquifers are the most used sources of water (Clarey, 2011). Cenozoic aquifers are used as a source of water for stock, domestic, industrial, irrigation, and public-supply purposes.

7.2.1 Quaternary unconsolidated-deposit aquifers

The physical and chemical characteristics of Quaternary unconsolidated deposits in the Bear River Basin are described in this section of the report.

Physical characteristics

Unconsolidated deposits of Quaternary age can contain aquifers (referred to herein as "Quaternary unconsolidated-deposit aquifers") that are highly productive locally, and are the source of water for many wells in the Bear River Basin. In the Bear River Basin, Quaternary unconsolidated-deposit aquifers are the most used sources of water, for stock, domestic, industrial, irrigation, and public-supply purposes.

Quaternary-age unconsolidated deposits are composed primarily of sand and gravel interbedded with finer-grained sediments such as silt and clay, although coarser deposits such as cobbles and boulders occur locally (Berry, 1955; Robinove and Berry, 1963; Rubey et al., 1980; Ahern et al., 1981; Glover, 1990; Eddy-Miller et al., 1996; Sunrise Engineering, 1997). Many different types of unconsolidated deposits of Quaternary age are present in the Bear River Basin (**Pl. 3**). Collectively, the unconsolidated deposits throughout the Bear River valley commonly are referred to as "valley fill" because the deposits grade into and (or) overlie one another and are bounded laterally or vertically (rest on top of) bedrock through which the Bear River and related tributaries have eroded to form the present-day valley (Robinove and Berry, 1963).

Quaternary-age alluvium is composed of unconsolidated, poorly to well sorted mixtures of clay, silt, sand, and gravel deposited along streams, primarily as channel-fill and flood-plain deposits. Locally, alluvium can include alluvial fan and terrace deposits, valley side colluvium or talus, and sediments deposited in small bogs, lakes, or deltas. Alluvium commonly grades laterally and vertically into other adjacent Quaternary (and in places, laterally into Tertiary) unconsolidated deposits; consequently, it is often difficult to determine where to differentiate the different types of Quaternary unconsolidated deposits in the Bear River Basin. In addition, different investigators have not always been consistent when mapping/identifying ("lumping and splitting") the different types of Quaternary unconsolidated deposits. Furthermore, use of different scale geologic maps results in different groupings of the unconsolidated deposits.

Estimates of alluvium thickness vary substantially in the Bear River valley because few wells in the area fully penetrate the deposits. Robinove and Berry (1963) reported Quaternary-age alluvium thicknesses of 0 to 185 feet (ft) or more in the Bear River valley. Lines and Glass (1975, Sheet 1) reported that alluvium was at least 410-ft thick in the Bear River valley near the town of Border. The maximum thickness of alluvium along smaller stream valleys in the Bear River Basin such as the Smiths Fork generally is about 100 ft (Lines and Glass, 1975, Sheet 1). Glover (1990) reported that wells completed to a depth of 200 ft in the alluvium were common in the Cokeville area, and that well depths of 400 and 450 ft were known in the area. Alluvium commonly is locally thicker than 30 ft in the Kemmerer and Evanston areas (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Unconsolidated terrace deposits (also described as terrace gravel deposits or terrace, gravel, and fan deposits) are present throughout the Bear River Basin. Deposits generally are Quaternary in age, but some deposits are Tertiary (Pliocene) in age. Pliocene to Pleistocene (Tertiary and Quaternary) terrace deposits are composed of unconsolidated mixtures of silt, clay, sand, and coarse gravel located 30 to 100 ft or more above local streams; these deposits may be as much as 325-ft thick in western Wyoming and southeastern Idaho (Oriel and Platt, 1980). Robinove and Berry (1963, Table 1) reported thicknesses of as much as 50 ft or more for Quaternary terrace deposits in the Bear River valley. The Pleistocene to Holocene (Quaternary) terrace deposits consist of unconsolidated, poorly to moderately sorted, partly dissected, mixtures of silt, sand, and gravel. The deposits are as much as 15 to 250 ft above streams in the Cokeville area (Rubey et al., 1980). Pleistocene to Pliocene (?) (Quaternary) older gravel deposits underlie the bench located east of the Smiths Fork River and are composed of unconsolidated and poorly sorted mixtures of pebble- to boulder-sized gravel, sand, silt, and clay; they may be as much as 150-ft thick in the Cokeville area (Rubey et al., 1980). The Sublette Flat area east of the town of Cokeville is underlain by areally extensive terrace deposits that are 200 ft or more in thickness (Lines and Glass, 1975). Areally extensive terrace deposits also are present in the Hilliard Flat area.

Colluvium is composed of unconsolidated and poorly sorted, angular debris mantling major stream valley sides, tributary stream valleys, and hill slopes. Locally, colluvium includes soil and gravel. Thickness varies, but colluvium commonly is 3 ft or more thick in the Kemmerer and Evanston areas (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Colluvium commonly is included (mapped) with other types of unconsolidated deposits such as alluvium (mapped as alluvium) on geologic maps of the area.

Quaternary alluvial fan deposits are common along the Bear River valley in the area located to the north of the town of Cokeville (WSGS Plate 1; Plate 3). The alluvial fan deposits are composed of unconsolidated, poorly sorted, alluvium and colluvium forming well defined fan-shaped deposits at mouths of tributary valleys. Berry (1955) indicated that the deposits were not as well sorted and were more angular than alluvium, indicating that the deposits were locally derived. Thickness varies but alluvial fan deposits commonly are 30 ft or more in thickness in the Kemmerer and Evanston areas (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The upper parts of the alluvial fans generally are well drained of groundwater, and groundwater is not present except at deeper depths within the proximal and medial parts of the fan deposits and closer to local stream channels (Clarey, 2011). Berry (1955) stated that the deposits were not likely to yield as much water as alluvium.

Quaternary loess deposits, also defined as eolian deposits in some publications (for example, Robinove and Berry, 1963, Table 1), consist of wind-blown, light brown, unconsolidated silt and fine-grained sand (Rubey et al., 1980; M'Gonigle and Dover, 1992). Robinove and Berry (1963, Table 1) reported thicknesses of as much as 10 ft or more in the Bear River valley, but deposits reportedly are as much as 150-ft thick in the Cokeville area (Rubey et al., 1980). The deposits locally form dunes about 10-ft thick in the Kemmerer area (M'Gonigle and Dover, 1992). The loess deposits commonly are mapped with other Quaternary unconsolidated deposits on geologic maps, including on **Plate 3.** In most of the Bear River Basin, these deposits are topographically high and drained of water (Robinove and Berry, 1963); however, they may "serve as catchment areas for precipitation" (Robinove and Berry, 1963, p. V21), and presumably provide recharge to underlying deposits. Where saturated, the deposits are likely to yield very small volumes of groundwater because of predominantly fine grain size (Robinove and Berry, 1963, Table 1).

Quaternary landslide deposits are composed of masses of older bedrock that have moved downward and are partly broken and disaggregated (Rubey et al., 1980). The landslide deposits are composed of slumps, landslides, and mudflows of soil, sediment, and rock debris, including unconsolidated, angular rock debris and large slump blocks that have moved downslope in mass under gravity. The deposits are 30 ft or more in thickness in the Kemmerer and Evanston areas (Dover and M'Gonigle, 1993). No wells completed in Quaternary landslide deposits in the Bear River Basin were located/inventoried as part of this study, but springs issue from the deposits in some areas (discharge for one spring listed on **Plate 4**). Robinove and Berry (1963, Table 1) speculated that Quaternary landslide deposits (identified as "slope wash, and rock debris") might be capable of yielding small quantities of water sufficient for domestic and stock use. Lines and Glass (1975, Sheet 1) noted that landslide deposits (identified as "rock debris") were not a potential source of water because of poor sediment sorting and small saturated thickness.

Quaternary (Pleistocene) glacial deposits consist of unconsolidated, unsorted to poorly sorted mixtures of rock fragments (including boulders), silt, and clay. Deposits include tills and moraines of former mountain glaciers. Thickness varies but glacial deposits can be as much as 200-ft thick in the Cokeville area (Rubey et al., 1980). Moraine deposits may be 230 ft or more in thickness locally in the Evanston area (Dover and M'Gonigle, 1993); older moraine deposits in the same area may be 130 ft or more in thickness. Groundwater in the glacial deposits may be available for development where the unit is sufficiently water saturated, permeable, and in areas where a high content of sand and gravel is present in the deposits (Clarey, 2011).

Groundwater in Quaternary unconsolidated-deposit aquifers in the Bear River Basin typically is unconfined (water-table conditions predominate). Quaternary unconsolidated-deposit aquifers are small in areal extent and primarily occur in alluvium (commonly associated with colluvium and referred to herein as "alluvial aquifers") or terrace deposits (sometimes referred to as "terrace gravel deposits" or "terrace, gravel, and fan deposits" in some reports and referred to herein as "terrace-deposit aquifers") along valleys and in adjacent upland areas, and along streams and rivers in the Bear River Basin (**Pls. 3** and **5**). Consequently, most wells completed in Quaternary unconsolidated-deposit aquifers are located close to and along streams and rivers, primarily the Bear River. Along the flood plains, wells completed in alluvium are in hydraulic connection with streams and rivers, most notably along parts of the Bear River valley (Berry, 1955; Glover, 1990). Wells completed in the terrace deposits in the southern Bear River valley may "fail during relatively dry years because of the small saturated thickness" (Lines and Glass, 1975, Sheet 1). Although limited in the areal extent, Quaternary unconsolidated-deposit aquifers (primarily alluvial aquifers) are the most used aquifers in the Overthrust Belt, including the Bear River Basin (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; Clarey, 2011).

Hydrogeologic data describing the Quaternary unconsolidated deposits in the Bear River Basin (alluvial aquifers, terrace-deposit aquifers, and landslide deposits), including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Well yields in Quaternary alluvial and terrace-deposit aquifers in the Bear River Basin (**Pl. 4**) are directly related to the size and sorting of materials composing the deposits, as well as the saturated thickness of the deposits. In places, well yields are high because of large saturated thicknesses and very coarse deposits. Yields from wells completed in Quaternary alluvial aquifers ranged from 0.25 to 1,930 gallons per minute (gal/min), with a median of 20 gal/min (**Pl. 4**). Specific capacities for wells completed in Quaternary alluvial aquifers ranged from 0.3 to 150 gallons per minute per foot of drawdown [(gal/min)/ft] with a median of 18 (gal/min)/ft (**Pl. 4**). Estimates of transmissivity for wells completed in Quaternary alluvial aquifers ranged from 30.8 to 71,500 feet squared per day (ft^2/day), with a median of 4,260 ft^2/d (**Pl. 4**). One estimate of hydraulic conductivity for a well completed in a Quaternary alluvial aquifer was inventoried as part of this study and was 670 feet per day (ft/d) (**Pl. 4**). Of the remaining inventoried sites for Quaternary unconsolidated deposits, one well yield (14 gal/min) was inventoried for terrace-deposit aquifers, one well yield (20 gal/min) was inventoried for a spring issuing from terrace-deposit aquifers, and one discharge (2,000 gal/min) was inventoried for a spring issuing from landslide deposits (**Pl. 4**).

Hydraulic connection between the Bear River alluvial aquifer (stream-aquifer system composed of hydraulically connected Bear River and Quaternary-age alluvium) and underlying hydrogeologic units composed of bedrock in the Cokeville and Evanston areas (**Pls. 3** and **5**) was evaluated by Glover (1990). In the Cokeville area, the investigator determined that underlying aquifers in the Wasatch Formation, Nugget Sandstone, and Wells Formation (see **Pl. 6**) were not hydraulically connected to the Bear River alluvial aquifer. In contrast, the investigator determined that the Wasatch aquifer (composed of the Wasatch Formation) was in hydraulic connection with the Bear River alluvial aquifer in much of the Evanston area. Lower permeability rocks located on the upthrown sides of normal faults locally have isolated the Wasatch aquifer from the Bear River alluvial aquifer in the Evanston area.

In parts of the eastern Bear River valley in Uinta County, groundwater-quality from some wells completed in the alluvium is reportedly "poor" (TriHydro Corporation, 2000, p. 2-2). The investigators (TriHydro Corporation, 2000, p. 2-2) speculated that the poor water quality is "most likely due to the close proximity of the deeper normal fault system along the eastern Bear River valley," and that "this deeper normal fault system may allow deeper groundwaters of higher mineral content and containing sulfides and/or sulfates to migrate upwards into the overlying Bear River alluvium" in the area. Similarly, Sunrise Engineering (1997) noted groundwater-quality problems from some wells completed in the Bear River alluvial aquifer in the city of Evanston. The investigators (Sunrise Engineering, 1997) noted that wells on the south side of the Bear River "have historically produced good quality water while wells on the north side of the river have historically been plagued by sulfur and other problems."

The areal extent of Quaternary unconsolidated-deposit aquifers coincides with most of the population and irrigated cropland in the Bear River Basin, making these aquifers particularly susceptible to contamination from anthropogenic activities. Areas where alluvial deposits are relatively thin (30 ft or less) and depth to groundwater is shallow (10 ft or less) are particularly susceptible to effects from overlying anthropogenic activities (Hamerlinck and Arneson, 1998). Evidence of groundwater contamination of Quaternary unconsolidated-deposit aquifers by anthropogenic activities in the Bear River Basin has been indicated by detection of elevated nitrate concentrations and by detection of pesticides (Eddy-Miller et al., 1996, Table 14; Eddy-Miller and Norris, 2000; Eddy-Miller and Remley, 2004).

Recharge, discharge, and groundwater movement

Recharge to Quaternary unconsolidated-deposit aquifers is not only from direct infiltration of precipitation (snow and rain) and ephemeral and perennial streamflow losses, but also from infiltration of diverted surface water through unlined irrigation canals and ditches, from water applied to fields, and discharge from underlying bedrock aquifers (Berry, 1955; Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; Glover, 1990; Eddy-Miller et al., 1996; Sunrise Engineering, 1997). Some of the recharge to alluvium from streams may occur as water infiltrates the heads of alluvial fans along the margins of the Bear River valley (Lines and Glass, 1975, Sheet 1). In irrigated areas, water levels in the Quaternary unconsolidated-deposit aquifers in the Bear River Basin change in response to recharge from seasonal application of diverted surface water used to irrigate crops (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Glover, 1990). Water levels are the highest (shallowest) during the growing season when irrigation water recharges the aquifers, and water levels are the lowest (deepest) after irrigation has ceased during the winter when water is discharged from the aquifers.

In the alluvial aquifer along the Bear River in the Cokeville area (referred to herein as the Bear River alluvial aquifer; areal extent shown on **Plate 6** as Quaternary alluvium and colluvium and Quaternary terrace, gravel, and fan deposits), water levels vary in response to changing seasonal recharge, primarily from irrigation diversions (for example, Glover, 1990, Figure 10). During the irrigation season, water levels in the aquifer typically begin to rise during the spring and early summer months after irrigation by diverted surface water begins, and gradually decrease during the late summer months after the quantity of diverted water begins to decrease and irrigation ceases. Water levels in the aquifer from October through March are relatively stable, and reflect steady-state or "near steady-state" conditions (Glover, 1990, p. 19).

Discharge from Quaternary unconsolidated-deposit aquifers occurs by evapotranspiration, gaining streams, seeps, drains, spring flows, and withdrawals from wells (Berry, 1955; Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; Glover, 1990; Eddy-Miller et al., 1996; Sunrise Engineering, 1997). Evapotranspiration from Quaternary unconsolidated-deposit aquifers is likely to be highest in the summer in areas where the water table in the Bear River Basin is at or near land surface (Robinove and Berry, 1963; Glover, 1990, p. 28).

The direction of horizontal groundwater flow in the Bear River alluvial aquifer, in the Cokeville area is shown on a steady-state potentiometric-surface map constructed by Glover (1990, Figure 9; reproduced herein as **Pl. 6**). Areas of Bear River streamflow loss to and gain from the alluvial aquifer also can be visually identified on the map; these losses and gains also were quantified by measuring streamflow at paired streamflow-gaging stations (using monthly mean discharge) during the months of November and December when diversions for irrigation were not in operation and sources of possible error were minimized (Glover, 1990, Table 1). Potentiometric contours in the immediate vicinity of streams can indicate gaining streams by pointing in an upstream direction (potentiometric surface above water in the stream) or losing streams by pointing in a downstream direction (potentiometric surface below water in the stream). The streamflow loss/gain study indicated the generally north-flowing Bear River gained about 36 cubic feet per second (ft^3/s) from the alluvial aquifer in the study area (Glover, 1990, Table 1). Recharge to the alluvial aquifer from the Smiths Fork and associated tributaries, tributaries to the Bear River, is visually notable (**Pl. 6**), and the Smiths Fork lost about 19.4 ft^3/s to the aquifer (Glover, 1990).

In other areas along the Bear River valley in the Bear River Basin, groundwater flow in the alluvial aquifers generally is towards the center of the river or stream valley or generally in a downstream direction paralleling the direction of the surface water flow in the river or streams, including as underflow parallel to streamflow (Berry, 1955; Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; Glover, 1990). In terrace-deposit aquifers, the direction of groundwater flow generally is toward the principal surface drainage.

Little information is available to evaluate the potential for vertical groundwater flow in Quaternary unconsolidated-deposit aquifers in the Bear River Basin; however, Glover (1990, p. 18) found two wells completed in the Bear River alluvial aquifer in the Cokeville area located closely together (about 30 ft) and completed at different depths (one well completed about 200-ft deep and the other completed about 400-ft deep). Static water levels were essentially the same, indicating that vertical gradients in the Bear River alluvial aquifer were small; however, it is unknown how representative this small vertical gradient is for unconsolidated-deposit aquifers at other locations in the Bear River Basin.

Cokeville area groundwater-flow model

Glover (1990) constructed a groundwater-flow model of the Bear River alluvial aquifer in the Cokeville area. In the study, the alluvial aquifer was defined as an unconfined aquifer composed of saturated Quaternary unconsolidated deposits (primarily alluvium, but included some hydraulically connected terrace deposits) along the Bear River and associated tributaries underlain by bedrock with much lower permeability. Areal extent of the Bear River alluvial aquifer model matches that of the potentiometric-surface map reproduced herein as **Plate 6** because the map was constructed as part of the same study.

The Bear River alluvial aquifer was simulated by Glover (1990) using the finite-element model of Glover (1988). The groundwater-flow model was constructed to improve estimates of aquifer properties and to evaluate the effects of pumpage from area wells completed in the Bear River alluvial aquifer, including large-capacity irrigation wells, on streamflow of the Bear River and associated tributaries. Hydrologic data collected as part of the study and from previous studies were used to construct and calibrate the model under steady-state conditions. Study emphasis was placed on understanding the effects of current and predicted groundwater withdrawals on streamflow.

A steady-state groundwater budget was constructed from collected data and from successful model simulations (Glover, 1990, Table 7). The simulated water budget indicated that the Bear River gained about 36.8 ft^3/s from the alluvial aquifer, and that the tributaries lost about 21.2 ft^3/s to the alluvial aquifer through stream leakage. Underflow from the upstream model boundary was estimated at about 18.5 ft^3/s, and underflow across the downstream model boundary was estimated to be about 17.8 ft^3/s. Underflow through alluvium along small tributaries of the Bear River was estimated to be an additional 14.9 ft^3/s.

Steady-state and transient simulations were used to refine aquifer property estimates and to determine the distribution of groundwater recharge. The 1980 and 1981 irrigation seasons were used for calibration of transient simulations. Although steady-state groundwater recharge was primarily from stream leakage and underflow, seasonal recharge during the irrigation season occurred primarily in areas with large amounts of irrigation by diverted surface water. Calculated groundwater budgets for the 1980 and 1981 irrigation seasons indicated that the main source of recharge to the aquifer during the irrigation season was from flood-irrigated fields, whereas the main discharge area was to the Bear River. The investigator also concluded that groundwater pumpage from the alluvial aquifer was small compared with other groundwater discharge components.

The effects of pumping on streamflow during years of average, greater-than-average, or less-than-average streamflow also were evaluated. The effects of pumping on streamflow during years of average and greater-than-average streamflow could not be simulated because groundwater withdrawal rates were very small, and the effects of pumping were less than the accuracy of streamflow measurements.

The effects of pumping on streamflow were simulated for a year of less-than-average flow (1977). For 1977, the simulation indicated that streamflow was reduced a maximum of about 3.4 ft^3/s during August, within the period when maximum pumping typically occurs (July and August). The simulation indicated that by the start of the next irrigation season, the effects of pumping during the previous year would be reduced to less than 0.5 ft^3/s. Lastly, Glover (1990) estimated that about 84 percent of the water pumped by wells was derived from water that otherwise would have discharged to the Bear River, and 16 percent from water that otherwise would have been consumed by phreatophytes.

Evanston area streamflow depletion study

Glover (1990) also attempted to construct a finite-element groundwater flow model for the Bear River alluvial aquifer in the Evanston area. Available hydrogeologic data was insufficient for construction of a groundwater-flow model for the area. Consequently, the investigator used an analytical streamflow-depletion method (Jenkins, 1968a, 1968b) to evaluate the effects on streamflow of the Bear River in the Evanston area from pumpage of supply wells in Evanston that were completed in the Bear River alluvial aquifer and underlying Wasatch aquifer. Use of the analytical streamflow-depletion method indicated that the largest reduction in streamflow occurred during the pumping season, and that streamflow was affected after the pumpage was ended. Most of the reduction in streamflow was due to pumping from the Bear River alluvial aquifer, not the Wasatch aquifer. Use of the analytical streamflow-depletion method also indicated that pumping from the Wasatch aquifer was likely to affect streamflow only after several months.

Chemical characteristics

The chemical characteristics of groundwater from Quaternary alluvial aquifers, terrace-deposit aquifers, and landslide deposits in the Bear River Basin are evaluated in this section of the report.

7.2.1.1 Quaternary alluvial aquifers

The chemical composition of groundwater in Quaternary alluvial aquifers in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from as many as 39 wells. Summary statistics calculated for available constituents are listed in **Appendix E**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G**, **Diagram A**). TDS concentrations were variable and indicated that most waters were fresh (90 percent of samples) and remaining waters were slightly saline (**Appendix E; Appendix G, Diagram A**). TDS concentrations ranged from 212 to 1,770 mg/L, with a median of 458 mg/L.

Concentrations of some properties and constituents in water from Quaternary alluvial aquifers in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of some constituents exceeded health-based standards: mercury (one of three samples exceeded the USEPA MCL), nitrate plus nitrite (one of 18 samples exceeded the MCL of 10 mg/L), and nitrate (one of 26 samples exceeded the MCL of 10 mg/L). Concentrations of several properties and constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (11 of 29 samples exceeded the SMCL of 500 mg/L), iron (two of 14 samples exceeded the SMCL of 300 μg/L), sulfate (four of 29 samples exceeded the SMCL of 250 mg/L), manganese (one of 11 samples exceeded the SMCL of 50 μg/L), and chloride (two of 29 samples exceeded the SMCL of 250 mg/L).

Concentrations of some constituents exceeded State of Wyoming standards for agricultural use in the Bear River Basin. Constituents in environmental water samples that had concentrations greater than agricultural-use standards were sulfate (5 of 29 samples exceeded the WDEQ Class II standard of 200 mg/L), chloride (4 of 29 samples exceeded the WDEQ Class II standard of 100 mg/L), and iron (1 of 14 samples exceeded the WDEQ Class II standard of 5,000 μg/L). Mercury was the only constituent measured in water from an alluvial aquifer at a concentration that exceeded applicable State of Wyoming livestock water-quality standards (the one uncensored sample exceeded the WDEQ Class III standard of 0.05 μg/L).

7.2.1.2 Quaternary terrace-deposit aquifers

The chemical composition of groundwater in Quaternary terrace-deposit aquifers in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from nine wells and one spring. Summary statistics calculated for available constituents are listed in **Appendix E**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G**, **Diagram B**). TDS concentrations were variable and indicated that most waters were fresh (90 percent of samples) and remaining waters were slightly saline (**Appendix E**; **Appendix G**, **Diagram B**). TDS concentrations ranged from 297 to 1,030 mg/L, with a median of 476 mg/L. Concentrations of some properties and constituents in water from Quaternary terrace-deposit aquifers in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of nitrate exceeded health-based standards (USEPA MCLs and HALs): two of eight samples exceeded the MCL of 10 mg/L. Concentrations of several properties and constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (five of 10 samples exceeded the SMCL of 500 mg/L), manganese (one of two samples exceeded the SMCL of 50 μg/L), sulfate (one of 10 samples exceeded the SMCL of 250 mg/L), and pH (one of 10 samples above upper SMCL limit of 8.5).

Concentrations of some properties and constituents in water from Quaternary terrace-deposit aquifers exceeded State of Wyoming standards for agricultural and livestock use in the Bear River Basin. Constituents in environmental water samples that had concentrations greater than agricultural-use standards were chloride (two of 10 samples exceeded the WDEQ Class II standard of 100 mg/L) and sulfate (one of 10 samples exceeded the WDEQ Class II standard of 200 mg/L). One property (pH) had values outside the range for livestock-use standards (one of 10 samples above upper WDEQ Class III limit of 8.5).

7.2.1.3 Aquifers in Quaternary landslide deposits

The chemical composition of groundwater in Quaternary landslide deposits in the Bear River Basin was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram C**). The TDS concentration (187 mg/L) indicates that the water from the spring was fresh.

On the basis of the properties and constituents analyzed, the quality of water from the spring was suitable for most uses. No properties or constituents in water were measured at concentrations that approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.2 Tertiary hydrogeologic units

Tertiary hydrogeologic units are described in this section of the report. Although composed of rocks of both Paleocene and Late Cretaceous age, the Evanston Formation is included with Tertiary hydrogeologic units for descriptive purposes. Most wells completed in Tertiary hydrogeologic units in the Bear River Basin are for stock or domestic use, but a few are for public-supply or irrigation use. Tertiary formations comprising the hydrogeologic units are composed of nonmarine (continental) mixtures of many different lithologies, including shale, mudstone, siltstone, sandstone, conglomerate, lacustrine limestone, and volcanic tuff. These Tertiary formations commonly intertongue or interfinger with other formations, are relatively flat-lying, and unconformably overlie eroded and older formations.

7.2.2.1 Salt Lake aquifer

The Pliocene and Miocene Salt Lake Formation comprises the Salt Lake aquifer in the Bear River Basin (**Pl. 5**). The Salt Lake Formation consists of pale reddish gray conglomerate, sandstone, siltstone, clay, and white volcanic ash (Rubey, 1973; Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; Ahern et al., 1981, Table IV-1). Reported thickness of the Salt Lake Formation in the Overthrust Belt ranges from 0 to 1,000 ft (Lines and Glass, 1975, Sheet 1). The

Salt Lake Formation is present in some of the structurally down-dropped valley floors within the Overthrust Belt.

The Salt Lake Formation was classified as a major aquifer by Ahern et al. (1981) and in the Statewide Framework Water Plan (WWC Engineering et al., 2007), and that definition was tentatively retained herein (**Pl. 5**). Ahern et al. (1981, Table IV-1) reported a spring discharge of 8,000 gal/min for the Salt Lake aquifer in the Overthrust Belt. No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin as part of this study.

7.2.2.2 Bishop Conglomerate

The Oligocene Bishop Conglomerate occurs only in very limited areas in the southeastern part of the Bear River Basin (**Pl. 3**) as isolated caps believed to be remnants of a formerly more extensive depositional sheet that capped a pediment surface graded to the Uinta Mountains (Dover and M'Gonigle, 1993). The Bishop Conglomerate consists of well-rounded cobbles and boulders of quartzite, limestone, and metamorphic rocks (Bradley, 1964, p. 55; Lines and Glass, 1975, Sheet 1; Dover and M'Gonigle, 1993). Reported thickness of the Bishop Conglomerate ranges from 0 to 200 ft in the Overthrust Belt and adjacent areas (Lines and Glass, 1975, Sheet 1).

Little information is available for describing and assessing the hydrogeologic characteristics of the Bishop Conglomerate. No wells or springs associated with the Bishop Conglomerate in the Bear River Basin were inventoried as part of this study. In the Green River, Great Divide, and Washakie Basins to the east, Welder (1968, Sheet 2) and Welder and McGreevy (1966, Sheet 2) reported that the potential for groundwater development in the Bishop Conglomerate is not known, but is likely poor to fair. Welder (1968, Sheet 2) indicated that the deposits in the Green River Basin typically are topographically high and, consequently, probably well-drained in most areas. Bartos and Hallberg (2010) inventoried five measurements of spring discharge and one measurement of well yield for the Bishop Conglomerate in the Green River Basin (located east of the Bear River Basin). The five reported spring discharges ranged from 5 to 200 gal/min with a median discharge of 15 gal/min. The one measurement of well yield was 42 gal/min.

7.2.2.3 Fowkes aquifer

The physical and chemical characteristics of the Fowkes aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Fowkes aquifer is composed of the Eocene Fowkes Formation in the Bear River Basin (**Pl. 5**). The Fowkes Formation consists of a basal conglomerate overlain by tuffaceous mudstone, tuffaceous, calcareous sandstone, and rhyolitic ash. Thickness of the formation ranges from 0 to 2,600 ft (Oriel and Platt, 1980; Ahern et al., 1981, Table IV-1). The Fowkes Formation is divided into the Sillem, Bulldog Hollow, and Gooseberry Members (Oriel and Tracey, 1970; Lines and Glass, 1975) (individual members not shown on **Plate 5**). The Sillem Member is composed of a basal conglomerate overlain by mudstone and claystone interbedded with sandstone and algal limestone, and ranges from 100 to 400 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Bulldog Hollow Member is composed primarily of green and white tuffaceous mudstone and green to buff and brown tuffaceous, calcareous sandstone, and ranges from 200 to 2,000 ft in thickness (Oriel and Tracey, 1970; Nelson, 1973; Lines and Glass, 1975, Sheet 1; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Gooseberry Member is composed primarily of light gray to white conglomerate and calcareous rhyolitic ash, and is more than 200-ft thick (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992).

The Fowkes Formation is considered to be an aquifer in the Overthrust Belt by previous investigators (Robinove and Berry, 1963, Plate 1; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; TriHydro Corporation, 2002, 2003) (**Pl. 5**).

Robinove and Berry (1963, Plate 1) reported that the Fowkes Formation in the Bear River valley was capable of yielding small quantities of groundwater. Lines and Glass (1975, Sheet 1) noted that tuffaceous sandstones in the Fowkes Formation are probably capable of yielding small quantities of water to wells. Ahern et al. (1981, Figure II-7) classified the formation as a major aquifer in the Overthrust Belt (**Pl. 5**) and noted that both springs issuing from and wells completed in the formation locally yielded water. In the Wyoming Water Framework Plan, the Fowkes Formation was classified as a major sandstone aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

Hydrogeologic data describing the Fowkes aquifer in the Bear River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Spring discharge for three inventoried measurements ranged from 2 to 125 gal/min with a median of 5 gal/min (**Pl. 4**). Four measurements of well yield were inventoried for the Fowkes aquifer, and well yields ranged from 100 to 530 gal/min, with a median of 184 gal/min. One measurement of specific capacity was inventoried and was 0.63 (gal/min)/ft.

TriHydro Corporation (2002) described a 403-ft deep irrigation well (identified as the Thompson #4 and located in the SE¼, NE¼, section 12, T24N, R119W of Lincoln County, Wyoming) completed in the Fowkes Formation. The well reportedly yields as much as 1,000 gal/min from the Gooseberry Member of the Fowkes Formation that underlies Quaternary terrace deposits of the Sublette Flat area. The investigators reported that some groundwater from the overlying Quaternary terrace deposits moves downward and provides recharge to the underlying Fowkes aquifer.

TriHydro Corporation (2003) described two wells (identified as PCC#1 or South Martin well and PCC#2 or North Martin well) completed in the Fowkes aquifer with reported total depths of 320 and 350 ft, respectively, located near the mouth of Fowkes Canyon (located in the SW¼, NE¼, section 32, T17N, R120W, Uinta County). The water-bearing zones were identified as being composed of sandstone and conglomeratic sandstone from 240 to 320 ft below land surface. Measured static water levels were about 20 to 21 ft below land surface. A short duration (6 hour) constant-rate discharge aquifer test was conducted by pumping the South Martin well and using the North Martin well as an observation well. Based on the aquifer test, the following physical properties of the Fowkes aquifer were estimated: transmissivity of about 147 ft^2/d [1,100 gallons per day per foot (gpd/ft)] using discharge data, and about 161 ft^2/d [1,200 gpd/ft] using recovery data; hydraulic conductivity of about 3.8 ft/d [28.2 gallons per day per square foot (gpd/ft^2)]; specific capacity of 0.63 (gal/min)/ft; and a storage coefficient of 0.00024 (all values are shown individually or included as part of summary ranges provided on **Plate 4**).

Chemical characteristics

The chemical composition of groundwater for the Fowkes aquifer was characterized and the quality evaluated on the basis of environmental water samples from five wells completed in and three springs issuing from the Fowkes aquifer in the Bear River Basin. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram D**). TDS concentrations were variable and indicated that most waters were fresh (83 percent of samples) and remaining waters were slightly saline (**Appendix E**; **Appendix G, Diagram D**). TDS concentrations ranged from 248 to 1,570 mg/L, with a median of 537 mg/L.

Concentrations of a few properties and constituents in water from the Fowkes aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison of concentrations with health-based standards (USEPA MCLs and HALs), all water was suitable for domestic use. Concentrations of one property and one constituent exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (three of six samples exceeded the SMCL of 500 mg/L) and chloride (one of six samples exceeded the SMCL of 250 mg/L).Chloride was the only constituent measured at concentrations that exceeded State of Wyoming agriculture water-quality standards: (3 of 6 samples exceeded the WDEQ Class II standard of 100 mg/L). No properties or constituents had measurements or concentrations that approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.2.2.4 Conglomerate of Sublette Range

The Eocene and Paleocene Conglomerate of Sublette Range (Love et al., 1993) (**Pl. 5**) primarily consists of white, pink, dark gray, well-rounded, poorly sorted, pebble to boulder gravel composed of quartzite and gray chert mixed with silt and sand. Age and stratigraphic relation to the Evanston and Wasatch Formations is uncertain (Love et al., 1993). The formation may be as much as 600-ft thick in the Cokeville area (Oriel and Platt, 1980; Rubey et al., 1980; Salat, 1989; Salat and Steidtmann, 1991). The Conglomerate of Sublette Range is exposed only in several small outcrop areas in the Sublette Range, northwest of the town of Cokeville (T25N–T26N, R118W–R119W, Lincoln County, Wyoming). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit.

7.2.2.5 Green River aquifer and confining unit

The physical and chemical characteristics of the Green River aquifer and confining unit in the Bear River Basin are described in this section of the report.

Physical characteristics

The Green River aquifer and confining unit is composed of the Eocene Green River Formation in the Bear River Basin (**Pl. 5**). The Green River Formation in the Bear River Basin is divided into the Fossil Butte and Angelo Members (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993) (individual members not shown on **Plate 5**).

The Fossil Butte Member of the Green River Formation consists of light gray, tan, and light tan limestone, calcareous siltstone, marlstone, and shale; brown, laminated carbonaceous shale; and very thinly laminated oil shale. Tuffaceous interbeds are common and some calcareous beds rich in fossil fish are present, in addition to algal, gastropodal, and ostracodal limestone beds, mainly along the margins of the basin between Sillem Ridge and the Absaroka thrust fault. The Fossil Butte Member of the Green River Formation 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. Thickness of the Fossil Butte Member ranges from 200 to 325 ft (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

The Angelo Member of the Green River Formation consists of light gray to light tan, white-weathering, siliceous limestone, calcareous shale, and siltstone. The unit also includes minor interbedded tan laminated limestone, brown algal limestone, marlstone, sandstone, and brown organic shale. Calcareous beds in the Angelo Member of the Green River Formation interfinger with sandstone and shale beds of the Wasatch Formation to the south and southwest. Thickness of the Angelo Member ranges from 0 to 200 ft (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Little information is available describing the hydrogeologic characteristics of the Green River Formation in the Overthrust Belt, including the Bear River Basin. However, extensive study of the Green River Formation in the adjacent Green River Basin provides some insight into hydrogeologic properties of the unit. Hydrogeologic characteristics of the Green River Formation in the Green River Basin vary substantially, primarily because of changes in lithology. Consequently, the Green River Formation is classified as an aquifer, confining unit, or both, depending upon lithologic characteristics in the area of the Green River Basin examined (Ahern et al., 1981; Martin, 1996; Naftz, 1996; Glover et al., 1998; Bartos and Hallberg, 2010). Because similar differences in Green River Formation lithology also occur in the Bear River Basin, the lithostratigraphic unit is classified as an aquifer and confining unit herein (**Pl. 5**).

Few hydrogeologic data were available describing the Green River aquifer and confining unit in the Bear River Basin. One measurement of discharge from a spring issuing from the Angelo Member of the Green River was inventoried and was 1 gal/min (**Pl. 4**). Seven measurements of discharge for springs issuing from the Fossil Butte Member of the Green River Formation were inventoried and ranged from 5 to 200 gal/min, with a median of 14 gal/min.

Chemical characteristics
The chemical composition of groundwater in the Green River aquifer and confining unit in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from eight springs—one spring issuing from the Angelo Member and seven springs issuing from the Fossil Butte Member. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on trilinear diagrams (**Appendix G**, **Diagram E** and **Diagram F** for the Angelo and Fossil Butte Members, respectively). TDS concentrations indicated that waters were fresh (**Appendix E**; **Appendix G, Diagram E** and **Diagram F**). The TDS concentration in the Angelo Member was 244 mg/L. TDS concentrations in the Fossil Butte Member ranged from 333 to 908 mg/L, with a median of 751 mg/L.

Concentrations of few properties and constituents in water from the Green River aquifer and confining unit in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison of concentrations with health-based standards (USEPA MCLs and HALs), all water was suitable for domestic use. On the basis of the few properties and constituents analyzed for in the Angelo Member spring sample, waters were likely suitable for most uses as no properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Concentrations of one property and one constituent exceeded aesthetic standards (USEPA SMCLs) for domestic use of the Fossil Butte Member: TDS (five of six samples exceeded the SMCL of 500 mg/L) and sulfate (five of six samples exceeded the SMCL of 250 mg/L). Concentrations of one constituent exceeded State of Wyoming agriculture water-quality standards: sulfate (five of six samples exceeded the WDEQ Class II standard of 200 mg/L). No properties or constituents had concentrations that approached or exceeded applicable State of Wyoming livestock water-quality standards in samples from the Fossil Butte Member.

7.2.2.6 Wasatch aquifer

The physical and chemical characteristics of the Wasatch aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics
The Eocene Wasatch Formation comprises the Wasatch aquifer in the Bear River Basin (**Pl. 5**). Currently (2013) used as a source of water for domestic, stock, industrial, and public-supply purposes, the Wasatch aquifer is the second most utilized aquifer in the Bear River Basin, although withdrawals are much smaller than withdrawals from the Quaternary unconsolidated-deposit aquifers.

The Wasatch Formation consists of variegated mudstone, claystone, siltstone, shale, sandstone, conglomeratic sandstone, and conglomerate. It is a thick sequence of nonmarine sedimentary rock with named members of the formation (discussed below but individual members not shown on **Plate 5**) in some areas. The Wasatch Formation and various members interfinger eastward with the members of the Green River Formation in the Fossil Basin and Green River Basin.

The Wasatch Formation in the Bear River Basin is divided into a basal conglomerate, a lower unnamed member, the main body of the formation, and the Bullpen and Tunp Members

(Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The basal conglomerate is a lenticular conglomerate of sandstone pebbles and cobbles, and ranges from 0 to 300 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992). The lower unnamed member is composed predominantly of drab-colored mudstone and sandstone, and ranges from 0 to 300 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992). The main body is composed predominantly of red, purple, and tan mudstone, with some sandstone, and ranges from 1,500 to 2,000 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Bullpen Member is composed predominantly of red and salmon colored mudstone, and gray and brown mudstone, and ranges from 0 to 400 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; M'Gonigle and Dover, 1992). The Tunp Member is composed of conglomeratic mudstone and diamictite, and ranges from 200 to 500 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; Hurst, 1984; Hurst and Steidtmann, 1986; M'Gonigle and Dover, 1992). Parts of the Wasatch Formation are composed of diamictite, especially the Tunp Member.

The Wasatch Formation is considered to be an aquifer in the Overthrust Belt by previous investigators (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981; Forsgren Associates, Inc., 2000; TriHydro Corporation, 2000, 2003) (**Pl. 5**). In the Wyoming Water Framework Plan, the Wasatch Formation is classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). The Wasatch aquifer is an important aquifer in the adjacent Green River Basin to the east (Ahern et al., 1981; Martin, 1996; Naftz, 1996; Glover et al., 1998; Bartos and Hallberg, 2010). Ahern et al. (1981, Figure II-7) classified the formation as a major aquifer in the Overthrust Belt (**Pl. 5**) and noted that both springs issuing from and wells completed in the formation locally yielded water. The Wasatch Formation has been defined as a "productive aquifer" in the Deer Mountain Subdivision area near the town of Bear River in the Bear River Basin (Forsgren Associates, Inc., 2000, p. 3-2; TriHydro Corporation, 2000, p. 3-2).

Although little information was available at the time of their studies, Berry (1955) and Robinove and Berry (1963) speculated that small to moderate yields sufficient for domestic and stock use were likely from permeable beds in the Wasatch Formation. Lines and Glass (1975, Sheet 1) noted that conglomeratic sandstones and conglomerates in the Wasatch Formation likely were capable of yielding "moderate to large quantities" of water to wells. In addition, the investigators (Lines and Glass, 1975, Sheet 1) noted that fine-grained sandstones in the Wasatch Formation were capable of yielding "small to moderate" quantities of water, but that well yields were likely "greatly dependent" on saturated sandstone bed thickness. Similarly, Ahern et al. (1981) noted that permeable sandstones, conglomeratic sandstones, and conglomerates of the Wasatch Formation could yield moderate to large quantities of water to wells. Sandstones, conglomeratic sandstones, and conglomerates composing the Wasatch aquifer primarily are under confined conditions, except in outcrop areas where unconfined (water-table) conditions are present.

Hydrogeologic data describing the Wasatch aquifer in the Bear River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Measured discharges of springs issuing from the Wasatch aquifer ranged from 0.5 to 75 gal/min with a median of 5 gal/min (**Pl. 4**).Yields from wells completed in the Wasatch aquifer ranged from 0.1 to 1,300 gal/min, with a median of 27.5 gal/min (**Pl. 4**). Specific capacities for wells completed in the Wasatch aquifer ranged from 0.2 to 14 (gal/min)/ft with a median of 0.7 (gal/min)/ft (**Pl. 4**). Estimates of transmissivity for wells completed in the Wasatch aquifer ranged from 26.8 to 4,020 ft^2/d, with a median of 92.3 ft^2/d (**Pl. 4**). One estimate of hydraulic conductivity for a well completed in the Wasatch was inventoried and was 4.3 ft/d (**Pl. 4**).

Additional insight into Wasatch aquifer hydraulic characteristics in the Bear River Basin is provided by one recent study with a well-documented aquifer test (TriHydro Corporation, 2003). One well in the Deer Mountain area near the town of Bear River (Deer Mountain #6 Well, located in the SE¼, SW¼, section 2, T16N, R121W, Uinta County) was completed to a depth of about 544 ft below land surface in the Wasatch aquifer. Two primary water-bearing zones consisting of sandstone and conglomeratic sandstone were screened from about 272 to 313 ft below land surface and from about 502 to 523 ft below land surface. The static water level was measured at about 47 ft below land surface. Three step-drawdown discharge tests were conducted by pumping the Deer Mountain #6 well at rates of 75, 100, and 125 gal/min to help determine an optimal pumping rate for a constant-rate discharge aquifer test. Subsequently, a 5-day, single-well, constant-rate discharge aquifer test was conducted by pumping the Deer Mountain #6 well at a rate of 100 gal/min. Based on the aquifer test, the following physical properties of the Wasatch aquifer were estimated: transmissivity was estimated to be about 97 ft^2/d [727 gpd/ft] and 112 ft^2/d [836 gpd/ft] using drawdown data and about 87 ft^2/d [650 gpd/ft] and 118 ft^2/d [884 gpd/ft] using recovery data; hydraulic conductivity of about 4.3 ft/d [32 gpd/ft^2]; and a specific capacity of 0.71 (gal/min)/ft (all values shown individually or included as part of summary ranges provided on **Plate 4**).

The Wasatch aquifer likely receives substantial recharge where overlain by Quaternary-age alluvium in the Bear River valley (Glover, 1990; Forsgren Associates, Inc., 2000). Hydraulic connection between the Bear River alluvial aquifer (stream-aquifer system composed of hydraulically connected Bear River and Quaternary-age alluvium) and the underlying Wasatch aquifer, in the Cokeville and Evanston areas (**Pls. 3** and **5**) was evaluated by Glover (1990). In the Cokeville area, the investigator determined that the Wasatch aquifer was not hydraulically connected to the Bear River alluvial aquifer. In contrast, the investigator determined that the Wasatch aquifer was in hydraulic connection with the Bear River alluvial aquifer in much of the Evanston area. Lower permeability rocks located on the upthrown sides of normal faults have isolated the Wasatch aquifer from the Bear River alluvial aquifer in some of the Evanston area.

Glover (1990) used an analytical streamflow-depletion method (Jenkins, 1968a, 1968b) to evaluate the effects on streamflow of the Bear River in the Evanston area from pumpage of supply wells in Evanston that were completed in the Bear River alluvial aquifer and underlying Wasatch aquifer. Use of the analytical streamflow-depletion method indicated that the largest reduction in streamflow occurred during the pumping season, and that streamflow was affected after the pumpage was ended. Most of the reduction in streamflow was due to pumping from the Bear River alluvial aquifer, not the Wasatch aquifer. Use of the analytical streamflow-depletion method also indicated that pumping from the Wasatch aquifer was likely to affect streamflow only after several months.

Chemical characteristics

The chemical composition of groundwater in the Wasatch aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from 15 wells and nine springs. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram G**). TDS concentrations were variable and indicated that most of the waters were fresh (90 percent of samples) and remaining waters were slightly to moderately saline (**Appendix E; Appendix G, Diagram G**). TDS concentrations ranged from 176 to 5,400 mg/L, with a median of 411 mg/L.

Concentrations of some properties and constituents in water from the Wasatch aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of some constituents exceeded health-based standards (USEPA MCLs and HALs): radon (in the one sample analyzed for this constituent, the concentration exceeded the proposed USEPA MCL of 300 pCi/L, but did not exceed the alternative MCL of 4,000 pCi/L) and arsenic (one of seven samples exceeded the MCL of 10 μg/L). Concentrations of several properties and constituents exceeded aesthetic standards for domestic use: aluminum (the one uncensored sample of 100 μg/L exceeded the USEPA lower SMCL limit of 50 μg/L), iron (five of 13 samples exceeded the SMCL of 300 μg/L), TDS (seven of 20 samples exceeded the SMCL of 500 mg/L), manganese (two of nine samples exceeded the SMCL of 50 μg/L), sulfate (three of 21 samples exceeded the SMCL of 250 mg/L), chloride (two of 21 samples exceeded the SMCL of 250 mg/L), and pH (one of 22 samples above upper SMCL limit of 8.5).

Concentrations of some properties and constituents exceeded State of Wyoming standards for agricultural and livestock use in the Bear River Basin. Properties and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (two of 12 samples exceeded the WDEQ Class II standard of 8), sulfate (three of 21 samples exceeded the WDEQ Class II standard of 200 mg/L), chloride (four of 21 samples exceeded the WDEQ Class II standard of 100 mg/L), and TDS (one of 20 samples exceeded the WDEQ Class II standard of 2,000 mg/L). Properties and constituents measured at concentrations greater than livestock-use standards were chloride (one of 21 samples exceeded the WDEQ Class III standard of 2,000 mg/L), TDS (one of 20 samples exceeded the WDEQ Class III standard of 5,000 mg/L), and pH (one of 22 samples above upper WDEQ Class III limit of 8.5).

7.2.2.7 Evanston aquifer

The physical and chemical characteristics of the Evanston aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Evanston aquifer is composed of the Paleocene and Upper Cretaceous Evanston Formation in the Bear River Basin (**Pl. 5**). The Evanston Formation consists of interbedded gray siltstone, sparse red sandstone, and minor lignite/coal beds; thickness is about 820 ft (Oriel and Platt, 1980). The Evanston Formation has been divided into an unnamed lower member, the Hams Fork Conglomerate Member, and a main body (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993) (individual members not shown on **Plate 5**).

The unnamed lower member of the Evanston Formation consists of gray, brown, and black shale; gray, green, yellow, and brown siltstone; thin- to massively-bedded, fine- to coarse-grained sandstone; and thin coal beds. Locally, the unnamed lower member contains gray quartzite and brown and black chert-pebble conglomerate at the base of the member (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

The Hams Fork Conglomerate Member of the Evanston Formation consists of pebble to boulder conglomerate containing well-rounded, pebble, cobble and boulder gravel of quartzite, chert, and limestone; gray and brown sandstone; and gray mudstone. The unit is about 1,000-ft thick in the Bear River Basin (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

The main body of the Evanston Formation is as much as 650-ft thick and consists of gray, carbonaceous claystone and siltstone with interbedded tan sandstone. Coal interbeds are present locally (Oriel and Tracey, 1970, Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Previous investigators classified the Evanston

Formation as an aquifer. Robinove and Berry (1963, Plate 1) speculated that the Evanston Formation in the Bear River valley "may be capable of yielding small supplies of groundwater." Lines and Glass (1975, Sheet 1) noted that conglomeratic sandstones and conglomerates in the Evanston Formation likely were capable of yielding "moderate to large quantities" of water to wells, and that fine-grained sandstones were capable of yielding "small to moderate" quantities of water, but that well yields were likely "greatly dependent" on saturated sandstone bed thickness. Ahern et al. (1981, Table IV-1) classified the Evanston Formation in the Overthrust Belt as a minor aquifer, and that definition was retained herein (**Pl. 5**). The investigators noted that conglomerates and conglomeratic sandstones present in the unit were capable of yielding "moderate to large quantities of water to wells" (Ahern et al., 1981, Table IV-1, p. 46).

Areas of the Evanston Formation with fine-grained lithologies can act as confining units. Glover (1990, p. 52) noted that fine-grained impermeable lithologies of the upper Evanston Formation in the area immediately south of the Medicine Butte Fault provided hydraulic isolation between the Bear River alluvial aquifer and underlying bedrock aquifers.

Hydrogeologic data describing the Evanston aquifer in the Bear River Basin, including spring-discharge and well-yield measurements, and specific capacity, are shown on **Plate 3** and summarized on **Plate 4**. One spring discharge of 25 gal/min was inventoried (**Pl. 4**).Two measurements of well yield (0.5 and 200 gal/min) were inventoried for the Evanston aquifer (**Pl. 4**). One measurement of specific capacity was inventoried and was 20 (gal/min)/ft.

Chemical characteristics

The chemical composition of groundwater in the Evanston aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and one spring. Individual constituent concentrations are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram H**). The TDS concentration from the spring (662 mg/L) indicated that the water was fresh, and the TDS concentration from the well (4,880 mg/L) indicated that the water was moderately saline (**Appendix E; Appendix G, Diagram H**).

The chemical composition of groundwater in the Evanston aquifer also was characterized and the quality evaluated on the basis of one produced-water sample from one well completed in the Evanston aquifer. Summary statistics calculated for available constituents are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram A**). The TDS concentration from the well (4,400 mg/L) indicated that the waters were moderately saline (**Appendix F; Appendix H, Diagram A**).

Concentrations of some properties and constituents in environmental water samples from the Evanston aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards (USEPA MCLs and HALs). Concentrations of several properties and constituents frequently exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (well and spring samples exceeded the SMCL of 500 mg/L), chloride (well sample exceeded the SMCL of 250 mg/L), iron (well sample exceeded the SMCL of 300 μg/L), fluoride (well sample exceeded the SMCL of 2 mg/L), manganese (well sample exceeded the SMCL of 50 μg/L), and sulfate (well sample exceeded the SMCL of 250 mg/L).

Chemical analyses of many properties and constituents were not available for the produced-water samples; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. The produced-water sample had concentrations of one property and one constituent that exceeded aesthetic standards for domestic use:

TDS and chloride (USEPA SMCLs of 500 mg/L and 250 mg/L, respectively).

Concentrations of some properties and constituents in water from the Evanston aquifer exceeded State of Wyoming standards for agricultural and livestock use in the Bear River Basin. Properties and constituents in environmental water samples that had concentrations greater than agricultural-use standards were sulfate (well and spring samples exceeded the WDEQ Class II standard of 200 mg/L), SAR (well sample exceeded the WDEQ Class II standard of eight), TDS (well sample exceeded the WDEQ Class II standard of 2,000 mg/L), and chloride (well sample exceeded the WDEQ Class II standard of 100 mg/L). No properties or constituents had concentrations that approached or exceeded applicable State of Wyoming livestock water-quality standards.

The produced-water sample had concentrations of one property and one constituent that exceeded agricultural-use standards: TDS and chloride (WDEQ Class II standards of 2,000 mg/L and 100 mg/L, respectively). Chloride was measured in the produced-water sample at a concentration that exceeded the WDEQ Class III livestock-use standard (2,000 mg/L).

7.3 Mesozoic Hydrogeologic Units

In the Bear River Basin, Mesozoic hydrogeologic units generally are composed of impermeable fine-grained rocks (for example, shale) that isolate discrete water-bearing units such as sandstone. Rocks composing the hydrogeologic sequence range from Lower Triassic to Upper Cretaceous (**Pl. 5**). The complex intertonguing and interfingering relation between the different facies within some of the hydrogeologic units creates numerous small permeable zones that can function as individual aquifers (or subaquifers). In addition, many of the lithostratigraphic units within this sequence consist of more than one sequence/facies, some of which function as confining units (shales and siltstones) and some as aquifers (sandstones and carbonates) (**Pl. 5**). Compared with aquifers of Cenozoic, Paleozoic, and Precambrian age, Mesozoic aquifers are the second most used source of water (Clarey, 2011).

Numerous petroleum (oil and gas) wells are completed in many of the formations composing the Mesozoic hydrogeologic units, but relatively few water wells are completed in the units. Most water wells completed in Mesozoic Hydrogeologic units are in outcrop areas where drilling depths are relatively shallow and waters are relatively fresh. Most of these wells are completed for domestic or stock purposes, but some have other uses, such as public supply. Much of the geologic and hydrogeologic data for the Mesozoic hydrogeologic units are from petroleum exploration. Groundwater in many of the hydrogeologic units, especially away from outcrop areas and at great depths, is highly mineralized and not suitable for most uses, as indicated by produced-water samples.

7.3.1 Adaville aquifer

The Upper Cretaceous Adaville Formation comprises the Adaville aquifer (**Pl. 5**) and consists of brown-weathering, gray sandstone, siltstone, and carbonaceous shale. The formation is as much as 2,100-ft thick and is conglomeratic in the upper part with coal beds present in the lower part (Oriel, 1969; Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; Ahern et al., 1981; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Lazeart Sandstone Member forms thick cliffs in outcrop and is composed of very light gray, yellow-brown, tan, fine- to medium-grained, lithic "salt and pepper" sandstone with interbedded brown-gray shale; coal is present in slopes between sandstone cliffs in outcrop (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

The Adaville Formation was speculatively identified as either a "major aquifer" or "minor aquifer" in the Overthrust Belt by Ahern et al. (1981, Figure II-7, and Table IV-1); the classification of the lithostratigraphic unit as an aquifer was tentatively retained herein (**Pl. 5**). Lines and Glass (1975, Sheet 1) speculated that "small quantities" of water were likely available from the Lazeart Sandstone Member of the Adaville Formation in the Overthrust Belt. One well yield of 20 gal/min was inventoried as part of this study (**Pl. 4**). No data were located describing the chemical characteristics of the hydrogeologic unit.

7.3.2 Hilliard confining unit

The Hilliard confining unit is composed of the Upper Cretaceous Hilliard Shale (**Pl. 5**). The Hilliard Shale consists of interbedded dark gray to tan claystone, siltstone, and sandy shale and ranges from 5,600- to 5,900-ft thick; sandstone also is present and sandstone content increases northward and westward (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; Ahern et al., 1981; M'Gonigle and Dover, 1992; and Dover and M'Gonigle, 1993). The Hilliard Shale underlies the Adaville Formation and overlies the Frontier Formation in the southern Overthrust Belt (Pl. 5) and western Green River structural basin. The Hilliard Shale is not exposed above and to the west of the Absaroka thrust fault in the Kemmerer area where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies the Lower Cretaceous Sage Junction Formation (M'Gonigle and Dover, 1992). East of the Overthrust Belt and the western 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.

Because of the predominance of fine-grained lithologies such as shale, the Hilliard Shale was classified as a major confining unit [aquitard] by previous investigators (Ahern et al., 1981, Figure II-7, and Table IV-1) and in the Wyoming Water Framework Plan (WWC Engineering et al., 2007, Figure 4-9), and that classification is retained herein (**Pl. 5**). Despite being classified as a confining unit, water likely can be obtained locally from the Hilliard confining unit in areas where discontinuous sandstone beds or zones with fractures are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981, Table IV-1). No data were located describing the physical and chemical characteristics of the hydrogeologic unit.

7.3.3 Frontier aquifer

The physical and chemical characteristics of the Frontier aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Frontier aquifer is composed of the Upper Cretaceous Frontier Formation (**Pl. 5**). The Frontier Formation consists of interbedded white to brown fine- to medium-grained sandstone and dark gray shale with beds of abundant oyster fossils in the upper part of the formation (Oyster Ridge Sandstone Member), and coal and lignite beds in the lower part. Thickness of the Frontier Formation ranges from 2,200 to 3,000 ft (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; Ahern et al., 1981; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Frontier Formation is not exposed above and to the west of the Absaroka thrust fault (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993), where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies the Lower Cretaceous Sage Junction Formation. The Frontier Formation was divided into additional members by Hale (1960), including the Dry Hollow, Allen Hollow Shale, Coalville, and Chalk Creek Members. Individual members not shown on **Plate 5**.

Previous investigators have classified the Frontier Formation as an aquifer, and that definition is retained herein (**Pl. 5**). Robinove and Berry (1963, Plate 1) speculated that the Frontier Formation in the Bear River valley was "possibly an aquifer in areas." Lines and Glass (1975, Sheet 1) noted that sandstone aquifers in the Frontier Formation were capable of yielding moderate quantities of water and were the "best aquifers" in their "hydrogeologic division 5" (identified as being composed of Cretaceous shales and sandstones and shown on **Plate 5**) in the Overthrust Belt. Similarly, the Frontier Formation was classified as a minor aquifer yielding moderate quantities of water by Ahern et al. (1981, Figure II-7, and Table IV-1) in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). Interbedded discontinuous sandstone beds compose the aquifer (Ahern et al., 1981; Lines and Glass, 1975, Sheet 1). Because sandstone beds compose the aquifer, permeability is primarily intergranular and related to the amount of cementation, except where fractured (Ahern et al., 1981). In the Wyoming Water Framework Plan, the Frontier Formation was classified as a minor aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

Hydrogeologic data describing the Frontier aquifer, including transmissivity, porosity, and permeability are shown on **Plate 3** and summarized on **Plate 4**. One estimate of transmissivity for one well completed in the Frontier aquifer was inventoried and was 2.68 ft^2/d (**Pl. 4**). One porosity estimate obtained from petroleum exploration was available and was 16 percent (**Pl. 4**). One permeability estimate obtained from petroleum exploration was inventoried and was 30 millidarcy (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Frontier aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of one environmental water sample from a well. Individual constituent concentrations are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram II**). The TDS concentration (608 mg/L) indicated that the water was fresh (**Appendix E; Appendix G, Diagram II**).

The chemical composition of groundwater also was characterized and the quality evaluated on the basis of one produced-water sample from a well completed in the Frontier aquifer. Individual constituent concentrations are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram B**). The TDS concentration (11,600 mg/L) from the produced waters indicated that the water was very saline (**Appendix F; Appendix H, Diagram B**).

Concentrations of some properties and constituents in the Frontier aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison of concentrations in one environmental water sample with health-based standards (USEPA MCLs and HALs), the environmental water was suitable for domestic use, but concentrations of one constituent exceeded health-based standards: gross-alpha radioactivity (USEPA MCL of 15 pCi/L). One property (TDS; USEPA SMCL of 500 mg/L) and one constituent (sulfate; SMCL of 250 mg/L) exceeded aesthetic standards for domestic use. Concentrations of some properties and constituents exceeded State of Wyoming standards for agriculture and livestock use in the Bear River Basin. Gross-alpha radioactivity and sulfate were measured in the environmental water sample at a concentration greater than their respective agricultural-use standards (WDEQ Class II standards of 15 pCi/L, and 200 mg/L, respectively). Gross-alpha radioactivity had a concentration that exceeded the State of Wyoming livestock standard (WDEQ Class III standard of 15 pCi/L).

Chemical analyses for few properties and constituents were available for the one produced-water sample; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. Nonetheless, concentrations of some properties and constituents in the Frontier aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. None of the constituents analyzed had applicable health-based standards; however, concentrations of TDS, chloride, and sulfate exceeded aesthetic standards (USEPA SMCLs of 500 mg/L, 250 mg/L, and 250 mg/L, respectively) for domestic use and exceeded State of Wyoming agricultural-use standards (WDEQ Class II standards of 2,000 mg/L, 100 mg/L, and 200 mg/L, respectively). TDS and chloride concentrations exceeded livestock-use standards (WDEQ Class III standards of 5,000 mg/L and 2,000 mg/L mg/L, respectively). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in the produced-water sample.

7.3.4 Sage Junction Formation

The physical and chemical characteristics of the Sage Junction Formation in the Bear River Basin are described in this section of the report.

Physical characteristics
The Upper Cretaceous Sage Junction Formation (**Pl. 5**) is more than 3,000-ft thick and consists primarily of gray and tan siltstone, sandstone, and quartzite with minor amounts of porcellanite, limestone, conglomerate, and some coal beds (Rubey, 1973; Lines and Glass, 1975, Sheet 1; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The formation is a lateral western stratigraphic 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, 1973). The Sage Junction Formation is at least 3,375-ft thick above and to the west of the Absaroka thrust fault and in the northwestern part of the Kemmerer area (M'Gonigle and Dover, 1992). West and above the Absaroka thrust fault, the Upper Cretaceous lower member of the Evanston Formation unconformably overlies the Sage Junction Formation (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Changes in stratigraphic nomenclature between the western and eastern Cretaceous lithostratigraphic units occur at the Absaroka thrust fault in the Wyoming Overthrust Belt (Rubey, 1973). Lithostratigraphic units located above and to the west of the Absaroka thrust, including the hanging wall of the fault, are the western units (Smiths, Thomas Fork, Cokeville, Quealy, and Sage Junction Formations), whereas those located below and to the east of the Absaroka thrust, including the footwall of the fault, are the eastern units (Bear River Formation and Aspen Shale).

Few hydrogeologic data were available for the Sage Junction Formation. One measurement of discharge (0.2 gal/min) for a spring issuing from the Sage Junction Formation, and one measurement of well yield (15 gal/min) were inventoried as part of this study (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Sage Junction Formation in the Bear River Basin was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations in the environmental water sample are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram J**). The TDS concentration (458 mg/L) indicated that the water was fresh. On the basis of the few properties and constituents analyzed for in the environmental water sample, the quality of water from Sage Junction Formation in the Bear River Basin was likely suitable for most uses. No concentrations of properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.5 Aspen confining unit

The physical and chemical characteristics of the Aspen confining unit in the Bear River Basin are described in this section of the report.

Physical characteristics
The Aspen confining unit is composed of the Upper and Lower Cretaceous Aspen Shale (**Pl. 5**). The Aspen Shale consists of interbedded light to dark gray shale, siltstone, and claystone with minor quartz-rich sandstone and porcellanite. Thickness of the Aspen Shale ranges from 800 to 2,000 ft (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Aspen Shale is laterally equivalent to the Mowry Shale to the east. Some beds are present that are transitional from the Aspen Shale to the lower part of the Blind Bull Formation located north of the Bear River Basin (Rubey et al., 1980).

Little hydrogeologic information is available for the Aspen Shale in the Bear River Basin. The Aspen Shale was identified as either "discontinuous aquifers with local confining beds" or a "locally utilized aquifer" in the Overthrust Belt by Ahern et al. (1981, Figure II-7, and Table IV-1) (**Pl. 5**). In the Wyoming Water Framework Plan, the

Aspen Shale was classified as a major confining unit [major aquitard] (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Because shale is the predominant lithology, the Aspen Shale is classified as a confining unit herein (**Pl. 5**); however, it is recognized that water can be obtained locally from the Aspen confining unit in areas where discontinuous sandstone beds or zones with fractures are present (Lines and Glass, 1975, Sheet 1; Richter et al., 1981, Table IV-1). Few hydrogeologic data were located as part of this study, but one measurement of porosity (15 percent) from petroleum exploration was inventoried for the Aspen confining unit (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Aspen confining unit in the Bear River Basin was characterized and the quality evaluated on the basis of two produced-water samples. Constituent concentrations are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram C**). The TDS concentrations (28,300 mg/L and 31,000 mg/L) indicated the water was very saline and likely was unusable for all purposes. Health-based standards (USEPA MCLs and HALs) were not applicable for any of the constituents analyzed in the produced-water samples. Concentrations of TDS and chloride in both samples exceeded aesthetic standards (USEPA SMCLs of 500 mg/L and 250 mg/L, respectively) for domestic use, as well as State of Wyoming agricultural and livestock-use standards (WDEQ Class II standards of 2,000 mg/L and 100 mg/L, respectively, and WDEQ Class III standards of 5,000 mg/L and 2,000 mg/L, respectively). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in both produced-water samples.

7.3.6 Wayan Formation

The Upper and Lower Cretaceous Wayan Formation (**Pl. 5**) consists of variegated mudstone, siltstone, and sandstone (Love et al., 1993, Sheet 2). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit in the Bear River Basin.

7.3.7 Quealy Formation

The Upper and Lower Cretaceous Quealy Formation (**Pl. 5**) is about 1,000-ft thick northeast of the town of Cokeville and consists of red and variegated pastel-tinted mudstone and minor interbedded pink, gray, and tan sandstone (Rubey, 1973; Lines and Glass, 1975). The formation thins southward and is absent to the east and south of the town of Cokeville (Rubey, 1973). The Quealy Formation thins eastward from about 1,100 ft in Idaho to about 500 ft in Wyoming (Oriel and Platt, 1980; Rubey et al., 1980). The Quealy Formation is the western stratigraphic equivalent of the middle to lower part of the Aspen Shale (Rubey, 1973). 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 directly overlies the Cokeville Formation (Rubey, 1973). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit.

7.3.8 Cokeville Formation

The Lower Cretaceous Cokeville Formation (**Pl. 5**) consists 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, 1973; Lines and Glass 1975; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The coal beds are located in the upper part of the Cokeville Formation; these coal beds were mined about one-half mile west of Sage (Rubey, 1973). In the Sage area, the Cokeville Formation ranges from 1,900- to 2,500-ft thick (Rubey, 1973). The Cokeville Formation thickens southeastward from about 850 ft in Idaho to about 3,000 ft in Wyoming (Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The upper part of the Cokeville Formation is the western stratigraphic equivalent of the lower part of the Aspen Shale, and the lower part of the formation is the western stratigraphic equivalent to the upper Bear River Formation (Rubey, 1973). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit.

7.3.9 Bear River aquifer

The physical and chemical characteristics of the Bear River aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Lower Cretaceous Bear River Formation consists of fissile black shale interbedded with brown fine-grained sandstone, and minor interbedded fossiliferous limestone and bentonite. Thickness of the formation in the Overthrust Belt ranges from about 650 to 1,800 ft (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Previous investigators have classified the Bear River Formation as an aquifer, and that definition is retained herein (**Pl. 5**). Berry (1955) identified the Bear River Formation as a potential aquifer in the Cokeville area. Robinove and Berry (1963, Plate 1) speculated that the Bear River Formation in the Bear River valley "possibly may yield small amounts of water." Lines and Glass (1975, Sheet 1) noted that "small quantities" of water were available from the discontinuous sandstone beds in the formation. In the Overthrust Belt, the Bear River Formation was identified as either a "discontinuous aquifer with local confining beds" or "minor aquifer" by Ahern et al. (1981, Figure II-7, and Table IV-1) (**Pl. 5**). Interbedded discontinuous sandstone beds compose the aquifer (Ahern et al., 1981; Lines and Glass, 1975, Sheet 1). In the Wyoming Water Framework Plan, the Bear River Formation was classified as a marginal aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Few hydrogeologic data are available, but one discharge measurement (100 gal/min) was inventoried for a spring issuing from the Bear River aquifer (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Bear River aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, diagram K**).The TDS concentration (386 mg/L) indicated that the water was fresh. On the basis of the few properties and constituents analyzed for in the environmental water sample, the quality of water from Bear River aquifer in the Bear River Basin was likely suitable for most uses. No concentrations of properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of groundwater in the Bear River aquifer in the Bear River Basin also was characterized and the quality evaluated on the basis of one produced-water sample from one well. Individual constituent concentrations for this sample are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram D**).The TDS concentration (1,150 mg/L) indicated that the water was slightly saline. Chemical analyses for few properties and constituents were available for the one produced-water sample; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. Nonetheless, concentrations of one property in the Bear River aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. None of the constituents analyzed had applicable health-based standards; however, the concentration of TDS exceeded aesthetic standards (USEPA SMCL of 500 mg/L) for domestic use. None of the concentrations of properties or constituents exceeded State of Wyoming agricultural- and livestock-use standards.

7.3.10 Thomas Fork aquifer

The physical and chemical characteristics of the Thomas Fork aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Thomas Fork aquifer is composed of the Lower Cretaceous Thomas Fork Formation (**Pl. 5**). The Thomas Fork Formation consists of variegated, banded, red, purple, brown, and green mudstone and minor interbedded gray to tan sandstone (Rubey, 1973; Lines and Glass 1975; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). In part, the sandstone is conglomeratic with sediments (pebbles and cobbles) as large as 4 inches in diameter, and the mudstone contains gray to brown limestone nodules as large as several inches in diameter (Rubey, 1973). The formation thickens northward to about 2,000-ft thick in the southwestern part of Star Valley, and thins southward to about 350-ft thick in the Sage area (Rubey, 1973; Oriel and Platt, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The formation merges to the south with and is lithologically indistinguishable from the upper part of the Early Cretaceous-age Kelvin Formation in northeastern Utah (Dover and M'Gonigle, 1993).

Most information about the physical and chemical characteristics of the Thomas Fork aquifer was obtained through installation and subsequent testing of three wells completed in the aquifer to replace three springs as the water supply for the town of Cokeville (Forsgren Associates, Inc., 1993a, b; TriHydro Corporation, 1993, 2002, 2003). The Thomas Fork Formation is classified as an aquifer in the Bear River Basin herein based on these investigations. In fact, previous descriptions of the hydrogeologic characteristics of the Thomas Fork Formation were very limited. Lines and Glass (1975, Sheet 1) speculated that sandstone beds in the Thomas Fork Formation may yield "small quantities" of water to wells.

TriHydro Corporation (2002) summarized all information obtained from drilling, installation, and testing of the three wells completed in the Thomas Fork aquifer to supply water for the town of Cokeville. One of the three wells was a test well and the other two wells were completed at depths of about 141 and 174 ft below land surface as production wells (Cokeville #2 and Cokeville #3) for the town. The investigators (TriHydro Corporation, 2002, p. 3-7) reported that sandstone beds composing the aquifer typically were well cemented with calcite cement, and typically have poor intergranular porosity in "an unweathered and unfractured condition." Porosity and permeability were attributed to fractures in the sandstone beds composing the aquifer. Based on interpretation of aquifer tests conducted on both production wells, the investigators concluded that the Thomas Fork aquifer was a semiconfined, fracture-flow aquifer with primarily conduit flow. A hydraulic gradient of 0.073 foot per foot was calculated for the aquifer using water levels measured in all three wells. Using this hydraulic gradient, an estimated porosity of 17 percent, and a hydraulic conductivity estimate obtained from the aquifer tests, TriHydro Corporation (2002) estimated the average groundwater-flow velocity for the Thomas Fork aquifer in the area to be 22.6 ft/d.

The investigators (TriHydro Corporation, 2002, p. 3-10) also conceptually described potential sources of recharge to the aquifer in the area where both wells were installed. Potential sources of recharge identified were (1) streamflow losses along Pine, Spring, and Sublette Creeks and direct infiltration of precipitation and seepage to overlying lithostratigraphic units (Quaternary alluvial, terrace, and loess deposits, and the Tertiary-age Fowkes Formation) and subsequent movement of water in these units downward into the underlying Thomas Fork aquifer; and (2) direct infiltration of precipitation (rain and snow) on Thomas Fork aquifer outcrop areas.

Hydrogeologic data describing the Thomas Fork aquifer in the Bear River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Two measurements of discharge for springs issuing from the Thomas Fork were available and were 0.2 and 0.5 gal/min. Yields from wells completed in Thomas Fork aquifer ranged from 250 to 747 gal/min, with a median of 653 gal/min (**Pl. 4**). Specific capacities ranged from 8.9 to 51 (gal/min)/ft with a median of 12 (gal/min)/ft (**Pl. 4**). Estimates of transmissivity using all methods for wells completed in the Thomas Fork aquifer ranged from 5,210 to 18,800 ft^2/d, with a median of 8,060 ft²/d (**Pl. 4**). Estimates of hydraulic conductivity for wells completed in the Thomas Fork aquifer ranged from 34 to 210 ft/ per day, with a median of 56 ft/d (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Thomas Fork aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well [and one spring (only specific conductance is available for the spring sample)]. Individual constituent concentrations are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, diagram L**).The TDS concentration (390 mg/L) indicated that the water was fresh (**Appendix E; Appendix G, Diagram L**). On the basis of the few properties and constituents analyzed for in the environmental water sample, the quality of water from Thomas Fork aquifer in the Bear River Basin was suitable for most uses. No concentrations of properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.11 Smiths Formation

The Lower Cretaceous Smiths Formation is composed of ferruginous black shale and interbedded tan, quartz-rich, very fine-grained sandstone. Thickness of the Smiths Formation is about 750 ft along the Smiths Fork located to the northeast of the town of Cokeville (Rubey, 1973; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The black shale and tan sandstone are interbedded throughout the formation, but the upper unnamed member primarily is tan sandstone, and the lower unnamed member primarily is black shale (Rubey, 1973; Rubey et al., 1980). The Smiths Formation thins southward to about 300 to 400 ft in thickness near the Sage and Kemmerer areas, and to about 115 to 200 ft in the Evanston area (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Smiths Formation thickens eastward from about 300 ft in Idaho to about 850 ft in Wyoming (Oriel and Platt, 1980; Rubey et al., 1980). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit.

7.3.12 Gannett aquifer and confining unit

The physical and chemical characteristics of the Gannett aquifer and confining unit in the Bear River Basin are described in this section of the report.

Physical characteristics
The Gannett aquifer and confining unit is composed of the Lower Cretaceous Gannett Group. The Gannett Group consists of red sandy mudstone, sandstone, and chert-pebble conglomerate. Some thin limestone and dark gray shale are present in the upper part of the unit, and the lower part is more conglomeratic. Thickness of the Gannett Group decreases from about 3,000 ft in Idaho to about 800 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). In the Cokeville area of Lincoln County, the Gannett Group thins southeastward from about 2,900 to 790 ft (Rubey et al., 1980). The Gannett Group is as much as 2,100-ft thick above and to the west of the Absaroka thrust fault, and thins eastward to about 650 ft below and to the east of the Absaroka thrust fault in the Kemmerer area (M'Gonigle and Dover, 1992).

In some areas, the Gannett Group is mapped as separate formations or groups of formations. The Gannett Group was described in detail by Eyer (1969) and Furer (1967, 1970). The Gannett Group is composed of five formations (in descending order from top to bottom): Smoot Formation, Draney Limestone, Bechler Conglomerate, Peterson Limestone, and Ephraim Conglomerate.

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

The Draney Limestone of the Gannett Group consists of dark to medium gray limestone, weathering light gray, very fine-crystalline to aphanitic and interbedded with dark gray calcareous shale and siltstone (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980). The unit is about 200-ft thick when combined with the overlying Smoot Formation.

The Bechler Conglomerate of the Gannett Group 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 (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980). A few thin limestone interbeds occur locally. The formation is about 1,300-ft thick.

The Peterson Limestone of the Gannett Group consists of light to medium gray and pastel-colored, weathering very light gray, very fine-crystalline limestone and pastel-colored calcareous mudstone (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980). The unit is about 230-ft thick.

The basal Ephraim Conglomerate 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; and red to brown, chert-pebble conglomerate. Thickness of the Ephraim Conglomerate decreases eastward from about 3,300 ft in Idaho to about 490 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992).

Permeability in the Gannett Group likely is small on a regional scale, and thus, in most areas the unit is capable of yielding only small quantities of water locally. However, more permeable water-bearing parts of the Gannett Group capable of yielding larger quantities of water are present in the conglomeratic formations (Bechler and Ephraim Conglomerates) and in areas where fractures and secondary permeability (solution openings) are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern et al., 1981, Table IV-1). In addition, sandstone beds in the lower part of the Gannett Group also may be permeable and water-bearing (Ahern et al., 1981, Table IV-1). Ahern et al. (1981, Figure II-7) classified the Gannett Group as a series of "discontinuous aquifers with local confining units" in the Overthrust Belt and the adjacent Green River Basin (**Pl. 5**). Glover (1990) considered the Ephraim Conglomerate of the Gannett Group (identified as a conglomerate near the base of the Gannett Group) to be a minor aquifer in the Bear River valley in the Evanston area. He also noted that aquifers in the Gannett Group were hydraulically isolated from the overlying Evanston aquifer (Hams Fork Conglomerate Member of the Evanston Formation), Wasatch aquifer, and Bear River alluvial aquifer. TriHydro Corporation (1993, p. II-3) reported that the Ephraim Conglomerate produced about 10 gal/min during drilling of a test boring at an anticline in the vicinity of Spring Creek near Cokeville. In the Wyoming Water Framework Plan, the Gannett Group was classified as a marginal aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Because the unit has low overall permeability, but with distinct zones and formations of higher permeability with potential to yield water to wells, the Gannett Group was classified as both an aquifer and confining unit herein (**Pl. 5**).

Hydrogeologic data describing the Gannett aquifer and confining unit in the Bear River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Measured discharges of springs issuing from the Gannett aquifer and confining unit ranged from 0.25 to 800 gal/min with a median of 20 gal/min (**Pl. 4**). Two measurements of well yield were available and were 30 and 200 gal/min (**Pl. 4**). One estimate of transmissivity obtained from petroleum exploration was inventoried and was 0.08 ft^2/d (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Gannett aquifer and confining unit in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from two wells and six springs. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram M**).TDS concentrations indicated that waters were fresh (**Appendix E; Appendix G, Diagram M**). TDS concentrations ranged from 243 to 854 mg/L, with a median of 376 mg/L.

Concentrations of some properties and constituents in the Gannett aquifer and confining unit in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison of concentrations with health-based standards (USEPA MCLs and HALs), all water was suitable for domestic use. Concentrations of one property and one constituent exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (one of six samples exceeded the SMCL of 500 mg/L) and fluoride (one of six samples exceeded the SMCL of 2 mg/L).

Concentrations of some properties and constituents exceeded State of Wyoming standards for agricultural and livestock use in the Bear River Basin. The property and constituent in environmental water samples that had concentrations greater than agricultural-use standards were SAR (one of three samples exceeded the WDEQ Class II standard of eight) and chloride (one of six samples exceeded the WDEQ Class II standard of 100 mg/L). No properties or constituents had concentrations that exceeded State of Wyoming livestock standards.

7.3.13 Stump Formation

The Upper to Middle Jurassic Stump Formation consists of interbedded light to dark green, green-gray, glauconitic, fine-grained sandstone, siltstone, and limestone (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Pipiringos and Imlay (1979) divided the Stump Formation into two members—the Upper Jurassic Redwater Member and the Middle Jurassic Curtis Member. 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; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The upper member of the Stump Formation is similar to the silty to sandy facies of the Redwater Member of the Sundance Formation eastward in Wyoming, whereas the lower member is similar to the Curtis Formation in the San Rafael Swell area of central Utah (Pipiringos and Imlay, 1979). Individual members are not shown on **Plate 5**.

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

The Curtis Member of the Stump Formation consists of two lithologic units (Pipiringos and Imlay, 1979). The upper lithologic unit is composed of green-gray to olive-green, soft, flaky to fissile claystone with minor thin interbeds of sandstone and oolitic, fossiliferous limestone. The lower lithologic unit is composed of green-gray to brown-gray, glauconitic, thin- to thick-bedded, ripple-marked, crossbedded, fine- to very fine-grained sandstone (some silty and medium-grained sandstone).

Little information is available describing the hydrogeologic characteristics of the Stump Formation. In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Stump Formation was likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) noted that rocks in the Stump Formation were relatively impermeable and in most areas were probably capable of yielding only small quantities of water. Ahern et al. (1981, Figure II-7) classified the Stump Formation as a confining unit [aquitard] or poor aquifer (**Pl. 5**). No data were located describing the physical and chemical characteristics of the hydrogeologic unit.

7.3.14 Preuss Sandstone or Redbeds

The physical and chemical characteristics of the Preuss Sandstone or Redbeds in the Bear River Basin are described in this section of the report.

Physical characteristics

The Middle Jurassic Preuss Sandstone or Redbeds (**Pl. 5**) 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 (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Beds of red, gray, and tan, fine-grained, thin-bedded and regular-bedded sandstone also are present. Formation thickness decreases eastward from about 1,640 ft in Idaho to 360 ft in Wyoming (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980). The Preuss Sandstone or Redbeds are overlain by the Stump Formation and underlain by the Twin Creek Limestone (**Pl. 5**).

Little information is available describing the hydrogeologic characteristics of the Preuss Sandstone or Redbeds. In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Preuss Sandstone or Redbeds were likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) noted that rocks in the Preuss Sandstone or Redbeds were relatively impermeable and in most areas were probably capable of yielding only small quantities of water. Ahern et al. (1981, Figure II-7) classified the formation as a confining unit [aquitard] or poor aquifer (**Pl. 5**).

In outcrop and shallow groundwater areas, bedded halite (rock salt) in the lower part of the formation has been removed by dissolution (Imlay, 1952). In areas where evaporite beds have been removed by dissolution, breccia zones and collapse structures may have formed and consequently, may have increased permeability.

Few hydrogeologic data are available, but five measurements of discharge for springs issuing from the Preuss Sandstone or Redbeds were inventoried as part of this study. Spring discharge measurements ranged from 0.1 to 50 gal/min with a median of 2 gal/min. (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Preuss Sandstone or Redbeds in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations in the environmental water samples are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram N**). Both TDS concentrations (664 and 715 mg/L) indicated that the water was slightly saline (**Appendix E; Appendix G, Diagram N**).

On the basis of the few properties and constituents analyzed for in the environmental water samples, the quality of water from the Preuss Sandstone or Redbeds in the Bear River Basin was likely suitable for most uses. On the basis of comparison of concentrations with health-based standards (USEPA MCLs and HALs), all water was suitable for domestic use. Concentrations of one property in both samples exceeded aesthetic standards for domestic use: TDS (USEPA SMCL of 500 mg/L). One constituent (chloride) had concentrations greater than State of Wyoming agricultural-use standards (WDEQ Class II standard of 100 mg/L) in both samples. No concentrations of properties or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.3.15 Twin Creek aquifer

The physical and chemical characteristics of the Twin Creek aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Twin Creek aquifer is composed of the Middle Jurassic Twin Creek Limestone (**Pl. 5**). The Twin Creek Limestone consists of green-gray argillaceous (shaly) limestone and calcareous siltstone. Thickness of the formation decreases eastward from about 3,300 ft in Idaho to about 440 ft in Wyoming (Imlay, 1967; Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992). The formation is as much as 2,900-ft thick above and to the west of the Absaroka thrust fault. Thickness of the Twin Creek Limestone below and to the east of the Absaroka thrust fault in the Kemmerer area ranges from 800 to 1,000 ft (M'Gonigle and Dover, 1992). The Twin Creek Limestone was deposited in a Jurassic seaway marine environment, as reflected by the presence of pelecypod fossils such as *Gryphaea* (Imlay, 1967). Imlay (1967) defined and described seven members of the Twin Creek Formation in the Overthrust Belt of Wyoming-Idaho-Utah. 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, and Gypsum Spring Member. Individual members are not shown on **Plate 5**.

The Giraffe Creek Member of the Twin Creek Limestone consists 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. Sand and glauconite content increases to the west, and the Giraffe Creek Member of the Twin Creek Limestone grades upward into red, soft siltstone at the base of the Preuss Sandstone or Redbeds. Thickness decreases eastward and northward from 295 to 25 ft (Imlay, 1967).

The Leeds Creek Member of the Twin Creek Limestone consists of light gray, dense, shaly, soft limestone, which weathers into slender splinters, and minor interbeds of oolitic silty or sandy, ripple-marked limestone. Clay content increases to the northeast in Idaho and Wyoming and to the south in Utah. The Leeds Creek Member is the least resistant member of the Twin Creek Limestone and commonly forms valleys in outcrop areas. The Leeds Creek Member of the Twin Creek Limestone grades upward into the harder, silty to sandy, basal limestone of the overlying Giraffe Creek Member. Thickness decreases eastward from about 1,600 to 260 ft (Imlay, 1967).

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

The Boundary Ridge Member of the Twin Creek Limestone consists of red, green, and yellow, soft siltstone with interbedded silty to sandy or oolitic limestone. The Boundary Ridge Member grades eastward into red, gypsiferous, soft siltstone and claystone, and grades westward into cliff-forming, oolitic to dense limestone with minor interbedded red siltstone. The Boundary Ridge Member is overlain by the cliff-forming, basal limestone of the Watton Canyon Member. Thickness decreases eastward from about 285 to 30 ft (Imlay, 1967).

The Rich Member of the Twin Creek Limestone consists of gray, shaly limestone that is very soft at the base; clay content increases to the north, and the upper part grades into the basal hard sandy limestone or red, soft siltstone of the Boundary Ridge Member of the Twin Creek Limestone. Pelecypod and cephalopod fossils are present. Thickness of the Rich Member decreases eastward from 500 to 40 ft (Imlay, 1967).

The Sliderock Member of the Twin Creek Limestone consists of gray-black, medium- to thin-bedded limestone with oolitic basal beds, and commonly forms a low ridge between adjacent members. Pelecypod and cephalopod fossils are present. Thickness of the Sliderock Member decreases eastward from 285 to 20 ft (Imlay, 1967).

The Gypsum Spring Member of the Twin Creek Limestone consists of red to yellow, soft siltstone and claystone, interbedded with brecciated, vuggy, or chert-bearing limestone. In Wyoming, a basal unit of brecciated limestone is present and 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 of the Gypsum Spring Member is a green tuff. Thickness of the Gypsum Spring Member decreases eastward from 400 to 12 ft (Imlay, 1967). In areas of Wyoming located east of the Bear River Basin, the Gypsum Spring Member of the Twin Creek Limestone has been elevated to formation rank and is referred to as the Gypsum Spring Formation.

The Twin Creek Limestone is classified as an aquifer or potential aquifer by investigators and that classification is retained herein (**Pl. 5**). In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Twin Creek Limestone was likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) noted that permeability in the upper part of the Twin Creek Limestone likely was low compared to the lower part and thus, the formation likely would yield small quantities of water to wells completed in the upper part of the unit. The investigators noted that limestone in the lower part of the Twin Creek Limestone is brecciated and honeycombed; thus, wells completed in the lower part of the formation were more likely to yield moderate quantities of water (Lines and Glass, 1975, Sheet 1). In the Wyoming Water Framework Plan, the Twin Creek Limestone was classified as a minor aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

The Twin Creek aquifer likely is in hydraulic connection with the underlying Nugget aquifer (Lines and Glass, 1975, Plate 1; Ahern et al., 1981). In fact, Lines and Glass (1975, Sheet 1) noted that few springs issue from the lower part of the Twin Creek Limestone, possibly because the overlying unit may be in hydraulic connection with, and "drain into" the underlying Nugget aquifer. Clarey (2011) speculated that groundwater from the Gypsum Spring Member in areas where gypsum deposits are present may have the potential for calcium-sulfate-type waters and large TDS concentrations.

Hydrogeologic data describing the Twin Creek aquifer, including spring-discharge measurements and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Two measured discharges of springs issuing from the Twin Creek aquifer were 15 and 25 gal/min (**Pl. 4**). Porosity estimates obtained from petroleum exploration ranged from 0.65 to 3.8 percent (**Pl. 4**). Permeability estimates obtained from petroleum exploration ranged from 0.005 to 1.9 millidarcies (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Twin Creek aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations in the environmental water samples are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram O**). The TDS concentrations (282 and 366 mg/L) indicated that the water was fresh. On the basis of the few properties and constituents analyzed for in the environmental water samples, the quality of water from Twin Creek aquifer in the Bear River Basin was likely suitable for most uses. On the basis of comparison of concentrations with health-based standards (USEPA MCLs and HALs), all water was suitable for domestic use. Concentrations of two constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use in one sample: iron (SMCL of 300 μg/L) and manganese (SMCL of 50 μg/L). No concentrations of properties or constituents approached or exceeded applicable State of Wyoming agriculture, or livestock water-quality standards.

The chemical composition of groundwater also was characterized and the quality evaluated on the basis of seven produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram E**). TDS concentrations from produced-water samples indicated that most waters were briny (71 percent of samples) and the remaining water was very saline (**Appendix F; Appendix H, Diagram E**). TDS concentrations ranged from 31,100 to 329,000 mg/L, with a median of 137,000 mg/L. Most available water-quality analyses were from produced-water samples, for which chemical analyses of few properties and constituents were available; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. The produced-water samples generally had concentrations of several properties and constituents that exceeded aesthetic standards for domestic use: TDS (all 7 samples exceeded the SMCL of 500 mg/L), chloride (all 7 samples exceeded the SMCL of 250 mg/L), sulfate (all 7 samples exceeded the SMCL of 250 mg/L), and pH (2 of 7 samples below lower SMCL limit of 6.5). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in all 7 produced-water samples.

The produced-water samples generally had concentrations of several properties and constituents that exceeded agricultural-use standards: TDS (all 7 samples exceeded the WDEQ Class II standard of 2,000 mg/L), chloride (all 7 samples exceeded the WDEQ Class II standard of 100 mg/L), and sulfate (all seven samples exceeded the WDEQ Class II standard of 200 mg/L). The produced-water samples generally had concentrations of several properties and constituents that exceeded livestock-use standards: TDS (all seven samples exceeded the WDEQ Class III standard of 5,000 mg/L), chloride (all seven samples exceeded the WDEQ Class III standard of 2,000 mg/L), sulfate (three of seven samples exceeded the WDEQ Class III standard of 3,000 mg/L), and pH (two of seven samples below lower WDEQ Class III limit of 6.5).

7.3.16 Nugget aquifer

The physical and chemical characteristics of the Nugget aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Nugget aquifer is composed of the Triassic (?) to Jurassic (?) Nugget Sandstone (**Pl. 5**). The Nugget Sandstone consists of tan to pink, crossbedded, well-sorted, quartz-rich sandstone. Thickness of the Nugget Sandstone ranges from about 600 ft to more than 1,000 ft (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992). In the Kemmerer area, the formation is as much as 1,475-ft thick west of the Absaroka thrust fault and about 650-ft thick east of the Absaroka thrust fault (M'Gonigle and Dover, 1992). Age of the Nugget Sandstone is uncertain, but the unit is possibly Triassic to Jurassic in age (Love et al., 1993) (**Pl. 5**). The lower part of the formation may be Triassic but the lack of diagnostic fossils in the sandstone has made the age of the formation uncertain. The Nugget Sandstone has been interpreted as deposited as an eolian (wind-blown) sand dune sequence from a desert or a beach environment.

The Nugget Sandstone is classified as an aquifer by all investigators and that classification is retained herein (**Pl. 5**). Robinove and Berry (1963, Plate 1) speculated that the Nugget Sandstone was likely to yield small quantities of groundwater to wells in the Bear River valley. Lines and Glass (1975, Sheet 1) considered the Nugget Sandstone to be the "best aquifer" in their "hydrogeologic division 4" (identified as being composed of Jurassic- and Cretaceous-age sandstones and limestones and shown on **Plate 5**) in the Overthrust Belt. The investigators (Lines and Glass, 1975, Sheet 1) reported that the Nugget aquifer was capable of yielding moderate to large quantities of water where "outcrop or recharge areas are large, where bedding is continuous and not offset by faults, and in topographic lows where large thickness of sandstone is saturated." Furthermore, the investigators (Lines and Glass, 1975, Sheet 1) noted that few springs issue from the lower part of the Twin Creek Limestone, possibly because the overlying unit may be in hydraulic connection with, and "drain into" the underlying Nugget aquifer. Springs commonly issue from the Nugget aquifer in the Overthrust Belt (Lines and Glass, 1975, Sheet 1). In the Wyoming Water Framework Plan, the Nugget Sandstone was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

Ahern et al. (1981, Figure II-7, and Table IV-1) classified the Nugget Sandstone as a major aquifer in the Overthrust Belt and the adjacent Green River Basin (**Pl. 5**). The Nugget aquifer was considered to be part of an aquifer system, identified as the Nugget aquifer system, composed of the overlying Twin Creek Limestone and the underlying Ankareh Formation and Thaynes Limestone (**Pl. 5**). The investigators noted that porosity and permeability in the Nugget aquifer were "good," especially in the crossbedded upper part. The investigators also speculated that smaller transmissivities for the Nugget aquifer in the adjacent Green River Basin may be attributable to increased lithostatic pressure (deeper burial) and decreased fracture occurrence.

Clarey (2011) noted that the upper part of the Nugget Sandstone in some areas of the Overthrust Belt has calcite (calcium carbonate) cement with slightly increased permeability, and that the lower part of the formation has siliceous (quartz) cement with decreased permeability. The investigator reported that 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.

Hydrogeologic data describing the Nugget aquifer in the Bear River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are shown on **Plate 3** and summarized on **Plate 4**. Measured discharges of springs issuing from the Nugget aquifer ranged from 2 to 300 gal/min with a median of 5 gal/min (**Pl. 4**). Estimates of transmissivity obtained from petroleum exploration for wells completed in the Nugget aquifer ranged from 0.25 to 8.84 ft^2/d, with a median of 4.36 ft^2/d (**Pl. 4**). Porosity estimates obtained from petroleum exploration ranged from 2 to 22 percent (**Pl. 4**). Permeability estimates obtained from petroleum exploration ranged from 0.01 to 1,400 millidarcies (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Nugget aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from six springs. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram P**). TDS concentrations indicated that waters were fresh (**Appendix E; Appendix G, Diagram P**). TDS concentrations ranged from 54 to 824 mg/L, with a median of 210 mg/L.

The chemical composition of groundwater in the Nugget aquifer in the Bear River Basin was also characterized and the quality evaluated on the basis of 14 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram F**).TDS concentrations from produced waters were variable and indicated that waters were very saline (50 percent of samples) or briny (**Appendix F; Appendix H, Diagram F**). TDS concentrations ranged from 14,100 to 113,000 mg/L, with a median of 33,500 mg/L.

Concentrations of some properties and constituents in water from the Nugget aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards (USEPA MCLs and HALs). Concentrations of several properties and constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (one of five samples exceeded the SMCL of 500 mg/L), sulfate (one of five samples exceeded the SMCL of 250 mg/L), and pH (one of six samples below lower SMCL limit of 6.5).

Some water-quality analyses were from produced-water samples, for which chemical analyses of few properties and constituents were available; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. The produced-water samples generally had concentrations of several properties and constituents that exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (all 14 samples exceeded the SMCL of 500 mg/L), chloride (all 14 samples exceeded the SMCL of 250 mg/L), iron (all three samples exceeded the SMCL of 300 μg/L), sulfate (all 14 samples exceeded the SMCL of 250 mg/L), and pH (five of 14 samples below lower SMCL limit of 6.5). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in all 14 of produced-water samples.

Concentrations of some properties and constituents exceeded State of Wyoming standards in the Bear River Basin. The constituent in environmental water samples measured at concentrations greater than agricultural-use standards was sulfate (one of five samples exceeded the WDEQ Class II standard of 200 mg/L). Values of one property (pH) exceeded livestock-use standards and (one of six samples below lower WDEQ Class III limit of 6.5).

The produced-water samples generally had concentrations of several properties and constituents that exceeded agricultural-use standards: TDS (all 14 samples exceeded the WDEQ Class II standard of 2,000 mg/L), chloride (all 14 samples exceeded the WDEQ Class II standard of 100 mg/L), iron (all three samples exceeded the WDEQ Class II standard of 5,000 mg/L5,000 μg/L), sulfate (all 14 samples exceeded the WDEQ Class II standard of 200 mg/L), and pH (one of 14 samples below lower WDEQ Class II limit of 4.5). The produced-water samples had concentrations of several properties and constituents that exceeded livestock-use standards: TDS (all 14 samples exceeded the WDEQ Class III standard of 5,000 mg/L), chloride (all 14 samples exceeded the WDEQ Class III standard of 2,000 mg/L), sulfate (seven of 14 samples exceeded the WDEQ Class III standard of 3,000 mg/L), and pH (five of 14 samples below lower WDEQ Class III limit of 6.5).

7.3.17 Ankareh aquifer

The Upper Triassic Ankareh Formation composes the Ankareh aquifer (**Pl. 5**). The Ankareh Formation consists of red and maroon shale and pale purple limestone with minor white to red, fine-grained, quartz-rich sandstone; thickness of the formation increases eastward from about 460 ft in Idaho to about 920 ft in Wyoming (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). In central Wyoming, the Ankareh Formation is the stratigraphic equivalent of the upper part of the Chugwater Group or Formation (including the Red Peak Member, Alcova Limestone Member, unnamed redbeds of interbedded siltstone and sandstone, and Popo Agie Member of the Chugwater Group or Formation) (Kummel, 1954). The sandstone 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 (Kummel, 1954). Redbeds present below the thin limestone or sandstone in the Ankareh Formation may correlate westward to the Lanes Tongue of the Ankareh Formation (Kummel, 1954).

Previous investigators have defined the Ankareh Formation as an aquifer, and that definition is tentatively retained herein (**Pl. 5**). In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Ankareh Formation was likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) noted that rocks in the Ankareh Formation were relatively impermeable in most areas, but that the unit was probably capable of yielding small quantities of water locally. Ahern et al. (1981, Figure II-7, and Table IV-1) defined the Ankareh Formation as a minor aquifer or minor regional aquifer (locally confining) in the Overthrust Belt (**Pl. 5**). No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin..

7.3.18 Thaynes aquifer

The physical and chemical characteristics of the Thaynes aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics
The Thaynes aquifer is composed of the Upper and Lower Triassic Thaynes Limestone (**Pl. 5**). The Thaynes Limestone consists of gray limestone and brown-weathering, gray, calcareous siltstone with abundant dark gray shale and limestone abundant in the lower part of the formation (Lines and Glass 1975; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). Thickness of the Thaynes Limestone decreases eastward from about 1,640 ft in Idaho to about 700 ft in Wyoming.

Kummel (1954) defined several members of the Thaynes Limestone and the interfingering Ankareh Formation, which the investigator considered a member of the Thaynes Limestone. The Timothy Sandstone Member is the uppermost member of the Thaynes Limestone and is missing at Cokeville and at Spring Canyon in Sublette Ridge, Wyoming (Kummel, 1954). This Timothy Sandstone 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. In Wyoming, the Timothy Sandstone Member is present in the Grays Range. Individual members are not shown on **Plate 5**.

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

The Lanes Tongue of the Thaynes Limestone consists of red, interbedded shale and siltstone, and the unit is 200-ft thick at Cokeville Canyon and 645-ft thick at Spring Canyon in Sublette Ridge, Wyoming (Kummel, 1954). The redbeds member is similar to the overlying Ankareh Formation (Kummel, 1954). The upper calcareous siltstone member consists of light tan, thin- to massively-bedded, silty limestone and calcareous siltstone that is about 1,000-ft thick at Spring Canyon at Sublette Ridge (Kummel, 1954).

The middle shale member of the Thaynes Limestone consists of black shale and shaly limestone with cephalopod, ammonite, and pelecypod fossils (Kummel, 1954). The middle shale member is about 50-ft thick at Cokeville, Wyoming. The middle limestone member of the Thaynes Limestone consists of gray, massive, fine-crystalline limestone with brachiopod and pelecypod fossils; the unit is about 90-ft thick at Cokeville (Kummel, 1954). The lower shale member of the Thaynes Limestone is composed of dark gray, silty limestone and is about 107-ft thick at Cokeville (Kummel, 1954). The lower limestone member of Thaynes Limestone consists of gray-blue to gray (weathers gray), massive limestone with cephalopod fossils and is about 50-ft thick at Spring Canyon in Sublette Ridge (Kummel, 1954).

Previous investigators have defined the Thaynes Limestone as an aquifer and that definition is retained herein (**Pl. 5**). In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Thaynes Limestone was likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) considered the Thaynes Limestone to be the "best aquifer" in their "hydrogeologic division 3" (identified as being composed of Triassic and Permian siltstones and limestones and shown on **Plate 5**) in the Overthrust Belt. Ahern et al. (1981, Figure II-7, and Table IV-1) defined the Thaynes Limestone as a major aquifer or regional aquifer in the Overthrust Belt. Limestone in the Thaynes aquifer likely yields moderate quantities of water to wells; yields are greatest in areas with bedding-plane partings and where secondary permeability in the form of fractures or solution openings, or both, has developed (Lines and Glass, 1975, Sheet 1; Ahern et al., 1981, Figure II-7, and Table IV-1).

Hydrogeologic data describing the Thaynes aquifer, including spring-discharge and well-yield measurements and other hydraulic properties, are summarized on **Plate 4**. Four measured discharges of springs issuing from the Thaynes aquifer ranged from 20 to 300 gal/min with a median of 47.5 gal/min (**Pl. 4**). Two measurements of yields from flowing wells completed in the Thaynes aquifer (12 and 150 gal/min) were inventoried (**Pl. 4**).

Porosity estimates obtained from petroleum exploration data ranged from 1 to 8 percent (**Pl. 4**). Two permeability estimates were obtained from petroleum exploration data and were 0.1 and 0.2 millidarcies (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Thaynes aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and three springs. Summary statistics calculated for available constituents are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram Q**). TDS concentrations indicated that waters were fresh (**Appendix E; Appendix G, Diagram Q**). TDS concentrations ranged from 127 to 386 mg/L, with a median of 299 mg/L. On the basis of the few properties and constituents analyzed for in the environmental water sample, the quality of water from Bear River aquifer and confining unit in the Bear River Basin was likely suitable for most uses. No concentrations of properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of groundwater in the Thaynes aquifer in the Bear River Basin also was characterized and the quality evaluated on the basis of three produced-water samples from two wells (two of the three samples were from different depth intervals within one of the wells). Individual constituent concentrations for this sample are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram G**). The TDS concentrations indicated that the waters were briny (**Appendix F; Appendix H, Diagram G**). TDS concentrations ranged from 36,600 to 72,600 mg/L, with a median of 46,100 mg/L.

Some water-quality analyses were from produced-water samples, for which chemical analyses of few properties and constituents were available; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. The produced-water samples generally had concentrations of several properties and constituents that exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (all three samples exceeded the SMCL of 500 mg/L), chloride (all three samples exceeded the SMCL of 250 mg/L), and sulfate (all three samples exceeded the SMCL of 250 mg/L).
The produced-water samples generally had concentrations of several properties and constituents that exceeded agricultural-use standards: TDS (all three samples exceeded the WDEQ Class II standard of 2,000 mg/L), chloride (all three samples exceeded the WDEQ Class II standard of 100 mg/L), and sulfate (all three samples exceeded the WDEQ Class II standard of 200 mg/L). The produced-water samples had concentrations of several properties and constituents that exceeded livestock-use standards: TDS (all three samples exceeded the WDEQ Class III standard of 5,000 mg/L), chloride (all three samples exceeded the WDEQ Class III standard of 2,000 mg/L), and sulfate (two of three samples exceeded the WDEQ Class III standard of 3,000 mg/L). All TDS concentrations in the produced-water samples exceeded the State of Wyoming Class IV standard of 10,000 mg/L.

7.3.19 Woodside confining unit

The physical and chemical characteristics of the Woodside confining unit in the Bear River Basin are described in this section of the report.

Physical characteristics
The Woodside confining unit is composed of the Lower Triassic Woodside Shale (**Pl. 5**). The Woodside Shale consists of interbedded red siltstone and shale with minor sandstone and gray limestone interbeds; thickness decreases eastward across the Overthrust Belt from about 390 ft in Idaho to about 650 ft in Wyoming (Kummel, 1954; Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). The Woodside Formation overlies the Dinwoody Formation and is overlain by the Thaynes Limestone in the Bear River Basin (**Pl. 5**). The upper part of the Woodside Shale is stratigraphically equivalent to the Red Peak

Member of the Chugwater Group or Formation (Kummel, 1954).

Little information is available describing the hydrogeologic characteristics of the Woodside Shale. In the Bear River valley, Robinove and Berry (1963, Plate 1) speculated that the Woodside Shale was likely to yield small quantities of groundwater to wells. Lines and Glass (1975, Sheet 1) noted that rocks in the Woodside Shale were relatively impermeable and in most areas were probably capable of yielding only small quantities of water. Ahern et al. (1981, Figure II-7) classified the formation as a confining unit [aquitard] and that definition is tentatively retained herein (**Pl. 5**). Two measurements of discharge (2 and 10 gal/min) from springs issuing from the Woodside confining unit were inventoried as part of this study (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Woodside confining unit in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations in the environmental water samples are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram R**). The TDS concentration (302 mg/L) indicated that the water was fresh (**Appendix E; Appendix G, Diagram R**). On the basis of the few properties and constituents analyzed for in the environmental water samples, the quality of water from Woodside confining unit in the Bear River Basin was likely suitable for most uses. No concentrations of properties or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of groundwater in the Woodside confining unit in the Bear River Basin also was characterized and the quality evaluated on the basis of one produced-water sample from one well. Individual constituent concentrations for this sample are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram H**). The TDS concentration (25,000 mg/L) indicated that the water was very saline.

Chemical analyses for few properties and constituents were available for the one produced-water sample; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. Nonetheless, concentrations of some properties and constituents in the Woodside confining unit in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. None of the constituents analyzed had applicable health-based standards. Concentrations of TDS, chloride, and sulfate exceeded aesthetic standards (USEPA SMCLs of 500 mg/L, 250 mg/L, and 250 mg/L, respectively) for domestic use, as well as standards for agricultural use (WDEQ Class II standards of 2,000 mg/L, 100 mg/L, and 200 mg/L, respectively). Concentrations of TDS and chloride also exceeded livestock-use standards (WDEQ Class III standards of 5,000 mg/L and 2,000 mg/L, respectively). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in the produced-water sample.

7.3.20 Dinwoody aquifer and confining unit

The Dinwoody aquifer and confining unit is composed of the Lower Triassic Dinwoody Formation (**Pl. 5**). The Dinwoody Formation consists of basal, middle, and upper units (Kummel, 1954). The 50- to 175-ft thick basal unit of the Dinwoody Formation consists of light tan to tan, silty limestone and calcareous siltstone. The 25- to 350-ft thick middle unit of the Dinwoody Formation consists of interbedded, gray silty limestone, gray crystalline limestone, and olive-light tan to gray shale beds. The 100- to 300-ft thick upper unit consists 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 Sublette Ridge and 180 ft along Muddy Creek in

Lincoln County, Wyoming (Kummel, 1954).

Permeability in the Dinwoody aquifer and confining unit likely is small on a regional scale, and thus, in most areas the unit is probably capable of yielding only small quantities of water from permeable zones where fractures and secondary permeability is present (Lines and Glass, 1975, Sheet 1; Ahern et al., 1981, Table IV-1). Ahern et al. (1981, Figure II-7, and Table IV-1) classified the Dinwoody Formation as a confining unit [aquitard] with locally productive permeable zones in the Overthrust Belt and the adjacent Green River Basin. The investigators (Ahern et al., 1981, Table IV-1) noted that the most productive parts of the Dinwoody Formation were in areas where fractures were present and in interbedded sandstones in the upper part of the formation. In the Wyoming Water Framework Plan, the Dinwoody Formation was classified as a marginal aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Because the unit has low overall permeability, but with distinct zones of higher permeability with potential to yield water to wells, the Dinwoody Formation was classified as both an aquifer and confining unit herein (**Pl. 5**). No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin.

7.4 Paleozoic hydrogeologic units

Lithostratigraphic units of Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian age compose the Paleozoic hydrogeologic units in the Bear River Basin (**Pl. 5**). Paleozoic hydrogeologic units (aquifers and confining units) in the Bear River Basin have a combined thickness averaging about 5,000 ft, with a maximum thickness estimated at 9,800 ft (Clarey, 2011). Thickness of Paleozoic hydrogeologic units in the Bear River Basin generally increases to the west. Compared with aquifers of Cenozoic, Mesozoic and Precambrian age, Paleozoic aquifers are the third most used source of water (Clarey, 2011).

Paleozoic hydrogeologic units underlie Cenozoic and Mesozoic hydrogeologic units in the Bear River Basin, except in areas where structural deformation has uplifted and exposed the Paleozoic units in the mountains and highlands of the Overthrust Belt. Outcrops of Paleozoic hydrogeologic units are limited to small areas located along the Crawford thrust fault system in the western part of the Bear River Basin, along the Tunp thrust fault system east of Cokeville, and along the northeastern part of the Bear River Basin (**Pl. 1**). Paleozoic hydrogeologic units are accessible in or very close to these outcrop areas. Paleozoic aquifers produce water from bedrock composed primarily of carbonate rocks [for example, limestone (rock composed of the mineral calcite) and dolostone (rock composed of the mineral dolomite)] and siliciclastic rocks (for example, sandstone) deposited primarily in marine environments. Development of secondary permeability in Paleozoic hydrogeologic units such as fractures, faults, and solution openings is usually required for successful siting and construction of high yielding wells.

Paleozoic hydrogeologic units generally are 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 characterize and develop groundwater resources from Mesozoic and Paleozoic hydrogeologic units. Where structurally deformed by folding and faulting in the Overthrust Belt, permeability of the sandstone, limestone, and dolostone (dolomite) beds composing the Paleozoic hydrogeologic units may be enhanced by bedding-plane partings, faults, fractures, and solution openings.

Like the Mesozoic hydrogeologic units, numerous petroleum (oil and gas) wells are completed in many of the lithostratigraphic units composing the Paleozoic hydrogeologic units, but relatively few water wells are completed in the units, with most in outcrop areas where drilling depths are relatively shallow and waters are relatively fresh. Most of these wells are completed for domestic or stock purposes, but some are used for other purposes. Much of the geologic and hydrogeologic data for the Paleozoic hydrogeologic units are from petroleum exploration. Groundwater in many of the hydrogeologic units, especially away from outcrop areas and at great depths, is highly mineralized and not suitable for most uses, as indicated by produced-water samples.

7.4.1 Phosphoria aquifer

The physical and chemical characteristics of the Phosphoria aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics
The Phosphoria aquifer is composed of the Permian Phosphoria Formation (**Pl. 5**). The Phosphoria Formation consists of an upper part of dark to light gray, cherty shale and sandstone, and a lower part of brown-weathering, dark, phosphatic shale and limestone. Thickness of the Phosphoria Formation decreases eastward from about 425 ft in Idaho to about 230 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992).

The formation is divided into two members at some locations. The Rex Chert Member 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 are present in the middle and lower part of the Rex Chert Member (Rubey et al., 1980). The Meade Peak Member consists of dark gray, non-resistant, and brown phosphatic siltstone and cherty siltstone, gray dolomite, several blue beds of phosphorite, and one bed of vanadium-bearing carbonaceous siltstone (Rubey et al., 1980). Individual members are not shown on **Plate 5**.

The Phosphoria Formation is classified as an aquifer by most investigators and that definition is retained herein (**Pl. 5**). Robinove and Berry (1963, p. V18) identified the Phosphoria Formation and the underlying Wells Formation as potential Paleozoic aquifers in the Bear River valley; the investigators noted that both formations "may be expected to yield small to moderate amounts of water to wells." Primary permeability in the Phosphoria aquifer likely is small, and in most areas the unit probably is capable of yielding only "small quantities" of water (Lines and Glass, 1975, Sheet 1). However, in areas where fractures are present and secondary permeability is developed, the aquifer is capable of yielding "moderate quantities" of water (Lines and Glass, 1975, Sheet 1). Ahern et al. (1981, Figure II-7, and Table IV-1) classified the Phosphoria Formation as a locally confining minor aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). The investigators (Ahern et al., 1981, Table IV-1) noted that the most productive parts of the Phosphoria Formation were in areas where fractures were present and in interbedded sandstones in the upper part of the formation. In the Wyoming Water Framework Plan, the Phosphoria Formation was classified as a minor aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

Hydrogeologic data describing the Phosphoria aquifer, including spring-discharge and well-yield measurements and other hydraulic properties, are summarized on **Plate 4**. One discharge (300 gal/min) was inventoried for a spring issuing from the Phosphoria aquifer (**Pl. 4**). One well-yield measurement for a flowing well (200 gal/min) was inventoried as part of this study and indicates that the Phosphoria aquifer is capable of providing moderate quantities of water at some locations in the Bear River Basin (**Pl. 4**). Two estimates of transmissivity for the Phosphoria aquifer (0.17 and 0.46 ft^2/d) were inventoried (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Phosphoria aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and one spring. Individual constituent concentrations in the environmental water sample are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram S**). The TDS concentration from the spring (1,230 mg/L) indicated that the water was slightly saline, and the TDS concentration from the well (4,560 mg/L) indicated that the water was moderately saline (**Appendix E; Appendix G, Diagram S**).

Concentrations of some properties and constituents in water from the Phosphoria aquifer in the Bear

River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards (USEPA MCLs and HALs). Concentrations of several properties and constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (well and spring samples exceeded the SMCL of 500 mg/L), sulfate (well and spring samples exceeded the SMCL of 250 mg/L), chloride (well sample exceeded the SMCL of 250 mg/L), and fluoride (well sample exceeded the SMCL of 2 mg/L).

Concentrations of some properties and constituents exceeded State of Wyoming standards for agricultural and livestock use in the Bear River Basin. Properties and constituents in environmental water samples that had concentrations greater than agricultural-use standards were sulfate (well and spring samples exceeded the WDEQ Class II standard of 200 mg/L), TDS (well sample exceeded the WDEQ Class II standard of 2,000 mg/L), and chloride (well sample exceeded the WDEQ Class II standard of 100 mg/L). No concentrations of properties or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.4.2 Wells aquifer

The physical and chemical characteristics of the Wells aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics

The Wells aquifer is composed of the Lower Permian and Upper to Middle Pennsylvanian Wells Formation (**Pl. 5**). The Wells Formation consists of interbedded gray limestone and pale yellow calcareous sandstone with minor gray dolomite beds; the lower part of the formation is cherty. Thickness of the Wells Formation decreases eastward from about 2,000 ft in Idaho to about 600 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992).

The Wells Formation is classified as an aquifer by most investigators and that definition is retained herein (**Pl. 5**). In the Cokeville area, Berry (1955) identified the Wells Formation (referred to as the Tensleep Sandstone) as a potential aquifer (**Pl. 5**). Robinove and Berry (1963, p. V18) identified the Wells Formation and overlying Phosphoria Formation as potential Paleozoic aquifers in the Bear River valley; the investigators noted that both formations "may be expected to yield small to moderate amounts of water to wells." Similarly, Lines and Glass (1975, Sheet 1) noted that sandstone beds composing the formation were aquifers capable of yielding moderate to large quantities of water, depending upon local recharge, sandstone bed continuity, and development of secondary permeability from fractures. In addition, the investigators (Lines and Glass, 1975, Sheet 1) noted that sandstone beds "on topographic highs may be drained, especially if underlying limestones have extensive solution development." Ahern et al. (1981, Figure II-7, and Table IV-1) classified the Wells Formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Wells Formation was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**).

Hydrogeologic data describing the Wells aquifer, including spring-discharge and well-yield measurements and other hydraulic properties, are summarized on **Plate 4**. One discharge (1,800 gal/min) was inventoried for a spring issuing from the Wells aquifer (**Pl. 4**). Two measurements of yields from wells completed in the Wells aquifer (300 and 700 gal/min) were inventoried (**Pl. 4**). One specific capacity for one well completed in the Wells aquifer was inventoried and was 6 (gal/min)/ft (**Pl. 4**). One estimate of transmissivity for one well completed in the Wells aquifer was inventoried and was 1,340 ft^2/d (**Pl. 4**). Porosity estimates obtained from petroleum exploration ranged from 2 to 12 percent (**Pl. 4**). One permeability estimate obtained from petroleum exploration was inventoried and was 0.2 millidarcy (**Pl. 4**).

Chemical characteristics

The chemical composition of groundwater in the Wells aquifer in the Bear River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and one spring. Individual constituent concentrations in the environmental water sample are listed in **Appendix E**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix G, Diagram T**). The TDS concentration from the spring (110 mg/L) and the well (521 mg/L) indicated that the waters were fresh (**Appendix E; Appendix G, Diagram T**). On the basis of the few properties and constituents analyzed for in the environmental water samples, the quality of water from the Wells aquifer in the Bear River Basin was likely suitable for most uses. Environmental waters from both samples were suitable for domestic use, as no concentrations of constituents exceeded health-based standards (USEPA MCLs and HALs). Concentrations of one property (TDS) exceeded aesthetic standards (USEPA SMCLs) for domestic use (well sample exceeded the SMCL of 500 mg/L). No concentrations of properties or constituents approached or exceeded applicable State of Wyoming agriculture, or livestock water-quality standards.

The chemical composition of groundwater in the Wells aquifer in the Bear River Basin also was characterized and the quality evaluated on the basis of one produced-water sample from one well. Individual constituent concentrations for this sample are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram I**). The very large TDS concentration (144,000 mg/L) indicated that the water was briny and, combined with other very poor water-quality characteristics, was unlikely to be usable for any purposes. Chemical analyses for few properties and constituents were available for the one produced-water sample; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. Nonetheless, concentrations of some properties and constituents in the Wells aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. None of the constituents analyzed had applicable health-based standards. Concentrations of TDS, chloride, and sulfate exceeded aesthetic standards (USEPA SMCLs of 500 mg/L, 250 mg/L, and 250 mg/L, respectively) for domestic use, as well as standards for agricultural use (WDEQ Class II standards of 2,000 mg/L, 100 mg/L, and 200 mg/L, respectively). Concentrations of TDS and chloride also exceeded livestock-use standards (WDEQ Class III standards of 5,000 mg/L and 2,000 mg/L, respectively). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in the produced-water sample.

7.4.3 Amsden aquifer

The Amsden aquifer is composed of the Upper Mississippian to Pennsylvanian Amsden Formation (**Pl. 5**). The Amsden Formation consists of red and gray cherty limestone and yellow siltstone, sandstone, and conglomerate; formation thickness decreases eastward across the Overthrust Belt from about 560 ft in Idaho to about 150 ft in Wyoming (Mallory, 1967; Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992). The Amsden Formation is overlain by the Wells Formation and underlain by the Madison Limestone (**Pl. 5**). The Amsden Formation has been divided into as many as three members in some areas, including the Ranchester Limestone Member (Lower Pennsylvanian), the Horseshoe Shale Member (Upper Mississippian to Lower Pennsylvanian), and the Darwin Sandstone Member (Upper Mississippian) (Mallory, 1967).

Little information is available describing the hydrogeologic characteristics of the Amsden Formation in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Lines and Glass (1975, Sheet 1) noted that small quantities of water might be available from cherty limestone in the formation in the Overthrust Belt, but "on topographic highs, the Amsden Formation is probably well-drained, especially if underlying limestones have extensive solution development." Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a minor locally confining aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Amsden Formation was classified as a marginal aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Amsden Formation in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer was retained herein (**Pl. 5**). In the upper Colorado River Basin and adjacent areas, Geldon (2003) classified the Ranchester Limestone and the Darwin Sandstone Members as aquifers and the Horseshoe Shale Member as a confining unit (see Bartos and Hallberg, 2010, Figure 5-4). Few hydrogeologic data describing the characteristics of the Amsden aquifer in the Bear River Basin were inventoried as part of this study. One transmissivity estimate of 0.05 ft^2/ day related to petroleum exploration was inventoried (**Pl. 4**). No data were located describing the chemical characteristics of the Amsden aquifer in the Bear River Basin.

7.4.4 Madison aquifer

The physical and chemical characteristics of the Madison aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics
The Madison aquifer is composed of the Lower to Upper Mississippian Madison Limestone (**Pl. 5**). The Madison Limestone consists of an upper part of light gray, massive limestone and a lower part of dark gray, thin-bedded limestone; dolostone (carbonate rock composed of the mineral dolomite) also is present throughout the formation (Lines and Glass 1975; Oriel and Platt, 1980). Thickness of the Madison Limestone ranges from about 1,000 ft to more than 1,800 ft in the Overthrust Belt (Lines and Glass 1975; Oriel and Platt, 1980).

Little information is available describing the hydrogeologic characteristics of the Madison Limestone in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Madison Limestone was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Madison Limestone in the adjacent Green River Basin and surrounding areas have classified the formation as an important regional aquifer (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Bear River Basin was retained herein (**Pl. 5**).

Like other Paleozoic carbonate aquifers in the Bear River Basin (Bighorn, Darby and Gallatin aquifers), permeability in the Madison aquifer is primarily in areas where secondary permeability is developed, primarily from fractures, bedding-plane partings, and solution openings (Ahern et al., 1981, Figure II-7, and Table IV-1; Geldon, 2003). Lines and Glass (1975, Sheet 1) noted that Madison Limestone outcrops have ancient solution openings (paleokarst) that probably developed before and during deposition of the overlying Amsden Formation, and thus, secondary permeability due to solution openings in the Madison aquifer probably is present at great depths below the land surface. In areas without secondary permeability development, primary permeability of the Madison Limestone is very small to nonexistent (impermeable) and the unit can be considered a confining unit.

Few hydrogeologic data describing the characteristics of the Madison aquifer in the Bear River Basin were inventoried as part of this study. Porosity estimates obtained from petroleum exploration ranged from 2 to 20 percent (**Pl. 4**). Permeability estimates obtained from petroleum exploration ranged from 0.23 to 1.5 millidarcies (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Madison aquifer also was characterized and the quality evaluated on the basis of eight produced-water samples from wells. Summary statistics

calculated for available constituents are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram J**). TDS concentrations were variable and indicated that most waters were briny (50 percent of samples) and remaining waters were fresh to very saline (**Appendix F; Appendix H, Diagram J**). TDS concentrations ranged from 327 to 160,000 mg/L, with a median of 29,700 mg/L.

The available water-quality analyses were from produced-water samples, for which chemical analyses of few properties and constituents were available; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. None of the constituents analyzed had applicable health-based standards. The produced-water samples generally had concentrations of several properties and constituents that exceeded aesthetic standards (USEPA SMCLs) for domestic use: TDS (seven of eight samples exceeded the SMCL of 500 mg/L), chloride (seven of sight samples exceeded the SMCL of 250 mg/L), sulfate (five of eight samples exceeded the SMCL of 250 mg/L), and pH (one of eight samples below lower SMCL limit of 6.5and one of eight samples above upper SMCL limit of 8.5).

The produced-water samples generally had concentrations of several properties and constituents that frequently exceeded agricultural-use standards: TDS (seven of eight samples exceeded the WDEQ Class II standard of 2,000 mg/L), chloride (seven of eight samples exceeded the WDEQ Class II standard of 100 mg/L), and sulfate (five of eight samples exceeded the WDEQ Class II standard of 200 mg/L). The produced-water samples generally had concentrations of several properties and constituents that exceeded livestock-use standards: TDS (seven of eight samples exceeded the WDEQ Class III standard of 5,000 mg/L), chloride (seven of eight samples exceeded the WDEQ Class III standard of 2,000 mg/L), pH (one of eight samples below lower WDEQ Class III limit of 6.5 and one of eight samples above upper WDEQ Class III limit of 8.5), and sulfate (one of eight samples exceeded the WDEQ Class III standard of 3,000 mg/L). Class IV standard of 10,000 mg/L for TDS was exceeded in six of eight produced-water samples.

7.4.5 Darby aquifer

The Darby aquifer is composed of the Upper Devonian Darby Formation (**Pl. 5**). The Darby Formation consists of an upper part of black, yellow, and red sandstone and siltstone and a lower part of dark gray dolomite and dolomitic limestone; thickness of the formation ranges from about 450 to 885 ft (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992).

Little information is available describing the hydrogeologic characteristics of the Darby Formation in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Darby Formation was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Darby Formation in the adjacent Green River Basin and surrounding areas have classified the formation as an important regional aquifer (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Bear River Basin was retained herein (**Pl. 5**).

Like other Paleozoic carbonate aquifers in the Bear River Basin (Madison, Bighorn, and Gallatin aquifers), permeability in the Darby aquifer is primarily in areas where secondary permeability is developed, primarily from fractures, bedding-plane partings, and solution openings (Ahern et al., 1981, Figure II-7, and Table IV-1; Geldon, 2003). In areas without secondary permeability development, primary permeability of the Darby Formation is very small to nonexistent (impermeable) and the unit can be considered a confining unit.

Few hydrogeologic data describing the characteristics of the Darby aquifer in the Bear River Basin were inventoried as part of this study. Two porosity estimates obtained from petroleum exploration were 2 and 7 percent (**Pl. 4**). No data were located describing the chemical characteristics of the hydrogeologic unit.

7.4.6 Laketown Dolomite

The Silurian Laketown Dolomite (**Pl. 5**) is composed of medium to light gray, white-weathering, fine-crystalline, thick-bedded dolomite; formation thickness decreases eastward from about 1,300 ft in Idaho to about 1,000 ft in Wyoming (Oriel and Platt, 1980). The Laketown Dolomite is present only in the southwestern corner of Lincoln County and is absent elsewhere in Wyoming, either due to non-deposition or later erosion that removed most Silurian lithostratigraphic units in Wyoming. No data were located describing the physical and chemical characteristics of the lithostratigraphic unit.

7.4.7 Bighorn aquifer

The physical and chemical characteristics of the Bighorn aquifer in the Bear River Basin are described in this section of the report.

Physical characteristics
The Bighorn aquifer is composed of the Upper Ordovician Bighorn Dolomite (**Pl. 5**). The Bighorn Dolomite consists primarily of light gray massive dolomite and dolomitic limestone, and thickness decreases eastward from about 820 ft in Idaho to about 400 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; Ahern et al., 1981; M'Gonigle and Dover, 1992).

Little information is available describing the hydrogeologic characteristics of the Bighorn Dolomite in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Bighorn Dolomite was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Bighorn Dolomite in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Bear River Basin was retained herein (**Pl. 5**).

Like other Paleozoic carbonate aquifers in the Bear River Basin (Madison, Darby, and Gallatin aquifers), permeability in the Bighorn aquifer is primarily in areas where secondary permeability is developed, primarily from fractures, bedding-plane partings, and solution openings (Ahern et al., 1981, Figure II-7, and Table IV-1; Geldon, 2003). In areas without secondary permeability development, primary permeability of the Bighorn Dolomite is very small to nonexistent (impermeable) and the unit can be considered a confining unit.

Little quantitative hydrogeologic information is available describing the physical or chemical characteristics of the Bighorn aquifer in the Bear River Basin because few wells are completed in the aquifer, but available hydraulic properties are summarized in **Plate 4**. Porosity estimates obtained from petroleum exploration ranged from 2 to 8 percent (**Pl. 4**). Permeability estimates obtained from petroleum exploration ranged from 0.1 to 0.75 millidarcies (**Pl. 4**).

Chemical characteristics
The chemical composition of groundwater in the Bighorn aquifer in the Bear River Basin also was characterized and the quality evaluated on the basis of two produced-water samples from two wells. Individual constituent concentrations for these samples are listed in **Appendix F**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix H, Diagram K**). The TDS concentrations (14,500 and 19,000 mg/L) indicated that the waters were very saline.

Chemical analyses for few properties and constituents were available for the two produced-water samples; thus, comparisons between concentrations in produced-water samples and health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards were limited. Nonetheless, concentrations of some properties and constituents in the Bighorn aquifer in the Bear River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. None of the available constituents analyzed for had applicable health-based standards. Concentrations of TDS (SMCL of 500 mg/L and WDEQ Class III standard of 5,000 mg/L) and chloride (SMCL of 250 mg/L and WDEQ Class III standard of 2,000 mg/L) in both samples, and pH (above upper SMCL and WDEQ Class III limit of 8.5) in one sample exceeded aesthetic standards (USEPA SMCLs) for domestic use and State of Wyoming standards for livestock use. Concentrations of TDS and chloride also exceeded agricultural-use standards (WDEQ Class II standards of 2,000 mg/L and 100 mg/L, respectively). The WDEQ Class IV standard of 10,000 mg/L for TDS was exceeded in both produced-water samples.

7.4.8 Gallatin aquifer

The Gallatin aquifer is composed of the Upper Cambrian Gallatin Limestone (**Pl. 5**). The Gallatin Limestone consists of interbedded, mottled yellow and tan, thin-bedded to massive dolostone (carbonate mineral composed of the mineral dolomite) and limestone; thickness ranges from 230 to 400 ft (Lines and Glass 1975; Oriel and Platt, 1980; Rubey et al., 1980; M'Gonigle and Dover, 1992).

Little information is available describing the hydrogeologic characteristics of the Gallatin Limestone in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a minor aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Bighorn Dolomite was classified as a minor aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Gallatin Limestone in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Bear River Basin was tentatively retained herein (**Pl. 5**).

Like other Paleozoic carbonate aquifers in the Bear River Basin (Madison, Darby, and Bighorn aquifers), permeability in the Gallatin aquifer is primarily in areas where secondary permeability is developed, primarily from fractures, bedding-plane partings, and solution openings (Ahern et al., 1981, Figure II-7, and Table IV-1; Geldon, 2003). In areas without secondary permeability development, primary permeability of the Gallatin Limestone is very small to nonexistent (impermeable) and the unit can be considered a confining unit. No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin.

7.4.9 Gros Ventre confining unit

The Gros Ventre confining unit is composed of the Middle to Upper Cambrian Gros Ventre Formation (**Pl. 5**). The Gros Ventre Formation is composed of gray and tan, oolitic in part, limestone with green-gray micaceous shale in the middle of the formation; thickness of the formation decreases eastward from about 1,300 ft in Idaho to about 650 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980).

Little information is available describing the hydrogeologic characteristics of the Gros Ventre Formation in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a confining unit [aquitard] or regional confining unit [regional aquitard] in the adjacent Green River Basin and in the Overthrust Belt (**Pl. 5**). In the Wyoming Water Framework Plan, the Bighorn Dolomite was classified as a minor aquifer (WWC Engineering et al., 2007, Figure

4-9) (**Pl. 5**). Previous studies of the Gros Ventre Formation in the adjacent Green River Basin and surrounding areas have classified the formation as a confining unit (Ahern et al., 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as a confining unit in the Bear River Basin was tentatively retained herein (**Pl. 5**). No data were located describing the physical and chemical characteristics of the hydrogeologic unit.

7.4.10 Flathead aquifer

The Flathead aquifer is composed of the Lower Cambrian Flathead Sandstone (**Pl. 5**). The Flathead aquifer is confined from above by the Gros Ventre confining unit and from below by the Precambrian basal confining unit (**Pl. 5**). The Lower Cambrian Flathead Sandstone in the Overthrust Belt is composed of white to pink, fine-grained sandstone and some lenses of coarse-grained sandstone; the upper part of the formation includes some green silty shale interbeds, and the lower part is conglomeratic (Lines and Glass, 1975). Thickness of the quartzitic Flathead Sandstone ranges from about 175 to 200 ft in the northern Overthrust Belt (Schroeder, 1969).

Little information is available describing the hydrogeologic characteristics of the Flathead Sandstone in the Bear River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from the Green River Basin to the east and adjacent areas and elsewhere in Wyoming. Ahern et al. (1981, Figure II-7, and Table IV-1) classified the formation as a minor aquifer in the Overthrust Belt and adjacent Green River Basin (**Pl. 5**). In the Wyoming Water Framework Plan, the Flathead Sandstone was classified as a major aquifer (WWC Engineering et al., 2007, Figure 4-9) (**Pl. 5**). Previous studies of the Flathead Sandstone in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern et al., 1981; Taylor et al., 1986; Lindner-Lunsford et al., 1989; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Bear River Basin was tentatively retained herein (**Pl. 5**). Based on lithology, Lines and Glass (1975, Sheet 1) noted that the Flathead Sandstone in the Overthrust Belt was "probably a potential source of water." No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin.

Reported descriptions of Flathead aquifer permeability in Wyoming varies by investigator and the location examined. In the Wind River Basin and Granite Mountains area, Richter (1981, Table IV-1) reported that porosity and permeability is intergranular, but that secondary permeability is present along bedding-plane partings and as fractures associated with folds and faults; the investigator classified the Flathead Sandstone as a "major aquifer" in the Wind River Basin and adjacent Granite Mountains area. Similarly, in the Bighorn Basin, previous investigators (Cooley, 1984, 1986; Doremus, 1986; Jarvis, 1986; Spencer, 1986) also reported intergranular porosity and permeability but also noted secondary permeability development along bedding-plane partings and as fractures associated with folds; all of these investigators classified the Flathead Sandstone as an aquifer. In contrast, Boner et al. (1976) and Weston Engineering, Inc. (2008) noted that the Flathead Sandstone in the southern Powder River Basin and northern flank of the Laramie Mountains was well cemented and poorly sorted with little primary (intergranular) permeability. In addition, Weston Engineering (2008, p. II-4) also noted that bedding-plane partings may provide some permeability, but that silica cement in the formation is not readily dissolved, and that "permeability of the unit is likely to be similar to that of the underlying Precambrian rocks."

7.5 Precambrian basal confining unit

The Precambrian basal confining unit consists of undifferentiated nonporous igneous and metamorphic rocks of the Precambrian basement that act as a basal confining unit for the Flathead aquifer, as well as for all aquifers and aquifer systems in the Bear River Basin (**Pl. 5**). The Precambrian rocks are composed mainly of quartzite with minor quantities of schist and gneiss. The Precambrian basal confining unit is not exposed at land surface within the Bear

River Basin, but underlies the younger geologic formations at greater depths. Precambrian rocks are exposed at land surface in areas adjacent to the Bear River Basin in southeastern Idaho and northern Utah and in the adjacent Snake-Salt and Green River Basins of Wyoming. Compared with hydrogeologic units of Cenozoic, Mesozoic, and Paleozoic age, the Precambrian basal confining unit is the least used and in fact, does not appear to be used as a source of water for any purposes in the Bear River Basin (Clarey, 2011). No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Bear River Basin.