

# Chapter 6

## *Groundwater quality*

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## Abbreviations and acronyms

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AMCL	Alternate maximum contaminant level
BAG	Basin Advisory Group
GGRB	Greater Green River Basin
GIS	Geographic Information System
HAL	Lifetime health advisory level
µg/L	Micrograms per liter
MCL	Maximum contaminant level
mg/L	Milligrams per liter
NWIS	National Water Information System
pCi/L	Picocuries per liter
PWD	Produced Water Database (USGS)
SAR	Sodium-adsorption ratio
SDWA	Safe Drinking Water Act
SMCL	Secondary maximum contaminant level
TDS	Total dissolved solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WQD	Water Quality Division (WDEQ)
WRDS	Water Resource Data System ( <i>University of Wyoming</i> )
WSEO	Wyoming State Engineer's Office
WSGS	Wyoming State Geological Survey
WWDC	Wyoming Water Development Commission
WWDO	Wyoming Water Development Office
WyGISC	Wyoming Geographic Information Science Center

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### GROUNDWATER QUALITY DATA

This section describes how data on the chemical constituents in GGRB groundwater were collected, accessed, screened, and statistically analyzed.

### Regulation and classification of groundwater

Groundwater quality in Wyoming is regulated by two agencies. The Wyoming Department of Environmental Quality (WDEQ) Water Quality Division (WQD) regulates groundwater quality in Wyoming, and the U.S. Environmental Protection Agency (USEPA) Region 8 Office, headquartered in Denver, regulates the public water systems located within the state. Each agency has established

groundwater standards, and revises and updates them periodically.

Groundwater in Wyoming is classified with respect to water quality in order to apply these standards. The State of Wyoming through the WDEQ/WQD has classified the groundwater of the state, per Water Quality Rules and Regulations, Chapter 8 – Quality Standards for Wyoming Groundwaters (Wyoming Department of Environmental Quality, 2005, p. 5), as:

- Class I Groundwater of the State – Groundwater suitable for domestic use.

- Class II Groundwater of the State – Groundwater suitable for agricultural use where soil conditions and other factors are adequate for such use.
- Class III Groundwater of the State – Groundwater suitable for livestock.
- Class Special (A) Groundwater of the State – Groundwater suitable for fish and aquatic life.
- Class IV Groundwater of the State – Groundwater suitable for industry.
- Class IV(A) Groundwater of the State – Groundwater that has a total dissolved solids (TDS) concentration not in excess of 10,000 milligrams per liter (mg/L). This level of groundwater quality in an aquifer is considered by the USEPA under Safe Drinking Water Act (SDWA) provisions as indicating a potential future drinking water source with water treatment.
- Class IV(B) Groundwater of the State – Groundwater with a TDS concentration in excess of 10,000 mg/L.
- Class V Groundwater of the State – Groundwater closely associated with commercial deposits of hydrocarbons (oil and gas) (Class V, Hydrocarbon Commercial) or other minerals (Class V, Mineral Commercial), or is a geothermal energy resource (Class V, Geothermal).
- Class VI Groundwater of the State – Groundwater unsuitable for any use.

### **Standards of groundwater quality**

In this chapter, groundwater quality is described in terms of a water's suitability for domestic, irrigation, and livestock use on the basis of USEPA and WDEQ standards (**Table 6-1**), and water-quality sample statistics are tabulated by geologic unit as quantile values (**Appendices 4 and 5**). In assessing suitability for domestic use (Class I groundwater), USEPA health-based maximum contaminant level (MCL) and health advisory level (HAL) standards are used (even though they are not legally enforceable for any of the sampling sites used in

this study). USEPA secondary maximum contaminant level (SMCL) standards for domestic use and WDEQ groundwater Class II standards for agriculture and Class III standards for livestock are used simply as guides.

Many groundwater analyses used in this study do not include every constituent for which a standard exists. Our assessment of an analyzed water for a given use is based *only* on the concentrations of constituents determined; the concentration of a constituent not determined could make the water unsuitable for a given use.

Water quality is measured against three types of USEPA standards: Maximum Contaminant Level (MCL), Secondary Maximum Contaminant Level (SMCL), and Lifetime Health Advisory Level (HAL) standards. The USEPA MCLs (U.S. Environmental Protection Agency, 2006) are legally enforceable standards that apply to public water systems that provide water for human consumption through at least 15 service connections or regularly serve at least 25 individuals. The purpose of MCLs is to protect public health by limiting the levels of contaminants in drinking water. MCLs do not apply to groundwater for livestock, irrigation, or self-supplied domestic use. They are, however, a valuable reference when assessing the suitability of water for these uses.

USEPA SMCLs (U.S. Environmental Protection Agency, 2006) are non-enforceable guidelines regulating contaminants in drinking water that may cause cosmetic effects (such as skin or tooth discoloration) or have negative aesthetic effects (such as taste, odor, or color). HALs are based on concentrations of chemicals in drinking water that are expected to cause adverse or carcinogenic effects over a lifetime of exposure (U.S. Environmental Protection Agency, 2006). Because of health concerns, the USEPA has proposed two drinking-water standards for radon (U.S. Environmental Protection Agency, 1999a): an MCL of 300 pCi/L and an alternative MCL (AMCL) of 4,000 pCi/L for communities with indoor air multimedia mitigation programs. Radon concentrations herein are compared, and exceedance frequencies calculated, in relation to the proposed MCL of 300 pCi/L.

**Table 6-1.** Selected groundwater quality standards and advisories

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; LHA, lifetime health advisory level; USEPA, U.S. Environmental Protection Agency; WDEQ, Wyoming Department of Environmental Quality; WQD, Water Quality Division; N, nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; SAR, sodium-adsorption ratio; TDS, total dissolved solids]

Physical characteristics and constituents		Groundwater quality standards				
		Domestic <sup>1</sup>			Agricultural <sup>2</sup>	Livestock <sup>2</sup>
		MCL (USEPA)	SMCL (USEPA)	LHA (USEPA)	Class II (WDEQ/WQD)	Class III (WDEQ/WQD)
<i>Physical characteristics</i>	pH (standard units)		6.5–8.50		4.5–9.0	6.5–8.5
<i>Major ions and related characteristics (mg/L)</i>	chloride (Cl <sup>-</sup> )		250		100	2,000
	fluoride (F <sup>-</sup> )	4	2			
	sulfate (SO <sub>4</sub> <sup>2-</sup> )		250		200	3,000
	TDS		500		2,000	5,000
	SAR (ratio)				8	
<i>Trace elements (µg/L)</i>	aluminum (Al) (range)		50–200		5,000	5,000
	antimony (Sb)	0.6				
	arsenic (As)	10			100	200
	barium (Ba)	2,000				
	beryllium (Be)	4			100	
	boron (B)			1,000	750	5,000
	cadmium (Cd)	5			10	50
	chromium (Cr)	100			100	50
	cobalt (Co)				50	1,000
	copper (Cu)	1,300	1,000		200	500
	cyanide <sup>3</sup> (CN <sup>-</sup> )	200				
	iron (Fe)		300		5,000	
	lead (Pb)	15			5,000	100
	lithium (Li)				2,500	
	manganese (Mn)		50		200	
	molybdenum (Mo)			40		
	mercury (Hg)	2				0.05
	nickel (Ni)			100	200	
	selenium (Se)	50			20	50
	silver (Ag)		100			
	thallium (Tl)			0.5		
	vanadium (V)				100	100
	zinc (Zn)		5,000	2,000	2,000	25,000
<i>Nutrients (mg/L)</i>	nitrate (NO <sub>3</sub> <sup>-</sup> ), as N	10				
	nitrite (NO <sub>2</sub> <sup>-</sup> ), as N	1				10
	nitrate + nitrite, as N					100
	ammonium (NH <sub>4</sub> <sup>+</sup> )			30		

**Table 6-1.** Selected groundwater quality standards and advisories – *continued*

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; LHA, lifetime health advisory level; USEPA, U.S. Environmental Protection Agency; WDEQ, Wyoming Department of Environmental Quality; WQD, Water Quality Division; N, nitrogen; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; SAR, sodium-adsorption ratio; TDS, total dissolved solids]

Physical characteristics and constituents	Groundwater quality standards				
	Domestic <sup>1</sup>			Agricultural <sup>2</sup>	Livestock <sup>2</sup>
	MCL (USEPA)	SMCL (USEPA)	LHA (USEPA)	Class II (WDEQ/WQD)	Class III (WDEQ/WQD)
gross-alpha radioactivity <sup>4</sup>	15			15	15
<i>Radiochemicals</i> (pCi/L)	strontium-90 (strontium)		4,000 (mg/L)	8	8
	radium-226 plus radium-228			5	5
	radon-222 (radon) <sup>5</sup>	300/4,000 (proposed) <sup>5</sup>			
	uranium (µg/L)	30			

<sup>1</sup>Selected from USEPA 2006 edition of the Drinking Water Standards and Health Advisories (U.S. Environmental Protection Agency, 2006).

<sup>2</sup>Selected from WDEQ, 2005, Water Quality Rules and Regulations, Chapter 8, Quality Standards for Wyoming Groundwaters, Table 1, p. 9.

<sup>3</sup>Trace ion, included for convenience

<sup>4</sup>Includes radium-226 but excludes radon-222 and uranium

<sup>5</sup>The 300 pCi/L standard is a proposed MCL, whereas the 4,000 pCi/L standard is a proposed alternative MCL for communities with indoor air multimedia mitigation programs (U.S. Environmental Protection Agency, 1999a).

Quality standards for Wyoming Class II and Class III groundwater (Wyoming Department of Environmental Quality, 1993) also are used for comparisons in this report. Class II groundwater is water suitable for agricultural (irrigation) use where soil conditions and other factors are adequate. Class III groundwater is water suitable for livestock watering. These Wyoming standards are designed to protect groundwater that meets the criteria of a given class from being degraded by human activity. They are not meant to prevent groundwater that does not meet the standards from being used for a particular use. Like the USEPA standards, they serve only as guides in this report, to help assess the suitability of groundwater for various uses.

### Sources, screening, and selection of data

Groundwater quality data were gathered from the USGS National Water Information System (NWIS) database, the USGS Produced Waters Database (PWD), the Wyoming Oil and Gas Conservation Commission (WOGCC) database, the University of Wyoming Water Resources Data

System (WRDS) database, and other sources such as consultant reports prepared in relation to development of public water supplies. Methods used to screen data differ among the data sources, but the overall objective of all screening was to identify and remove samples that (1) were duplicates; (2) were not assigned to hydrogeologic units or were assigned to hydrogeologic units that contradicted local geologic information, particularly for shallow wells; (3) had inconsistent water-chemistry information such as poor ion balances or substantially different values of total dissolved solids and the sum of major ions; or (4) were unlikely to represent the water quality of a hydrogeologic unit because of known anthropogenic effects – for example, samples from wells monitoring known or potential point-source contamination sites or mining spoils sites.

Many of the Greater Green River Basin (GGRB) groundwater sites had been sampled more than once; however, only one groundwater sample from a given site was selected for this study, to avoid biasing the statistical results in favor of multiple-sam-

ple sites. An exception involved some sets of PWD samples from the same well at different depths and from different geologic units. In choosing among multiple samples from a site or well/geologic-unit combination, either the most recent sample, the sample with the best ion balance, or the sample with the most complete analysis was retained in the final data set.

Groundwater-quality sample analyses from the USGS PWD are used in this report. Produced water is water co-produced with oil and gas. The PWD includes samples within the GGRB. Only those PWD samples from a wellhead or from a drill-stem test were used. Samples not assigned to a geologic unit were removed. The PWD samples were then screened to retain a single sample per well/geologic-unit combination. Some samples were removed because their water chemistry was identical to that of other samples, indicating probable duplication of sample records. PWD documentation indicated that the data generally had been screened to remove samples showing an ion balance greater than 15 percent – strictly, an imbalance between anion and cation activity of greater than 15 percent. The PWD generally contains chemical analyses for major ions and TDS. According to PWD documentation, some sample analyses may have reported the sum of sodium and potassium concentrations as sodium concentration alone.

Groundwater-quality sample analyses from the WOGCC database are used in this report. Major-ion balances were calculated for these samples. Samples with an ion balance of greater than 10 percent were generally removed, but some samples with an ion balance of between 10 and 15 percent from areas with few samples were retained.

Some groundwater-quality samples from the WRDS database are used in this report, where information was available to identify the geologic unit and locate the spring or well and the site was not in the USGS NWIS database. In addition, WDEQ monitoring wells located at sites of known or potential groundwater contamination were removed because the objective of this study is to describe general groundwater quality based on natural conditions. Samples showing an ion

balance greater than 10 percent were removed from the WRDS data set.

Groundwater quality in the GGRB varies widely, even within a single geologic unit. Water quality in any given geologic unit tends to be better near outcrop areas where recharge occurs, and to deteriorate as the distance from these areas increases (and residence time increases). Correspondingly, the water quality in a given geologic unit generally deteriorates with depth.

Many of the water-quality samples from Quaternary and Tertiary geologic units came from wells and springs that supplied water for livestock and wildlife. Wells that do not produce usable water are generally abandoned, and springs that do not produce usable water typically are not developed. In addition, where a geologic unit is deeply buried, it generally is not used for water supply if a shallower supply is available. For these reasons, the groundwater-quality samples from the Quaternary, Tertiary, and some Cretaceous geologic units are most likely biased toward better water quality, and do not represent random samples. Although this possible bias likely does not allow accurate characterization of the water quality of these geologic units, it probably allows more accurate characterization of the units in areas where they are shallow enough to be used economically.

Many of the groundwater-quality samples used in this study to characterize Mesozoic and Paleozoic geologic units are produced-water samples from the USGS PWD and WOGCC databases. Although these samples were from oil and gas production areas, we believe that they probably have less bias in representing ambient groundwater quality than samples used to characterize Quaternary and Tertiary geologic units.

### **Water-quality characteristics**

The total dissolved solids (TDS) concentration in groundwater tends to be high with respect to the USEPA SMCL in most of the GGRB, even in water from shallow wells. This is not surprising, given the arid climate and small rate of recharge in much of the study area. High TDS can adversely affect the taste and odor of drinking water, and a

high TDS concentration in irrigation water has a negative effect on crop production. High TDS concentrations also cause scale build-up in pipes and boilers. There is no USEPA MCL for TDS, and the USEPA SMCL for TDS is 500 milligrams per liter (mg/L) (U.S. Environmental Protection Agency, 2006). TDS concentration is loosely termed *salinity*. Groundwater samples are classified in this report in accordance with the USGS salinity classification (Heath, 1983), as follows:

<i>Classification</i>	<i>TDS</i>
Fresh	0–1,000 mg/L
Slightly saline	1,000–3,000 mg/L
Moderately saline	3,000–10,000 mg/L
Very saline	10,000–35,000 mg/L
Briny	more than 35,000 mg/L

The sodium-adsorption ratio (SAR) represents the ratio of sodium ion activity (concentration) to calcium and magnesium ion activities; it is used to predict the degree to which irrigation water enters into cation-exchange reactions in the soil. High SAR values predict sodium replacing adsorbed calcium and magnesium in soil, which damages soil structure (Hem, 1985) and reduces permeability of the soil to water infiltration. The high SAR of waters in some geologic units in the GGRB indicates that these waters are unsuitable for irrigation.

Many groundwater-quality samples reviewed for this report also contain high concentrations of sulfate, chloride, fluoride, iron, and manganese, with respect to USEPA and WDEQ water-quality standards. As expected, produced water (defined in the produced water samples section, below) commonly exceeded many USEPA and WDEQ standards.

Sulfate in drinking water can adversely affect the taste and odor of the water, and may cause diarrhea (U.S. Environmental Protection Agency, 2006). The USEPA SMCL for sulfate is 250 mg/L (U.S. Environmental Protection Agency, 2006); the WDEQ Class II groundwater (agricultural) standard is 200 mg/L, and the WDEQ Class III groundwater (livestock) standard is 3,000 mg/L. High chloride concentration can adversely affect the taste of drinking water, increase the corrosive-

ness of water, and damage salt-sensitive crops. The USEPA SMCL for chloride is 250 mg/L (U.S. Environmental Protection Agency, 2006); the WDEQ agricultural standard is 100 mg/L; and the WDEQ livestock standard is 2,000 mg/L.

High fluoride concentrations commonly are associated with produced water from deep geologic units in sedimentary structural basins. Low concentrations of fluoride in the diet have been shown to promote dental health, but higher doses can cause health problems such as dental fluorosis – a discoloring and pitting of the teeth – and bone disease (U.S. Environmental Protection Agency, 2006). The USEPA SMCL for fluoride is 2.0 mg/L, and the MCL is 4.0 mg/L.

Both iron and manganese may adversely affect the taste and odor of drinking water and cause staining. The USEPA has established SMCLs for iron at 300 micrograms per liter ( $\mu\text{g/L}$ ) and manganese at 50  $\mu\text{g/L}$  (U.S. Environmental Protection Agency, 2006). High concentrations of iron and manganese in irrigation water may have a detrimental effect on crop production.

### Statistical analysis

*Analysis* has two meanings in this chapter, *chemical analysis* and *statistical analysis*. Chemical analysis of a water sample is the determination (or the description) of the concentration of chemical species dissolved in the water: for example, *the concentration of calcium in the sample is 6 mg/L* [6 milligrams of calcium per liter of water]. Chemical analysis may include such physical measurements of chemical properties as pH [a measure of hydrogen ion activity]. The statistical analysis of a *set* of chemical analyses is the mathematical treatment of the set of data to describe and summarize those data in order to convey certain useful descriptive characteristics: for example, *the calcium concentration in groundwater samples from this formation ranges from 5.0 to 20 mg/L, with a median concentration of 17 mg/L*.

This section describes the approaches we used to assemble, analyze, and present water-quality data for samples of groundwater from the GGRB. **Supplementary data tables** contain all data used in this

chapter: these data are too numerous for inclusion in the memorandum, but are available online at <http://waterplan.state.wy.us/plan/green/green-plan.html>

From these data, we derived *summary statistics* for physical characteristics and major-ion chemistry of groundwater in GGRB geologic units, as tabulated in **Appendix 4** for environmental samples and **Appendix 5** for produced water samples. *Environmental water* is natural groundwater as produced from wellheads and springs; it is not associated with hydrocarbons. *Produced water* is water coproduced (pumped out of the ground) with oil and gas. We also used these data to compare water quality in GGRB geologic units with U.S. Environmental Protection Agency (USEPA) and Wyoming Department of Environmental Quality (WDEQ) standards for various uses, as the *groundwater quality standard exceedance frequencies* presented in this chapter.

A groundwater quality standard exceedance frequency is reported as a percentage, which is based on the number of samples analyzed for the characteristic or constituent, not the total number of samples available in the data set for the geologic unit. For some constituents, groundwater-quality data sets used in calculating summary statistics differed from the final data sets used in calculating groundwater-quality standard exceedance frequencies. All groundwater quality samples and analyses in the final data sets were used in calculating regulatory standard exceedance frequencies. Several laboratories produced data used in this chapter, and many different types of analyses and analytical methods were used for the same constituent in the final data sets. Many results were considered appropriate for calculation of exceedance frequencies after the initial data screening described in the *Sources, screening, and selection of data* section. However, after further review of available laboratory quality-control documentation, some results were judged to be unreliable for use in summary statistics: selected data from laboratories could be removed after the review. In some cases, further review of the final data sets resulted in a smaller number of samples for a given constituent being used

in calculating summary statistics than were used in calculating exceedance frequencies, or resulted in some constituents being compared with exceedance frequencies and not used in calculating summary statistics. For example, some values that exceeded groundwater quality standards are not shown in the summary statistics appendices; however, all data are shown in the supplementary data tables. In addition, groundwater-quality data sets used in calculating summary statistics for constituents with censored values may have differed from the final data sets used in calculating groundwater quality standard exceedance frequencies because of the sample size requirements of the statistical method used in calculating summary statistics (see below). All groundwater quality samples and analyses in the final data sets were used in calculating regulatory standard exceedance frequencies, including formations with fewer than four samples or fewer than three uncensored values for a constituent. Because the statistical method used only computes statistics for the interquartile range, large values that may have exceeded regulatory standards may not be shown in the summary statistics tables (**Appendices 4 and 5**).

Standard summary statistics (Helsel and Hirsch, 1992) for uncensored data were used. Censored data are data reported as above or below some threshold, such as “below detection limit” or “less than 1 mg/L.” For a small number of samples, censored values (“less-than”) may have been reported. These values were treated as values at the laboratory reporting limit. For a sample size of 1, only a minimum value is reported in Appendices 4 and 5; for a sample size of 2, minimum and maximum values are reported; for a sample size of 3, minimum, median (50th percentile), and maximum values are reported; for sample sizes of 4 or more, minimum, 25th percentile, median (50th percentile), 75th percentile, and maximum values are reported. For some constituents, several zeros were coded in the original data set. During sample evaluation, most of these values should have been reported as missing, not zero. Therefore, the zero-values were removed from the data set before statistical summary of the data.

Many nutrient concentrations were reported as censored values. In some cases, censored values expressed multiple detection limits (MDL). A statistical technique that computes summary statistics for MDL data (or left-censored data) was used to analyze such data in this report. Rather than assigning the laboratory reporting limit or another arbitrary limit to MDL data, we used censored-value analyses to compute summary statistics.

Regression on order statistics of log-transformed data and adjusted maximum likelihood estimation (AMLE) techniques are two methods designed to reduce the error of estimation during statistical summary of censored data (Helsel and Cohn, 1988). For this report, the AMLE technique was selected because it gave lowest errors for quartiles compared with other techniques (Helsel and Cohn, 1988, p. 1997). The summary statistics presented in the report for nutrient data by geologic unit are the 25<sup>th</sup> percentile, median, and 75<sup>th</sup> percentile. The sample size must be at least four for the AMLE method to compute percentiles; therefore, summary statistics are only shown for formations with a sample size of four or larger. Generally, the method is less reliable for small sample sizes.

As with nutrients, some trace element concentrations were reported as censored values. Therefore, the summary statistics presented in the report for trace element data by geologic unit are the 25<sup>th</sup> percentile, median, and 75<sup>th</sup> percentile, which were calculated using the AMLE method. Summary statistics are only shown for geologic units with a sample size of four or larger. No zero-values were coded as constituent concentrations in the original data set for the geologic units that have summary statistics.

As with nutrients and trace elements, some radiochemical concentrations were reported as censored values. Therefore, the summary statistics presented in the report for radiochemical data by geologic unit are the 25<sup>th</sup> percentile, median, and 75<sup>th</sup> percentile, which were calculated using the AMLE method. Summary statistics are only shown for geologic units with a sample size of four or larger. No zero-values in the original data set were

coded as constituent concentrations for the geologic units that have summary statistics.

#### *Environmental water samples*

Environmental water samples are from wells of all types except those used for resource extraction (primarily oil and gas production) or those used to monitor areas with known groundwater contamination. The environmental water samples used in this report were compiled from the USGS NWIS database, the WRDS database, the Sublette County Conservation District, and other sources such as consulting engineers' reports related to water supply exploration and development. The physical characteristics and constituents presented in this chapter are pH, major ions, nutrients, trace elements, and radiochemicals.

Physical characteristics of environmental waters, which are generally measured in the field on unfiltered waters, were pH (reported in standard units) and specific conductance (reported in microsiemens per centimeter at 25°C). If field values were not available, laboratory values were used.

Major-ion chemistry of environmental waters, comprising major ions and associated characteristics or constituents, was reported as laboratory analyses of filtered waters (or constituents were calculated from laboratory analyses). Major-ion chemistry constituents and related characteristics were hardness (calculated and reported as calcium carbonate), dissolved calcium, dissolved magnesium, dissolved potassium, sodium-adsorption ratio (calculated), dissolved sodium, alkalinity (reported as calcium carbonate), dissolved bromide, dissolved chloride, dissolved fluoride, dissolved silica, dissolved sulfate, and total dissolved solids.

For this report, a measured laboratory value of dissolved solids (residue on evaporation at 180°C) was commonly used. If a laboratory value was not available, a dissolved-solids value was calculated by summing concentrations of individual constituents (if complete analyses were available). For this report, a filtered laboratory value of alkalinity was used. If that was not available, an unfiltered laboratory value of acid-neutralizing capacity (ANC) was used for alkalinity; if that constituent was not avail-

able, a filtered field alkalinity was used; and if that was not available, an unfiltered field ANC was used to report alkalinity. These constituents are reported in milligrams per liter (mg/L).

Nutrient constituents in environmental waters, analyzed in a laboratory using filtered waters, were dissolved ammonia (reported as nitrogen), dissolved nitrate plus nitrite (reported as nitrogen), dissolved nitrate (reported as nitrogen), dissolved nitrite (reported as nitrogen), dissolved orthophosphate (reported as phosphorus), and dissolved phosphorus (reported as phosphorus). These constituents are reported in mg/L.

For dissolved ammonia, dissolved nitrate, and dissolved orthophosphate, several zeros were coded in the original data set. During sample evaluation, we inferred that these values should have been reported as missing or as censored values. Because a censoring limit was not coded with the historical samples, the zero values were removed from the data set before statistical summary of the data.

Trace element constituents in environmental waters, analyzed in a laboratory using filtered waters, were dissolved aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium-90 (referred to herein as *strontium*), thallium, vanadium, and zinc. In addition, total cyanide (unfiltered) was determined. These constituents are reported in micrograms per liter ( $\mu\text{g/L}$ ).

Radiochemical constituents in environmental waters, analyzed in a laboratory using filtered waters, were dissolved gross-alpha radioactivity (using a thorium-230 curve method), dissolved radium-226, dissolved radium-226 using a radon method, dissolved radium-228, dissolved uranium (natural), and radon-222 (unfiltered) (referred to herein as *radon*). All radiochemical constituents are reported in picocuries per liter (pCi/L) except uranium, which is reported as  $\mu\text{g/L}$ .

Negative numbers and zero values in the original data set were treated as missing values because censoring limits could not be determined. Standard

summary statistics for uncensored data were used because none of the original data were reported as censored data.

#### *Produced water samples*

Produced-water samples are from wells related to natural resource extraction (primarily oil and gas production). Produced water data were compiled from the WOGCC database, the USGS PWD, and the other sources listed under *environmental water samples*. The physical characteristics and constituents presented in this chapter for produced water samples are pH, major ions, and trace elements. Nutrients were not included because nitrite was the only constituent available; it was infrequently reported in the sample analyses, and the form (whether as nitrite or as nitrogen) was not reported. Radiochemical data were not included because radium-226 was the only constituent available; it was infrequently reported with the sample analyses, and the analytical method and reporting units were unknown.

The physical characteristics, major ion chemistry, and trace elements summarized for produced waters were generally the same as for environmental waters, with some exceptions. In the produced-waters data set, the water condition (filtered or unfiltered) was not reported with the data. The physical characteristics and major-ion chemistry constituents statistically analyzed herein are pH (in standard units), conductance (assumed to be specific conductance reported in microsiemens per centimeter at 25°C), calcium, magnesium, potassium, sodium-adsorption ratio (SAR, calculated), sodium, bicarbonate (reported as bicarbonate), carbonate (reported as carbonate), chloride, fluoride, silica, sulfate, and dissolved solids. The method for determining dissolved solids was not reported with the data. The reporting unit for major-ion chemistry was mg/L. The trace elements summarized were aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, mercury, nickel, selenium, strontium, and zinc. Trace-element concentrations in the original data set were reported in mg/L; we converted them to  $\mu\text{g/L}$  for the statistical summary.

## **GROUNDWATER QUALITY ASSOCIATED WITH GEOLOGIC UNITS**

This section discusses the quality of the groundwater in geologic units in the GGRB. For each geologic unit, groundwater-quality analyses are first discussed for the entire GGRB; the groundwater-quality analyses are then grouped and discussed by region for any of the nine geographic regions that compose the GGRB in which the unit occurs (**Figure 6-1**). In many cases, not enough groundwater-quality data were available to make accurate comparisons between regions, given the large variation in water quality within the regions. Given the proximity of the regions, it is likely that for many geologic units, differences in groundwater quality due to distance from recharge areas or to depth are more significant than differences between regions.

### **Cenozoic geologic units**

The water quality of Cenozoic geologic units, as divided into Quaternary and Tertiary geologic units, is discussed in this section of the report.

### **Quaternary geologic units**

The chemical composition of groundwater in undifferentiated Quaternary deposits in the Green River Basin was characterized and the quality evaluated on the basis of four environmental water samples from springs in the Green River Basin. On the basis of TDS concentrations, waters from three samples were classified as fresh and water from the fourth sample was classified as slightly saline. TDS concentrations ranged from 253 to 1,510 mg/L, with a median of 278 mg/L.

Concentrations of some characteristics and constituents in undifferentiated Quaternary deposits approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of waters for some uses. On the basis of comparison with health-based standards, all environmental waters were suitable for domestic use. Concentrations of a few characteristics and constituents exceeded aesthetic standards for domestic use: manganese (33% of samples), sulfate (25%), and TDS (25%).

For agricultural and livestock use, concentrations of one constituent exceeded State of Wyoming agricultural-use standards and no characteristics or constituents exceeded State of Wyoming livestock standards in the Green River Basin. Sulfate was the only constituent measured at concentrations greater than agricultural-use standards (standard exceeded in 25% of samples).

**Alluvium and colluvium.** The chemical composition of groundwater in alluvium and colluvium (herein termed *alluvium*) in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 70 wells and 12 springs. Major-ion composition of alluvial waters throughout the GGRB is shown in relation to TDS on a trilinear diagram (**Appendix 2, diagram A**). TDS concentrations varied widely and indicated that most waters were fresh (65% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents measured in environmental water samples in the GGRB 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: radon (86%), uranium (50%), strontium (43%), arsenic (33%), boron (21%), lead (20%), molybdenum (20%), selenium (14%), cadmium (11%), nitrite plus nitrate (8%), nitrate (5%), nitrite (3%), and ammonia (3%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (58%), sulfate (44%), manganese (29%), aluminum (22% exceeded upper limit of range; see **Table 6-1**), iron (22%), chloride (10%), and pH (8% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (53%), SAR (30%), boron (29%), selenium (29%), TDS (25%), chloride (21%), manganese (20%), cad-

mium (11%), iron (6%), and pH (3% exceeded upper limit). Characteristics and constituents measured at concentrations greater than livestock-use standards were lead (20%), selenium (14%), TDS (10%), sulfate (9%), pH (8% exceeded upper limit), chloride (4%), boron (4%), and nitrite plus nitrate (2%).

#### *Green River Basin*

The chemical composition of groundwater in alluvium in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from 48 wells and 4 springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (74% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 148 to 9,810 mg/L, with a median of 494 mg/L.

Concentrations of some characteristics and constituents in alluvium in the Green 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: arsenic (100%), radon (100%), molybdenum (67%), strontium (67%), uranium (50%), selenium (40%), boron (19%), nitrite plus nitrate (9%), nitrate (5%), nitrite (4%), and ammonia (4%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (48%), sulfate (37%), manganese (14%), pH (13% exceeded upper limit), and chloride (5%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (42%), selenium (40%), SAR (32%), boron (25%), TDS (19%), chloride (12%), manganese (9%), and pH (4% exceeded upper limit). Characteristics and constituents measured at concen-

trations greater than livestock-use standards were selenium (40%), pH (13% exceeded upper limit), TDS (5%), nitrite plus nitrate (3%), and sulfate (2%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in alluvium in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 11 wells and 6 springs. Summary statistics calculated for available characteristics and constituents are listed in **Appendix 4b**. TDS concentrations varied widely and indicated that most waters were fresh (71% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 193 to 59,000 mg/L, with a median of 736 mg/L.

Concentrations of some characteristics and constituents in alluvium in the Great Divide/Washakie/Sand Wash basins 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 a few constituents exceeded health-based standards: radon (100%), lead (50%), and cadmium (50%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: iron (100%), manganese (100%), TDS (64%), aluminum (50% exceeded lower and upper limits), sulfate (29%), and chloride (7%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (57%), cadmium (50%), TDS (21%), chloride (20%), selenium (20%), SAR (12%), and boron (11%). Characteristics and constituents measured at concentrations greater than livestock-use standards were lead (50%), sulfate (14%), TDS (14%), and chloride (7%).

### *Rock Springs Uplift*

The chemical composition of groundwater in alluvium on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from five wells. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations varied and indicated that most waters were moderately saline (60% of samples) and remaining waters were very saline (supplementary data tables). TDS concentrations ranged from 3,300 to 21,200 mg/L, with a median of 9,360 mg/L.

Concentrations of some characteristics and constituents in alluvium in the Rock Springs Uplift 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: boron (100%), radon (67%), uranium (67%), nitrite plus nitrate (33%), strontium (33%), arsenic (25%), nitrate (25%), and lead (20%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (100%), sulfate (100%), TDS (100%), chloride (80%), iron (60%), and aluminum (25% exceeded lower and upper limits).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were boron (100%), manganese (100%), sulfate (100%), TDS (100%), chloride (80%), SAR (80%), iron (40%), and selenium (25%). Characteristics and constituents measured at concentrations greater than livestock-use standards were sulfate (60%), TDS (60%), chloride (40%), boron (33%), and lead (20%).

### *Fossil Basin*

The chemical composition of groundwater in alluvium in the Fossil Basin, southern Overthrust Belt, was characterized and the quality evaluated on the basis of environmental water samples from five wells. Summary statistics calculated for avail-

able constituents are listed in **Appendix 4e**. TDS concentrations indicated that most waters were fresh (80% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 248 to 1,350 mg/L, with a median of 798 mg/L.

Concentrations of some characteristics and constituents in alluvium in the Fossil 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 with health-based standards, all water was suitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (60%), TDS (60%), and iron (20%).

For agricultural and livestock use, concentrations of two constituents exceeded State of Wyoming agricultural-use standards, and no concentrations of characteristics and constituents exceeded State of Wyoming livestock standards in the Fossil Basin. Constituents measured at concentrations greater than agricultural-use standards were sulfate (60%) and chloride (20%).

### *Overthrust Belt*

The chemical composition of groundwater in alluvium in the Overthrust Belt was characterized and the quality evaluated on the basis of environmental water samples from one well and two springs. Summary statistics calculated for available constituents are listed in **Appendix 4f**. TDS concentrations varied and indicated that most waters were slightly saline (67% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 1,070 to 3,440 mg/L, with a median of 1,840 mg/L.

Concentrations of some characteristics and constituents in alluvium in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, all water was suitable for domestic use. Concentrations of a few characteristics and constituents exceeded aesthetic

standards for domestic use: sulfate (100%), TDS (100%), and iron (100%).

For agricultural and livestock use, concentrations of one characteristic and two constituents exceeded State of Wyoming agricultural-use standards, and no concentrations of characteristics and constituents exceeded State of Wyoming livestock standards in the Overthrust Belt. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (100%), chloride (67%), and TDS (33%).

***Landslide deposits.*** The chemical composition of groundwater in landslide deposits in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from ten springs (four springs in the Green River Basin and six springs in the Great Divide/Washakie/Sand Wash basins). Summary statistics calculated for available constituents are listed in **Appendices 4a** and **4b**. TDS concentrations indicated that waters were fresh (supplementary data tables). TDS concentrations ranged from 220 to 383 mg/L, with a median of 246 mg/L in the Green River Basin. TDS concentrations ranged from 269 to 482 mg/L, with a median of 420 mg/L, in the Great Divide/Washakie/Sand Wash basins. On the basis of the characteristics and constituents analyzed, the quality of water from landslide deposits in the GGRB was suitable for most uses. No characteristics or constituents in the landslide deposits approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

***Dune sand (eolian) deposits.*** The chemical composition of groundwater in dune sand (eolian) deposits in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from two wells and five springs. TDS concentrations indicated that most waters were fresh (71% of samples) and remaining waters were slightly saline (supplementary data tables).

Concentrations of some characteristics and constituents in dune sand (eolian) deposits in the GGRB approached or exceeded applicable USEPA or State

of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, all water was suitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (50%), TDS (29%), pH (14% exceeded upper limit), and sulfate (14%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (17%), pH (14% exceeded upper limit), and sulfate (14%). The one characteristic measured at concentrations greater than livestock-use standards was pH (14% exceeded upper limit).

#### *Green River Basin*

The chemical composition of groundwater in dune sand (eolian) deposits in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations indicated that water from one spring was fresh and from the other was slightly saline (supplementary data tables). TDS concentrations ranged from 346 to 1,010 mg/L.

Concentrations of some characteristics and constituents in dune sand (eolian) deposits in the Green 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 with health-based standards, all water was suitable for domestic use. Concentrations of a few characteristics and constituents exceeded aesthetic standards for domestic use: manganese (50%), pH (50% exceeded upper limit), and TDS (50%).

For agricultural and livestock use, concentrations of two characteristics exceeded State of Wyoming standards in the Green River Basin. Characteristics measured at concentrations greater than agricultural-use standards were SAR (50%) and pH

(50% exceeded upper limit). The one characteristic measured at concentrations greater than livestock-use standards was pH (50% exceeded upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in dune sand (eolian) deposits in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from two wells and three springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations indicated that most waters were fresh (80% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 227 to 1,080 mg/L, with a median of 292 mg/L.

Concentrations of some characteristics and constituents in dune sand (eolian) deposits in the Great Divide/Washakie/Sand Wash Basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, all water was suitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (20%) and TDS (20%).

For agricultural and livestock use, sulfate was the only constituent that exceeded any State of Wyoming agricultural-use standards or livestock standards in the Great Divide/Washakie/Sand Wash Basins. Sulfate exceeded agricultural-use standards in 20% of the samples.

**Glacial deposits.** The chemical composition of groundwater in glacial deposits in the GGRB was characterized and the quality evaluated on the basis of one water sample from a well in the Green River Basin. Individual constituent concentrations are listed in **Appendix 4a**. On the basis of the TDS concentration (145 mg/L), the water was classified as fresh (supplementary data tables). On the basis of the few analyses available for this well, the water was suitable for domestic, agricultural, and livestock use.

**Terrace gravel deposits.** The chemical composition of groundwater in terrace gravel deposits (*terrace gravels*) in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from eight wells and eight springs. TDS concentrations varied and indicated that most waters were fresh (92% of samples) and remaining waters were slightly saline (supplementary data tables).

Concentrations of some characteristics and constituents in terrace gravels in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, high radon concentration (100%) made all water unsuitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (38%), sulfate (14%), chloride (7%), and pH (6% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were chloride (14%), sulfate (14%), boron (10%), SAR (8%), TDS (8%), and pH (6% exceeded upper limit). The characteristic measured at concentrations greater than livestock-use standards was pH (6% exceeded upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the terrace gravels in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from seven wells and six springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (92% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 118 to 2,460 mg/L, with a median of 432 mg/L. Concentrations of some characteristics and constituents in terrace gravels in the Green 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 with health-based standards, high radon concentration (100%) made all water unsuitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (42%), sulfate (17%), chloride (8%), and pH (8% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were chloride (17%), sulfate (17%), boron (11%), SAR (9%), TDS (8%), and pH (8% exceeded upper limit). The characteristic measured at concentrations greater than livestock-use standards was pH (8% exceeded upper limit).

#### *Fossil Basin*

The chemical composition of groundwater in the terrace gravels in the Fossil Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and one spring. Summary statistics calculated for available constituents are listed in **Appendix 4e**. One TDS concentration (344 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the characteristics and constituents that were determined, the quality of water from terrace gravels in the Fossil Basin was suitable for most uses. No characteristics or constituents in the terrace gravels approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

#### *Overthrust Belt*

The chemical composition of groundwater in the terrace gravels in the Overthrust Belt was characterized and the quality evaluated on the basis of environmental water samples from one spring. Summary statistics for available constituents are listed in **Appendix 4f**. On the basis of the few characteristics and constituents that were determined, the quality of water from terrace gravels in the Overthrust Belt was likely suitable for most uses. No characteristics or constituents in the

terrace gravels approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

***Alkalic extrusive and intrusive igneous rocks.*** The chemical composition of groundwater in alkalic extrusive and intrusive igneous rocks in the GGRB was characterized and the quality evaluated on the basis of a water sample from a spring on the Rock Springs Uplift. Individual constituent concentrations are listed in **Appendix 4d**. On the basis of TDS concentration (259 mg/L), the water was classified as fresh (supplementary data tables). On the basis of the few analyses available for this spring, the water was suitable for domestic, agricultural, and livestock use.

#### ***Tertiary geologic units***

Tertiary geologic units composed of sedimentary rock contain the most abundant and widely used shallow aquifers in the GGRB. Water quality in these aquifers is highly variable, in part reflecting the complex geology of the Tertiary stratigraphic units in the GGRB.

We attempted to compile groundwater-quality data from as many of these formations, members, and tongues as possible, but many of the units are small in area, and water-quality data were not available. Many of the water-quality samples from Tertiary geologic units were collected from water wells or springs that represent water quality in the shallower parts of those units. Shallower parts of the geologic units are more economical to use, and generally contain water of better quality, than deeper parts. For these reasons, we focused more on describing water quality from shallower parts of the geologic units.

Water quality depends on lithology, which is highly variable within the Tertiary geologic units. For some purposes, such as disposal of wastewater by underground injection, regulations require the use of parts of geologic units that have poor water quality. In general, water quality in the Tertiary geologic units deteriorates with increasing depth. Most geologic units contain both coarse sediments, such as sands and gravels, and fine sediments, such as silt and clay; water quality tends to be better in

the coarser sediments. For this reason, it is possible for the water quality in an aquifer to improve with a relatively small increase in depth if the lithology changes from a fine-grained to coarse-grained sediment. In general, over large increases in depth, the quality of the water decreases.

TDS concentrations tend to be high even in shallower parts of aquifers in Tertiary GGRB geologic units. In many areas, the TDS concentration in shallow groundwater makes the water unsuitable, or only marginally suitable, for domestic use. High SARs also are a problem in many geologic units, making water from parts of some aquifers unsuitable for irrigation.

Many water-quality samples from Tertiary geologic units had high concentrations of sulfate, making parts of the aquifers unsuitable, or marginally suitable, for domestic and irrigation uses. Likely sources of the high sulfate concentrations are the evaporite minerals gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), anhydrite ( $\text{CaSO}_4$ ), mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ), and thenardite ( $\text{Na}_2\text{SO}_4$ ). These minerals were deposited in closed lake basins during arid intervals of the Tertiary.

Moderately high to high fluoride concentrations were observed in some water-quality samples from several geologic units. Fluoride concentrations do not affect the water's suitability for irrigation or livestock use, but high concentrations make water unsuitable for domestic use. Welder (1968) reported high fluoride concentrations from Tertiary geologic units in the Green River Basin, and believed that the source of the fluoride was probably volcanic ash and tuff incorporated into the geologic units during deposition. This process may be responsible for high fluoride concentrations in other parts of the GGRB as well.

Boron concentrations also were high in some water-quality samples from shallow parts of the geologic units. Boron occurs naturally in very low concentration in some igneous rocks, but can be concentrated by evaporative processes in closed lake basins.

Some water-quality samples from shallow parts of the aquifers had high concentrations of iron and manganese. Sources of iron include igneous rock minerals such as pyroxene, amphibole, biotite, magnetite, and olivine (Hem, 1985, p. 77). Manganese also occurs in pyroxene, amphibole and olivine. Small amounts of iron and manganese also are commonly found in limestone (Hem, 1985, p. 85).

Overall, in many areas of the GGRB, water from shallow Tertiary geologic units is only marginally suitable, or is unsuitable, for domestic and irrigation uses. In most areas, water from the shallow part of the geologic units is suitable for livestock use.

### **Upper Tertiary geologic units**

The water quality of upper Tertiary geologic units is discussed in this section.

**Browns Park Formation.** The chemical composition of groundwater in the Browns Park Formation in the Great Divide/Washakie/Sand Wash basins of the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 5 wells and 13 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram B**). Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (88% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 84 to 2,740 mg/L, with a median of 262 mg/L.

Concentrations of some characteristics and constituents in the Browns Park Formation in the Great Divide/Washakie/Sand Wash basins 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: radon (80%), arsenic (17%), molybdenum (17%), and ammonia (9%). Concentrations of several characteristics and constituents exceeded aesthetic

standards for domestic use: manganese (38%), sulfate (18%), TDS (18%), and iron (6%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming agricultural-use standards, and no concentrations of characteristics and constituents exceeded State of Wyoming livestock standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were manganese (19%), sulfate (18%), TDS (12%), and iron (6%).

### **Lower Tertiary geologic units**

The water quality of lower Tertiary geologic units is discussed in this section.

**Bishop Conglomerate.** The chemical composition of groundwater in the Bishop Conglomerate in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and five springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations indicated that waters were fresh (supplementary data tables). TDS concentrations ranged from 70 to 594 mg/L, with a median of 252 mg/L.

Concentrations of some characteristics and constituents in the Bishop Conglomerate in the Green 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 with health-based standards, all water was suitable for domestic use. Concentrations of one characteristic and one constituent exceeded the aesthetic standards for domestic use: TDS (33% of samples) and manganese (20%).

For agricultural and livestock use, concentrations of one constituent exceeded State of Wyoming agricultural-use standards and concentrations of no characteristic or constituent exceeded State of Wyoming livestock standards. The constituent measured at a concentration greater than agricultural-use standards was sulfate (17%).

**Washakie Formation.** The chemical composition of groundwater in the Washakie Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from one well and nine springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram C**). Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (70% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 469 to 1,520 mg/L, with a median of 816 mg/L.

Concentrations of some characteristics and constituents in the Washakie Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, high radon concentrations (100%) made all water unsuitable for domestic use. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (90%), sulfate (50%), pH (30% exceeded upper limit), and manganese (17%).

For agricultural and livestock use, concentrations of three characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (80%), SAR (56%), and pH (20% exceeded upper limit). The characteristic measured at concentrations greater than livestock-use standards was pH (30% exceeded upper limit).

**Bridger Formation.** The chemical composition of groundwater in the Bridger Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from 11 wells and 13 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram D**). Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (67% of

samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 213 to 4,380 mg/L, with a median of 811 mg/L. Naftz (1996) mapped TDS concentrations in the Bridger aquifer (composed of the Bridger Formation) in the Green River Basin; Naftz's map is modified as **Figure 6-2**.

Concentrations of some characteristics and constituents in the Bridger Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most waters were suitable for domestic use, but concentrations of some constituents exceeded health-based standards: radon (100%), uranium (14%), and boron (11%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (54%), sulfate (33%), iron (13%), manganese (13%), pH (12% exceeded upper limit), and chloride (12%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (42%), SAR (36%), boron (26%), chloride (12%), TDS (12%), manganese (7%), and pH (4% exceeded upper limit). The characteristic measured at concentrations greater than livestock-use standards was pH (12% exceeded upper limit).

**Green River Formation.** The chemical composition of groundwater in the undifferentiated Green River Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from three wells. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were slightly saline (67% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 1,650 to 6,960 mg/L, with a median of 1,730 mg/L.

Concentrations of some characteristics and constituents in the undifferentiated Green River

Formation in the Green 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 the few samples with health-based standards, all water was suitable for domestic use. Concentrations of two characteristics and one constituent exceeded aesthetic standard for domestic use: TDS (100% of samples), sulfate (67%), and pH (33% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (100%), sulfate (67%), chloride (33%), pH (33% exceeded upper limit), and TDS (33%). Characteristics measured at concentrations greater than livestock-use standards were pH (33% exceeded upper limit) and TDS (33%).

**Laney Member.** The chemical composition of groundwater in the Laney Member of the Green River Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 42 wells and 23 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram E**). TDS concentrations varied widely and indicated that water ranged from fresh to briny (**Appendix 2, diagram E**; supplementary data tables). Naftz (1996) mapped TDS concentrations in the Laney aquifer (composed of the Laney Member of the Green River Formation) in the Green River Basin; **Figure 6-3** is a modified version of this map.

Concentrations of some characteristics and constituents in the Laney Member of the Green River Formation in the GGRB 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: radon (100% of samples), ammonia (13%), boron (16%), nitrate (8%), and nitrite plus nitrate (2%).

Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (92%), sulfate (68%), manganese (21%), pH (19% exceeded upper limit), chloride (10%), iron (5%), and fluoride (2%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (73%), SAR (49%), TDS (40%), boron (22%), manganese (17%), pH (16% exceeded upper limit), and chloride (14%). Characteristics and constituents measured at concentrations greater than livestock-use standards were mercury (50%), pH (19% exceeded upper limit), TDS (15%), sulfate (8%), boron (8%), and chloride (6%).

#### *Green River Basin*

The chemical composition of groundwater in the Laney Member of the Green River Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from 38 wells and 12 springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied widely and indicated that water ranged from fresh to briny (supplementary data tables). TDS concentrations ranged from 241 to 99,400 mg/L, with a median of 1,260 mg/L.

Concentrations of some characteristics and constituents in the Laney Member of the Green River Formation in the Green 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: radon (100% of samples), boron (22%), ammonia (8%), and nitrite plus nitrate (3%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (90%), sulfate (65%), manganese (24%), pH (23% exceeded upper limit), chloride (10%), iron (3%), and fluoride (2%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (71%), SAR (51%), TDS (38%), boron (30%), pH (21% exceeded upper limit), manganese (17%), and chloride (17%). Characteristics and constituents measured at concentrations greater than livestock-use standards were mercury (50%), pH (23% exceeded upper limit), TDS (18%), boron (11%), chloride (8%), and sulfate (8%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Laney Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 4 wells and 11 springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied widely and indicated that water ranged from fresh to moderately saline (supplementary data tables). TDS concentrations ranged from 528 to 7,210 mg/L, with a median of 1,810 mg/L.

Concentrations of some characteristics and constituents in the Laney Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins 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 three constituents exceeded health-based standards: radon (100% of samples), ammonia (50%), and nitrate (50%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), sulfate (80%), manganese (15%), iron (8%), chloride (7%), and pH (7% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples mea-

sured at concentrations greater than agricultural-use standards were sulfate (80%), TDS (47%), SAR (43%), manganese (15%), and chloride (7%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (7% exceeded upper limit), sulfate (7%), and TDS (7%).

**Wilkins Peak Member.** The chemical composition of groundwater in the Wilkins Peak Member of the Green River Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one well and 13 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram F**). TDS concentrations varied and indicated that most waters were fresh (57% of samples) and remaining waters were slightly saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Wilkins Peak Member of the Green River Formation in the GGRB 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 one constituent exceeded a health-based standard: boron (15%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (71%), sulfate (50%), chloride (14%), and pH (14% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (50%), chloride (21%), SAR (21%), TDS (21%), boron (15%), and pH (7% exceeded upper limit). The one characteristic measured at concentrations greater than livestock-use standards was pH (14% exceeded upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Wilkins Peak Member of the Green River Formation in the Green River Basin was characterized

and the quality evaluated on the basis of environmental water samples from one well and eight springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (56% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 388 to 2,780 mg/L, with a median of 987 mg/L.

Concentrations of some characteristics and constituents in the Wilkins Peak Member of the Green River Formation in the Green 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 one constituent exceeded a health-based standard: boron (25%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (78%), sulfate (56%), chloride (22%), and pH (22% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (56%), chloride (33%), SAR (33%), boron (25%), TDS (22%), and pH (11% exceeded upper limit). The one characteristic measured at concentrations greater than livestock-use standards was pH (22% exceeded upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Wilkins Peak Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from five springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (60% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 311 to 2,590 mg/L, with a median of 714 mg/L.

Concentrations of some characteristics and constituents in the Wilkins Peak Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, all water was suitable for domestic use. Concentrations of one characteristic and one constituent exceeded aesthetic standard for domestic use: TDS (60%) and sulfate (40%).

For agricultural and livestock use, concentrations of one characteristic and one constituent exceeded State of Wyoming agricultural-use standards and no concentrations of characteristics and constituents exceeded State of Wyoming livestock standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (40%) and TDS (20%).

***Tipton Shale Member.*** The chemical composition of groundwater in the Tipton Shale Member of the Green River Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from seven wells and eight springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram G**). TDS concentrations varied widely and indicated that most waters were fresh (73% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). The chemical composition was also characterized and the quality evaluated on the basis of one produced water sample. The TDS concentration indicated that the produced water sample was briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Tipton Shale Member of the Green River Formation in the GGRB 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 two constituents exceeded health-based standards: ammonia (67%), and boron (14%). Concentra-

tions of two characteristics and one constituent exceeded aesthetic standards for domestic use: TDS (87%), pH (46% exceeded upper limit), and sulfate (27%). One water-quality analysis was from produced water, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS, chloride, and sulfate.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (53%), sulfate (53%), pH (31% exceeded upper limit), boron (21%), chloride (7%), and TDS (7%). The characteristic measured at concentrations greater than livestock-use standards was pH (46% exceeded upper limit). The one produced water analysis had concentrations of one characteristic and two constituents that exceeded agricultural- and livestock-use standards: TDS, chloride, and sulfate.

#### *Green River Basin*

The chemical composition of groundwater in the Tipton Shale Member of the Green River Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from five wells and four springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (78% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 298 to 1,370 mg/L, with a median of 685 mg/L.

Concentrations of some characteristics and constituents in the Tipton Shale Member of the Green River Formation in the Green 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 concen-

trations of one constituent exceeded health-based standards: boron (25%). Concentrations of two characteristics and one constituent exceeded aesthetic standards for domestic use: TDS (78%), pH (71% exceeded upper limit), and sulfate (11%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (67%), pH (57% exceeded upper limit), boron (38%), and sulfate (22%). The characteristic measured at concentrations greater than livestock-use standards was pH (71% exceeded upper limit).

An oil-shale retort study was conducted in the Tipton Shale Member of the Green River Formation on White Mountain, between Rock Springs and Green River, in the mid 1970s. Leenheer and Noyes (1986, p. 31) reported that groundwater quality at the site was highly variable before the retort. Major chemical constituents in the groundwater were sodium, bicarbonate, sulfate, and chloride. TDS concentrations ranged from 1,100 to 44,900 mg/L, with total organic-carbon concentrations ranging from undetectable to 1,890 mg/L. This extreme variability is particularly interesting because the wells were within 1 mile of each other, and were drilled to similar depths, 240 to 305 feet.

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Tipton Shale Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from two wells and four springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied widely and indicated that most waters were fresh (67% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 568 to 4,200 mg/L, with a median of 850 mg/L. The chemical composition was also characterized and the quality evaluated on the basis of one produced water sample. Summary statistics calculated for available

constituents are listed in **Appendix 5b**. A TDS concentration of 105,000 mg/L indicated that the produced water sample was briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Tipton Shale Member of the Green River Formation in the Great Divide/Washakie/Sand Wash basins 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 one constituent exceeded a health-based standard: ammonia (100%). Concentrations of two characteristics and one constituent exceeded aesthetic standards for domestic use: TDS (100%), pH (17% exceeded upper limit), and sulfate (50%). One water-quality analysis was from produced water, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS, chloride, and sulfate.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (100%), SAR (33%), chloride (17%), and TDS (17%). The characteristic measured at concentrations greater than livestock-use standards was pH (17% exceeded upper limit). The one produced water analysis had concentrations of one characteristic and two constituents that exceeded agricultural- and livestock-use standards: TDS, chloride, and sulfate.

***Farson Sandstone Member of the Green River Formation and Alkali Creek Member of the Wasatch Formation.*** The chemical composition of groundwater in the Farson Sandstone Member of the Green River Formation and Alkali Creek Member of the Wasatch Formation in the GGRB was

characterized and the quality evaluated on the basis of environmental water samples from 15 wells and one spring in the Green River Basin. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram J**). Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (92% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 168 to 1,550 mg/L, with a median of 457 mg/L.

Concentrations of some characteristics and constituents in the Farson Sandstone Member of the Green River Formation and Alkali Creek Member of the Wasatch Formation in the Green River Basin of the GGRB 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 one constituent exceeded a health-based standard: lead (20%). Concentrations of two characteristics and one constituent exceeded aesthetic standards for domestic use: TDS (46%), pH (6% less than lower limit and 38% greater than upper limit), and sulfate (20%).

For agricultural and livestock use, concentrations of a few characteristics and constituents exceeded State of Wyoming standards in the Green River Basin of the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (44%), pH (38% exceeded upper limit), and sulfate (30%). The characteristics measured at concentrations greater than livestock-use standards was pH (6% less than lower limit and 38% greater than upper limit).

**Fossil Butte Member.** The chemical composition of groundwater in the Fossil Butte Member of the Green River Formation in the Fossil Basin was characterized and the quality evaluated on the basis of environmental water samples from five springs. Summary statistics calculated for available constituents are listed in **Appendix 4e**. TDS concentrations indicated that waters were fresh (supplementary data tables). TDS concentrations

ranged from 190 to 456 mg/L, with a median of 404 mg/L. On the basis of the characteristics and constituents that were determined, the quality of water from the Fossil Butte Member of the Green River Formation in the Fossil Basin was suitable for most uses. No characteristics or constituents in the Fossil Butte Member of the Green River Formation approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Wasatch Formation.** The chemical composition of groundwater in the Wasatch Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 336 wells and 48 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram H**). TDS concentrations varied and indicated that most waters were fresh (85% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 64 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3a, diagram A**). TDS concentrations from produced-water samples varied widely and ranged from fresh to briny (supplementary data tables). Naftz (1996, Figure 23) mapped TDS concentrations in the Wasatch zone of the GGRB Wasatch-Fort Union aquifer in the Green River Basin (composed of selected members and tongues of the Green River and Wasatch Formations, the Pass Peak Formation, and undifferentiated Oligocene, Eocene, and Miocene rocks in the northeastern basin) (**Figure 6-4**) and in the Great Divide/Washakie/Sand Wash basins (composed of the Battle Spring and Wasatch Formations) (**Figure 6-5**).

Concentrations of some characteristics and constituents in the Wasatch Formation in the GGRB 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: radon (91%), ammonia (31%), strontium (14%), alpha radioactivity (14%), radi-

um-226 plus radium-228 (9%), arsenic (5%), and boron (3%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: pH (60% exceeded upper limit), TDS (40%), sulfate (25%), manganese (11%), iron (11%), aluminum (6% exceeded upper limit of range; see **Table 6-1**), and chloride (3%). Some water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (88%), sulfate (40%), and pH (2% less than lower limit and 19% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (72%), pH (49% exceeded upper limit), sulfate (29%), alpha radioactivity (14%), radium-226 plus radium-228 (9%), chloride (8%), boron (7%), TDS (4%), manganese (4%), and iron (1%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (60% exceeded upper limit), alpha radioactivity (14%), radium-226 plus radium-228 (9%), boron (1%), TDS (1%), chloride (1%), and sulfate (<1%). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: boron (100%), chloride (94%), TDS (88%), sulfate (42%), and pH (2% exceeded upper limit). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (69%), chloride (66%), pH (2% less than lower limit and 19% greater than upper limit), and sulfate (2%).

#### *Green River Basin*

The chemical composition of groundwater in the Wasatch Formation in the Green River Basin was characterized and the quality evaluated on the basis

of environmental water samples from 299 wells and 27 springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (90% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 126 to 9,710 mg/L, with a median of 377 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 18 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations varied and indicated that most waters were moderately saline (72%) and remaining waters were slightly or very saline (supplementary data tables). TDS concentrations ranged from 1,050 to 20,600 mg/L, with a median of 5,810 mg/L.

Concentrations of some characteristics and constituents in the Wasatch Formation in the Green 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 a few constituents exceeded health-based standards: radon (100%), arsenic (25%), and boron (5%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: pH (68% exceeded upper limit), TDS (35%), sulfate (20%), manganese (5%), iron (5%), and chloride (3%). Some water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (89%), sulfate (47%), and pH (31% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations

greater than agricultural-use standards were SAR (75%), pH (58% exceeded upper limit), sulfate (24%), boron (9%), chloride (7%), manganese (2%), and TDS (2%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (68% exceeded upper limit), boron (2%), TDS (1%), chloride (1%), and sulfate (<1%). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: boron (100%), chloride (94%), TDS (89%), sulfate (47%), and pH (6% exceeded upper limit). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (56%), chloride (50%), pH (31% exceeded upper limit), and sulfate (7%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Wasatch Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 36 wells and 6 springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that waters ranged from fresh to moderately saline (supplementary data tables). TDS concentrations ranged from 149 to 4,100 mg/L, with a median of 1,060 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 46 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely and ranged from fresh to briny (supplementary data tables). TDS concentrations ranged from 947 to 136,000 mg/L, with a median of 13,700 mg/L.

Concentrations of some characteristics and constituents in the Wasatch Formation in the Great Divide/Washakie/Sand Wash basins 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: radon (80% of samples), ammonia (73%), stron-

tium (18%), alpha radioactivity (17%), and radium-226 plus radium-228 (14%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (86%), sulfate (67%), iron (27%), manganese (24%), pH (24% exceeded upper limit), aluminum (8% exceeded lower and upper limits), and chloride (5%). Some water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (87%), sulfate (38%), and pH (3% less than lower limit and 14% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (71%), SAR (68%), TDS (24%), alpha radioactivity (17%), radium-226 plus radium-228 (14%), chloride (12%), manganese (10%), pH (7% exceeded upper limit), iron (5%), and boron (3%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (24% exceeded upper limit), alpha radioactivity (17%), and radium-226 plus radium-228 (14%). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (93%), TDS (87%), and sulfate (40%). Produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (74%), chloride (72%), and pH (3% less than lower limit and 14% greater than upper limit).

#### *Fossil Basin*

The chemical composition of groundwater in the Wasatch Formation in the Fossil Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and 15

springs. Summary statistics calculated for available constituents are listed in **Appendix 4e**. TDS concentrations varied and indicated that most waters were fresh (92% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 201 to 1,090 mg/L, with a median of 340 mg/L.

Concentrations of some characteristics and constituents in the Wasatch Formation in the Fossil 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 with health-based standards, all water was suitable for domestic use. Concentrations of a few characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (17%), TDS (17%), and manganese (11%).

For agricultural and livestock use, concentrations of one characteristic and one constituent exceeded State of Wyoming agricultural-use standards, and concentrations of no characteristics or constituents exceeded State of Wyoming livestock standards in the Fossil Basin. The characteristic and constituent measured at concentrations greater than agricultural-use standards were SAR (9%) and sulfate (17%).

**Cathedral Bluffs Tongue.** The chemical composition of groundwater in the Cathedral Bluffs Tongue of the Wasatch Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 9 wells and 15 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram I**). TDS concentrations varied and indicated that most waters were fresh (92% of samples) and remaining waters were slightly saline (supplementary data tables). The chemical composition of groundwater also was characterized and the quality evaluated on the basis of one produced-water sample from a well. The TDS concentrations indicated that the produced water was moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Cathedral Bluffs Tongue of the Wasatch Formation in the GGRB 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 two constituents exceeded health-based standards: radon (75%) and boron (9%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (54%), pH (50% exceeded upper limit), iron (5%), manganese (5%), and sulfate (21%). One water-quality analysis was from a produced-water sample, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample had concentrations of a few characteristics and constituents that exceeded aesthetic standards for domestic use: TDS, chloride, and sulfate.

For agricultural and livestock use, concentrations of several characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (50%), pH (42% exceeded upper limit), sulfate (25%), and boron (9%). The characteristic measured at greater than the livestock-use standard was pH (50% exceeded upper limit). The produced water sample had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS, chloride, and sulfate.

#### *Green River Basin*

The chemical composition of groundwater in the Cathedral Bluffs Tongue of the Wasatch Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from eight wells. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations indicated that all waters were fresh (supplementary data tables). TDS concentrations ranged from 439 to 924 mg/L, with a median of 691 mg/L.

Concentrations of some characteristics and constituents in the Cathedral Bluffs Tongue of the Wasatch Formation in the Green 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 one constituent exceeded a health-based standard: boron (29%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: pH (100% exceeded upper limit), TDS (88%), and sulfate (12%).

For agricultural and livestock use, concentrations of several characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were pH (100% exceeded upper limit), SAR (100%), boron (29%), and sulfate (12%). The characteristics measured at concentrations greater than livestock-use standards was pH (100% exceeded upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Cathedral Bluffs Tongue of the Wasatch Formation in the Great Divide/Washakie/ Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from one well and 15 springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (88% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 163 to 1,310 mg/L, with a median of 342 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of one produced-water sample from a well. The TDS concentration (3,510 mg/L) indicated that produced water sample was moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Cathedral Bluffs Tongue of the Wasatch Formation in the Great Divide/Washakie/ Sand Wash basins 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 one constituent exceeded a health-based standard: radon (75%).

Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (38%), pH (25% exceeded upper limit), sulfate (25%), iron (7%), and manganese (7%).

One water-quality sample was from produced water, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample had concentrations of a few characteristics and constituents that exceeded aesthetic standards for domestic use: TDS, chloride, and sulfate.

For agricultural and livestock use, concentrations of several characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (31%), SAR (25%), and pH (12% exceeded upper limit). The characteristics measured at concentrations greater than livestock-use standards was pH (25% exceeded upper limit). The produced water sample had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS, chloride, and sulfate.

***La Barge Member.*** The chemical composition of groundwater in the La Barge Member of the Wasatch Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 17 wells and 5 springs in the Green River Basin. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram K**). Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were fresh (82% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 179 to 3,160 mg/L, with a median of 463 mg/L.

Concentrations of some characteristics and constituents in the La Barge Member of the Wasatch Formation in the Green 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: arsenic (100%), cadmium (100%), and mercury (100%). Concentrations of two characteristics and one constituent exceeded aesthetic standard for domestic use: pH (55% exceeded upper limit), TDS (45%), and sulfate (15%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were selenium (100%), SAR (44%), pH (27% exceeded upper limit), sulfate (20%), boron (14%), chloride (10%), and TDS (5%). The constituent and characteristic measured at concentrations greater than livestock-use standards were mercury (100%) and pH (55% exceeded upper limit).

**Niland Tongue.** The chemical composition of groundwater in the Niland Tongue of the Wasatch Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of one produced water sample, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. Individual constituent concentrations are listed in **Appendix 5b**. The TDS concentration (10,400 mg/L) indicated that the produced water sample was very saline (supplementary data tables). The produced water sample had concentrations of one characteristic and one constituent that exceeded aesthetic standards for domestic use, agricultural- and livestock-use standards: TDS and chloride.

**Chappo Member.** The chemical composition of groundwater in the Chappo Member of the Wasatch Formation in the Green River Basin was characterized and the quality evaluated on the basis of one water sample from one spring. Individual constituent concentrations are listed in **Appendix 4a**. On the basis of the TDS concentration (431 mg/L), the water was classified as fresh. On the

basis of the one analysis available, the water was suitable for domestic, agricultural, and livestock use with the exception of the concentration of one constituent: manganese.

**Bullpen Member.** The chemical composition of groundwater in the Bullpen Member of the Wasatch Formation in the Fossil Basin was characterized and the quality evaluated on the basis of one water sample from a spring. Summary statistics calculated for available constituents are listed in **Appendix 4e**. On the basis of the TDS concentration (197 mg/L), the water was classified as fresh. On the basis of the limited analyses available for this spring, the water was suitable for domestic, agricultural, and livestock use.

**Almy Formation.** The chemical composition of groundwater in the Almy Formation (basal conglomerate in the lower part of the Wasatch Formation main body) in the GGRB was characterized and the quality evaluated on the basis of 85 produced-water samples from wells in the Green River Basin. Major-ion composition in relation to TDS is shown in a trilinear diagram (**Appendix 3a, diagram B**). Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations varied and indicated that most waters were moderately saline (81% of samples) and remaining waters were slightly or very saline (supplementary data tables). TDS concentrations ranged from 1,150 to 13,100 mg/L, with a median of 6,330 mg/L.

Concentrations of some characteristics and constituents in the Almy Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses, but many characteristic and constituent analyses were not available and could not be compared with the standards. The produced-water samples generally had concentrations of one constituent that exceeded health-based standards: barium (100%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (98%), iron (50%), pH (30% exceeded upper limit), and sulfate (7%). The

produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: chloride (100%), TDS (93%), and sulfate (9%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (73%), TDS (72%), pH (30% exceeded upper limit), and sulfate (1%).

**Pass Peak Formation.** The chemical composition of groundwater in the Pass Peak Formation in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from one well in the Green River Basin. Individual constituent concentrations are listed in **Appendix 4a**. The TDS concentration (399 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the characteristics and constituents analyzed, the quality of water from the Pass Peak Formation in the GGRB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Battle Spring Formation.** The chemical composition of groundwater in the Battle Spring Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 27 wells and 8 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram L**). Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations indicated that most waters were fresh (97% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 102 to 2,820 mg/L, with a median of 280 mg/L.

Concentrations of some characteristics and constituents in the Battle Spring Formation in the Great Divide/Washakie/Sand Wash basins 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:

radon (100% proposed MCL, 67% AMCL), alpha radioactivity (38%), uranium (33%), radium-226 plus radium-228 (21%), ammonia (9%), and arsenic (5%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (29%), TDS (18%), iron (18%), pH (15% exceeded upper limit), and sulfate (9%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were alpha radioactivity (38%), SAR (33%), sulfate (26%), radium-226 plus radium-228 (21%), vanadium (6%), selenium (5%), TDS (3%), chloride (3%), and pH (3% exceeded upper limit). Characteristics and constituents measured at concentrations greater than livestock-use standards were alpha radioactivity (38%), radium-226 plus radium-228 (21%), pH (15% exceeded upper limit), and vanadium (6%).

**Fort Union Formation.** The chemical composition of groundwater in the Fort Union Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 21 wells and 2 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram M**). TDS concentrations were variable and indicated that most water ranged from fresh to moderately saline (supplementary data tables). The chemical composition of groundwater also was characterized and the quality evaluated on the basis of 117 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3a, diagram C**). TDS concentrations from produced waters varied widely, ranging from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Fort Union Formation in the GGRB 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 concen-

trations of a few constituents exceeded health-based standards: radon (100% of samples), lead (18%), and beryllium (17%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), manganese (77%), iron (69%), sulfate (57%), aluminum (30% exceeded lower limit and 20% exceeded upper limit), pH (18% exceeded upper limit), and chloride (13%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (95%), sulfate (28%), and pH (1% less than lower limit and 11% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (65%), SAR (44%), TDS (26%), manganese (23%), iron (19%), chloride (17%), and pH (5% exceeded upper limit). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (18% exceeded upper limit), lead (9%), and TDS (4%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (98%), TDS (94%), iron (70%), sulfate (34%), and pH (2% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (72%), chloride (70%), pH (1% less than lower limit and 11% greater than upper limit), and sulfate (2%).

#### *Green River Basin*

The chemical composition of groundwater in the Fort Union Formation in the Green 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 4a**. TDS concentrations varied and indicated that most water ranged from fresh to slightly saline (supplementary data tables). TDS concentrations indicated that waters were fresh (618 mg/L) and slightly saline (1,320 mg/L). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 43 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples indicated that most waters were moderately saline (55% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,170 to 51,200 mg/L, with a median of 7,180 mg/L.

Concentrations of some characteristics and constituents in the Fort Union Formation in the Green 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 one constituent exceeded a health-based standard: radon (100%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), pH (50% exceeded upper limit), and sulfate (50%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (95%), sulfate (28%), and pH (16% exceeded upper limit).

For agricultural and livestock use, concentrations of two characteristics and one constituent exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were pH (50% exceeded upper limit), SAR (50%), and sulfate (50%). The characteristics measured at con-

concentrations greater than livestock-use standards was pH (50% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (93%), iron (57%), sulfate (31%), and pH (5% exceeded upper limit). The produced-water samples generally had concentrations of two characteristics and one constituent that exceeded livestock-use standards: TDS (85%), chloride (77%), and pH (16% exceeded upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Fort Union Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 20 wells and 1 spring. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most water ranged from fresh to moderately saline (supplementary data tables). TDS concentrations ranged from 522 to 7,210 mg/L, with a median of 1,130 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 74 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely and ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,170 to 153,000 mg/L, with a median of 11,200 mg/L.

Concentrations of some characteristics and constituents in the Fort Union Formation in the Great Divide/Washakie/Sand Wash basins 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 a few constituents exceeded health-based standards: radon (100%), lead (20%), and beryllium (20%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), manganese (83%), iron (73%), sulfate (57%), aluminum (33% exceeded lower limit and 22% exceeded upper limit), pH (15% exceeded upper limit), and chloride (14%). Some

water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (95%), sulfate (28%), and pH (1% less than lower limit and 8% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (67%), SAR (44%), TDS (29%), manganese (25%), iron (20%), and chloride (19%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (15% exceeded upper limit), lead (10%), and TDS (5%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (97%), TDS (95%), iron (74%), and sulfate (35%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (69%), chloride (66%), pH (1% less than lower limit and 8% greater than upper limit), and sulfate (3%).

**Evanston Formation.** The chemical composition of groundwater in the Evanston Formation in the Fossil Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations are listed in **Appendix 4e**. One TDS concentration (1,020 mg/L) indicated that the water was slightly saline (supplementary data tables).

Concentrations of one characteristic and one constituent approached or exceeded applicable EPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of comparison with health-based standards, all wa-

ter was suitable for domestic use. Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS (100% of samples) and sulfate (50%). Concentrations of one constituent exceeded agricultural-use standards: sulfate (50%). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

### **Mesozoic geologic units**

The water quality of aquifers in Mesozoic geologic units varies greatly throughout the GGRB. Recharge to these aquifers generally occurs where the formations are exposed. Near recharge areas, water in these aquifers can be relatively fresh and may be suitable for most uses. These areas are where most domestic, municipal supply, or stock wells are completed. Elsewhere, and with increasing depth (as indicated by produced-water samples) and as the water moves away from outcrop, the water can have a TDS concentration several times that of seawater, and is not suitable for most uses or is only marginally suitable for livestock use. Only oil and gas wells penetrate deeply buried Mesozoic geologic units.

**Lance Formation.** The chemical composition of groundwater in the Lance Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from six wells. TDS concentrations indicated that most waters were slightly saline (67% of samples) and remaining waters were moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 218 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3b, diagram A**). TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Lance Formation in the GGRB 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: radon (100%), boron (50%), and arsenic (17%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), manganese (83%), aluminum (67% exceeded lower limit and 50% exceeded upper limits), iron (67%), sulfate (67%), and chloride (17%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one constituent that exceeded health-based standards: barium (60%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), iron (98%), chloride (96%), sulfate (8%), and pH (4% less than lower limit and 5% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (83%), sulfate (83%), TDS (67%), boron (50%), manganese (33%), aluminum (17%), chloride (17%), and iron (17%). The constituent measured at concentrations greater than livestock-use standards was aluminum (17%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: lithium (100%), SAR (100%), chloride (99%), TDS (95%), iron (78%), sulfate (9%), and pH (<1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (67%), TDS (67%), and pH (4% less than lower limit and 5% greater than upper limit).

### *Green River Basin*

The chemical composition of groundwater in the Lance Formation in the Green River Basin was characterized and the quality evaluated on the basis of 181 produced-water samples from wells. Summary statistics calculated for available constitu-

ents are listed in **Appendix 5a**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables). TDS concentrations ranged from 698 to 49,400 mg/L, with a median of 9,180 mg/L.

Concentrations of some characteristics and constituents in the Lance Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one constituent that exceeded health-based standards: barium (59% of samples). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), iron (99%), chloride (98%), pH (5% less than lower limit), and sulfate (3%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), lithium (100%), SAR (100%), TDS (96%), iron (79%), and sulfate (5%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (69%), TDS (68%), and pH (5% less than lower limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Lance Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of one environmental water sample from a well. Summary statistics calculated for available constituents are listed in **Appendix 4b**. The TDS concentration (2,000 mg/L) was slightly saline (supplementary data tables). The chemical composition of groundwater also was characterized and the quality evaluated on the basis

of 37 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely, ranging from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,200 to 80,400 mg/L, with a median of 8,140 mg/L.

Concentrations of some characteristics and constituents in the Lance Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water from the one well was suitable for domestic use, but the concentration of one constituent exceeded a health-based standard: radon. Concentrations of one characteristic and three constituents exceeded aesthetic standards for domestic use for the one well sampled: iron, manganese, sulfate, and TDS. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one constituent that exceeded health-based standards: barium (100% of samples). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (84%), iron (83%), sulfate (32%), and pH (27% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Constituents measured at concentrations greater than agricultural-use standards in the one environmental water sample were iron, manganese, and sulfate. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (95%), TDS (92%), iron (50%), sulfate (32%), and pH (3% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceed-

ed livestock-use standards: chloride (57%), TDS (62%), and pH (27% exceeded upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Lance Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from five wells. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations indicated that most waters were slightly saline (60% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 1,780 to 4,910 mg/L, with a median of 2,980 mg/L.

Concentrations of some characteristics and constituents in the Lance Formation on the Rock Springs Uplift 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 two constituents exceeded health-based standards: boron (100%) and arsenic (20%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (100%), aluminum (80% exceeded lower limit and 60% exceeded upper limits), manganese (80%), iron (60%), sulfate (60%), and chloride (20%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were boron (100%), SAR (100%), sulfate (80%), TDS (80%), aluminum (20%), chloride (20%), and manganese (20%). The constituent measured at concentrations greater than livestock-use standards was aluminum (20%).

**Fox Hills Sandstone.** The chemical composition of groundwater in the Fox Hills Sandstone in the GGRB was characterized and the quality evaluated on the basis of 13 produced-water samples from wells in the Great Divide/Washakie/Sand Wash basins. Summary statistics calculated for

available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied, ranging from moderately saline to briny (supplementary data tables). TDS concentrations ranged from 3,330 to 64,800 mg/L, with a median of 14,800 mg/L.

Concentrations of some characteristics and constituents in the Fox Hills Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), iron (100%), TDS (100%), sulfate (45%), and pH (23% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), lithium (100%), TDS (100%), iron (50%), sulfate (45%), and pH (8% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (69%), TDS (69%), pH (23% exceeded upper limit), and sulfate (9%).

**Lewis Shale.** The chemical composition of groundwater in the Lewis Shale in the Great Divide/Washakie/Sand Wash basins 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 4b**. TDS concentrations indicated that most waters were fresh (62% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS

concentrations ranged from 280 to 57,700 mg/L, with a median of 952 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 56 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables). TDS concentrations ranged from 720 to 54,600 mg/L, with a median of 9,200 mg/L.

Concentrations of some characteristics and constituents in the Lewis Shale in the Great Divide/Washakie/Sand Wash basins 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: ammonia (100%), radon (100%), nitrite plus nitrate (20%), and boron (12%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (88%), aluminum (50% exceeded lower limit), manganese (40%), pH (17% less than lower limit and 33% greater than upper limit), iron (29%), and sulfate (25%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. One produced water sample had concentrations of two constituents that exceeded health-based standards: barium and lead. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (88%), sulfate (15%), and pH (9% less than lower limit and greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (67%), boron (38%), chlo-

ride (38%), sulfate (25%), TDS (25%), manganese (20%), and pH (17% exceeded upper limit). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (17% less than lower limit and 33% greater than upper limit), TDS (25%), and sulfate (12%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: lithium (100%), TDS (96%), chloride (91%), iron (56%), sulfate (19%), and pH (2% less than lower limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (77%), chloride (68%), pH (9% less than lower limit and greater than upper limit), and sulfate (2%).

**Mesaverde Group (or Formation).** The chemical composition of groundwater in the Mesaverde Group or Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 17 wells and 7 springs. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 2, diagram N**). TDS concentrations varied and indicated that most waters were fresh (50% of samples) and remaining waters ranged from slightly too moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 543 produced-water samples from wells. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny; most of the concentrations indicated that the water was moderately saline (58%) (supplementary data tables). Freethey et al. (1988) mapped TDS concentrations in the Mesaverde aquifer (composed of the Lance Formation, Fox Hills Sandstone, Lewis Shale, and the Mesaverde Group and Formation) in the GGRB and adjacent areas and the map is reproduced in **Figure 6-6**.

Concentrations of some characteristics and constituents in the Mesaverde Group or Formation in the GGRB 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 two constituents exceeded

health-based standards: nitrate (14%) and boron (6%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (88%), manganese (38%), sulfate (29%), iron (24%), pH (12% exceeded upper limit), and chloride (4%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. A few produced-water samples generally had concentrations of several constituents that exceeded health-based standards: cadmium (100%), nitrite (100%), barium (78%), lead (67%), arsenic (33%), radium-226 plus radium-228 (30%), boron (17%), and zinc (14%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (94%), iron (82%), aluminum (80% exceeded lower and 20% exceeded upper limits), manganese (44%), sulfate (12%), and pH (4% less than lower limit and 7% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (47%), manganese (38%), sulfate (33%), boron (19%), TDS (12%), and chloride (8%). Characteristics and constituents measured at concentrations greater than livestock-use standards were pH (12% exceeded upper limit), sulfate (4%), and TDS (4%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: SAR (100%), selenium (100%), chloride (99%), TDS (94%), cadmium (67%), boron (50%), iron (48%), arsenic (33%), radium-226 plus radium-228 (30%), manganese (22%), sulfate (14%), zinc (14%), and pH (<1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (79%), chloride (70%), radium-226 plus radium-228 (30%), pH (4% less

than lower limit and 7% greater than upper limit), and sulfate (1%).

#### *Green River Basin*

The chemical composition of groundwater in the Mesaverde Group or Formation in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from one well and two springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations varied and indicated that most waters were slightly saline (67% of samples) and remaining waters were fresh (supplementary data tables). TDS concentrations ranged from 437 to 2,400 mg/L, with a median of 1,740 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 74 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples varied, ranging from slightly saline to briny, and most of the water was moderately saline (51%) (supplementary data tables). TDS concentrations ranged from 1,330 to 38,900 mg/L, with a median of 8,350 mg/L.

Concentrations of some characteristics and constituents in the Mesaverde Group or Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water was suitable for domestic use, as no concentrations of sampled constituents exceeded health-based standards. Concentrations of two characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (67%) and TDS (67%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. A few produced-water samples generally had concentrations of two constituents that exceeded health-based standards: nitrite (100%) and barium (67%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (96%),

iron (93%), sulfate (25%), and pH (1% less than lower limit and 15% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (67%) and TDS (33%). No characteristic or constituent was measured at concentrations greater than livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (96%), iron (64%), and sulfate (31%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (77%), chloride (72%), and pH (1% less than lower limit and 15% greater than upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Mesaverde Group or Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from 13 wells and 5 springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (56% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 477 to 2,300 mg/L, with a median of 985 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 469 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied, ranging from fresh to briny; however, most of the water was moderately saline (60%) (supplementary data tables). TDS concentrations ranged from 392 to 157,000 mg/L, with a median of 8,350 mg/L.

Concentrations of some characteristics and constituents in the Mesaverde Group or Formation in the Great Divide/Washakie/Sand Wash basins

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 one constituent exceeded a health-based standard: boron (8%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (94%), manganese (43%), iron (25%), sulfate (17%), and pH (17% exceeded upper limit). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several constituents that exceeded health-based standards: cadmium (100%), barium (78%), lead (67%), arsenic (33%), radium-226 plus radium-228 (30%), boron (17%), and zinc (14%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (94%), iron (82%), aluminum (80% exceeded lower and 20% exceeded upper limits), manganese (44%), sulfate (11%), and pH (4% less than lower limit and 5% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (54%), manganese (43%), sulfate (22%), boron (17%), chloride (6%), and TDS (6%). One characteristic was measured at concentrations greater than livestock-use standards: pH (17% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: SAR (100%), selenium (100%), chloride (98%), TDS (94%), cadmium (67%), boron (50%), iron (47%), arsenic (33%), radium-226 plus radium-228 (30%), manganese (22%), zinc (14%), sulfate (12%), and pH (<1% exceeded than upper limit). The produced-water samples generally had concentrations of several

characteristics and constituents that exceeded livestock-use standards: TDS (79%), chloride (70%), radium-226 plus radium-228 (30%), pH (4% less than lower limit and 5% greater than upper limit), and sulfate (1%).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Mesaverde Group or Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from three wells. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations varied, and indicated that most waters ranged from fresh to moderately saline (supplementary data tables). TDS concentrations ranged from 342 to 7,860 mg/L, with a median of 1,410 mg/L.

Concentrations of some characteristics and constituents in the Mesaverde Group or Formation on the Rock Springs Uplift 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 one constituent exceeded a health-based standard: nitrate (50% of samples). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (67%), TDS (67%), and chloride (33%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (67%), boron (50%), chloride (33%), and TDS (33%). Characteristics and constituents measured at concentrations greater than livestock-use standards were sulfate (33%) and TDS (33%).

**Almond Formation.** The chemical composition of groundwater in the Almond Formation of the Mesaverde Group in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from 14 wells and 1 spring. TDS concentrations varied, and indicated that most

waters were fresh (67% of samples) and remaining waters ranged from slightly to very saline (supplementary data tables). The chemical composition of groundwater also was characterized and the quality evaluated on the basis of 275 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3b, diagram B**). TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Almond Formation in the GGRB 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: ammonia (80%), lead (14%), and boron (11%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (56%), TDS (53%), aluminum (33% exceeded lower and upper limits), iron (33%), sulfate (33%), pH (7% less than lower limit and 13% greater than upper limit), and chloride (7%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several constituents that exceeded health-based standards: beryllium (100%), cadmium (100%), mercury (100%), strontium (100%), barium (84%), boron (67%), arsenic (60%), lead (50%), and chromium (20%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% exceeded lower limit), TDS (99%), chloride (95%), manganese (95%), iron (82%), sulfate (15%), and pH (4% less than lower limit and 8% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in the Almond Formation exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured

at concentrations greater than agricultural-use standards were SAR (50%), sulfate (33%), boron (22%), manganese (22%), TDS (20%), iron (8%), and chloride (7%). Characteristics and constituents measured at concentrations greater than livestock-use standards were lead (14%), pH (7% less than lower limit and 13% greater than upper limit), chloride (7%), sulfate (7%), and TDS (7%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (96%), SAR (95%), TDS (93%), boron (67%), manganese (63%), iron (51%), cadmium (43%), arsenic (20%), chromium (20%), sulfate (19%), copper (17%), and pH (1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: mercury (100%), TDS (82%), chloride (74%), chromium (40%), arsenic (20%), copper (8%), pH (4% less than lower limit and 8% greater than upper limit), and sulfate (1%).

#### *Green River Basin*

The chemical composition of groundwater in the Almond Formation of the Mesaverde Group in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from two wells. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations indicated that waters were fresh (supplementary data tables). TDS concentrations were 231 and 329 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of five produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples varied: three of the samples were slightly saline (60% of samples), and the other two samples were moderately saline and briny (supplementary data tables). TDS concentrations ranged from 1,990 to 37,500 mg/L, with a median of 3,000 mg/L.

Concentrations of some characteristics and constituents in the Almond Formation in the Green 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 with health-based standards, all water was suitable for domestic use. Concentrations of one characteristic exceeded an aesthetic standard for domestic use: pH (50% exceeded upper limit). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (80%), pH (60% exceeded upper limit), and sulfate (60%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. No characteristics and constituents were measured at concentrations greater than agricultural-use standards in environmental water samples. One characteristic was measured at concentrations greater than livestock-use standards: pH (50% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (80%), and TDS (80%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: pH (60% exceeded upper limit), chloride (20%), and TDS (20%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Almond Formation of the Mesaverde Group in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from seven wells. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations varied and indicated that most waters were fresh (71% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 337 to 1,090 mg/L, with a median of 483 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 269 produced-

water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables). TDS concentrations ranged from 115 to 95,300 mg/L, with a median of 9,600 mg/L.

Concentrations of some characteristics and constituents in the Almond Formation in the Great Divide/Washakie/Sand Wash basins 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 two constituents exceeded health-based standards: ammonia (100%) and boron (20%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (43%), pH (29% exceeded than upper limit), and manganese (20%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several constituents that exceeded health-based standards: beryllium (100%), cadmium (100%), mercury (100%), strontium (100%), barium (84%), boron (67%), arsenic (60%), lead (50%), and chromium (20%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% exceeded lower limit), TDS (99%), chloride (96%), manganese (95%), iron (82%), sulfate (14%), and pH (4% less than lower limit and 7% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (71%) and boron (40%). One characteristic measured at concentrations greater than livestock-use standards was pH (29%

exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: mercury (100%), chloride (96%), SAR (95%), TDS (94%), boron (67%), manganese (63%), iron (51%), cadmium (43%), arsenic (20%), chromium (20%), sulfate (18%), copper (17%), and pH (1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (83%), chloride (75%), chromium (40%), arsenic (20%), copper (8%), pH (4% less than lower limit and 7% greater than upper limit), and sulfate (1%).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Almond Formation of the Mesaverde Group on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from five wells and one spring. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations varied and indicated that most waters were fresh (50% of samples) and remaining waters ranged from slightly to very saline (supplementary data tables). TDS concentrations ranged from 459 to 21,100 mg/L, with a median of 1,510 mg/L. The chemical composition of groundwater also was characterized and the quality evaluated on the basis of one produced water sample from a well. Summary statistics calculated for available constituents are listed in **Appendix 5c**. The TDS concentration (12,300 mg/L) from the produced water sample was very saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Almond Formation on the Rock Springs Uplift 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 one constituent exceeded a health-based standard: lead (20%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (100%), sulfate (83%), TDS (83%), iron (80%), aluminum (50% exceeded lower and upper limits), and chloride (17%). Some

water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample did not have concentrations of constituents that exceeded health-based standards. The produced water sample had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride, pH (exceeded upper limit), and TDS.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (83%), manganese (50%), TDS (50%), SAR (40%), iron (20%), and chloride (17%). Characteristics and constituents measured at concentrations greater than livestock-use standards were lead (20%), chloride (17%), sulfate (17%), and TDS (17%). The produced water sample had concentrations of one characteristic and one constituent that exceeded agricultural-use standards: chloride and TDS. The produced water sample had concentrations of two characteristics and one constituent that exceeded livestock-use standards: chloride, pH (exceeded upper limit), and TDS.

**Ericson Sandstone.** The chemical composition of groundwater in the Ericson Sandstone of the Mesaverde Group in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from eight wells and four springs. TDS concentrations indicated that most waters were fresh (80% of samples) and remaining waters were slightly saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 24 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3b, diagram C**). TDS concentrations from produced-water samples were highly variable and ranged from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Ericson Sandstone in the GGRB 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: alpha radioactivity (100%), strontium (100%), radium-226 plus radium-228 (67%), and boron (14%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (50%), iron (40%), TDS (40%), pH (20% less than lower limit), chloride (10%), and sulfate (10%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. A produced water analysis had a concentration of one constituent that exceeded health-based standards: radium-226 plus radium-228. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% exceeded upper limit of range; see **Table 6-1**), iron (100%), manganese (100%), TDS (100%), chloride (83%), sulfate (46%), and pH (4% less than lower limit and 17% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were alpha radioactivity (100%), radium-226 plus radium-228 (67%), manganese (50%), SAR (33%), chloride (20%), iron (20%), sulfate (20%), and boron (14%). Characteristics and constituents measured at concentrations greater than livestock-use standards were alpha radioactivity (100%), radium-226 plus radium-228 (67%), and pH (20% less than lower limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: iron (100%), manganese (100%), radium-226 plus radium-228 (100%), chloride (96%), TDS (88%),

sulfate (50%), and pH (4% less than lower limit and greater than upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: radium-226 plus radium-228 (100%), chloride (79%), TDS (79%), pH (4% less than lower limit and 17% greater than upper limit), and sulfate (17%).

#### *Green River Basin*

The chemical composition of groundwater in the Ericson Sandstone of the Mesaverde Group in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from three wells and two springs. Summary statistics calculated for available constituents are listed in **Appendix 4a**. TDS concentrations indicated that most waters were fresh (80% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 382 to 1,210 mg/L, with a median of 446 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples ranged from slightly to very saline (supplementary data tables). TDS concentrations for produced-water samples ranged from 1,840 to 20,500 mg/L, with a median of 9,670 mg/L.

Concentrations of some characteristics and constituents in the Ericson Sandstone in the Green 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 two constituents exceeded health-based standards: strontium (100%) and boron (33%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (40%), manganese (33%), pH (25% less than lower limit), and chloride (20%). Some water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-

use standards. The produced-water samples did not have any concentrations of constituents that exceeded health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (67%), and sulfate (67%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were SAR (50%), manganese (33%), chloride (40%), boron (33%), and sulfate (20%). One characteristic was measured at concentrations greater than livestock-use standards: pH (25% less than lower limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), sulfate (67%), and TDS (67%). The produced-water samples generally had concentrations of one characteristic and one constituent that exceeded livestock-use standards: chloride (67%), and TDS (67%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Ericson Sandstone of the Mesaverde Group in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of an environmental water sample from one well. Summary statistics calculated for available constituents are listed in **Appendix 4b**. The TDS concentration (915 mg/L) indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 21 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples were highly variable and ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,020 to 74,500 mg/L, with a median of 14,100 mg/L.

Concentrations of some characteristics and constituents in the Ericson Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water from the one environmental water sample was suitable for domestic use. The concentration of one characteristic exceeded an aesthetic standard for domestic use: TDS. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. A produced water analyses had one concentration of one constituent that exceeded health-based standards: radium-226 plus radium-228. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% of samples exceeded upper limit of range; see **Table 6-1**), iron (100%), manganese (100%), TDS (100%), chloride (86%), sulfate (43%), and pH (5% less than lower limit and 19% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. In the one environmental water sample, the characteristic measured at a concentration greater than agricultural-use standards was SAR. No characteristic or constituent was measured at concentrations greater than livestock-use standards in the one environmental water sample. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: iron (100%), manganese (100%), radium-226 plus radium-228 (100%), chloride (95%), TDS (90%), sulfate (48%), and pH (5% less than lower limit and greater than upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: radium-226 plus radium-228 (100%), chloride (81%), TDS (81%), pH (5% less than lower limit and 19% greater than upper limit), and sulfate (19%).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Ericson Sandstone of the Mesaverde Group on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from four wells and two springs. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations indicated that most waters were fresh (75% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 322 to 1,010 mg/L, with a median of 340 mg/L.

Concentrations of some characteristics and constituents in the Ericson Sandstone on the Rock Springs Uplift 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 two constituents exceeded health-based standards: alpha radioactivity (100%) and radium-226 plus radium-228 (67%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: iron (100%), manganese (100%), sulfate (25%), TDS (25%), and pH (20% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were alpha radioactivity (100%), manganese (100%), radium-226 plus radium-228 (67%), iron (50%), and sulfate (25%). Characteristics and constituents measured at concentrations greater than livestock-use standards were alpha radioactivity (100%), radium-226 plus radium-228 (67%), and pH (20% less than lower limit).

**Allen Ridge Formation.** The chemical composition of groundwater in the Allen Ridge Formation of the Mesaverde Group in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from three springs. Summary statis-

tics calculated for available constituents are listed in **Appendix 4b**. On the basis of TDS concentrations, the waters were classified as fresh (supplementary data tables). TDS concentrations ranged from 183 to 796 mg/L, with a median of 278 mg/L. On the basis of the three analyses available for these springs, the water generally was suitable for domestic, agricultural, and livestock use with the exception of concentrations of one characteristic: TDS (33% of samples) exceeded the aesthetic standard for domestic use.

**Rock Springs Formation.** The chemical composition of groundwater in the Rock Springs Formation of the Mesaverde Group in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from three wells and one spring. TDS concentrations indicated that most waters were slightly saline (50% of samples) and remaining waters were fresh or moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 15 produced-water samples from wells. TDS concentrations from produced-water samples varied widely, ranging from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Rock Springs Formation in the GGRB 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 one constituent exceeded health-based standards: boron (33%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: manganese (100%), sulfate (100%), TDS (100%), and chloride (25%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (87%), sulfate

(47%), and pH (7% less than lower limit and 20% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were manganese (100%), sulfate (100%), boron (33%), SAR (33%), chloride (25%), and TDS (25%). Characteristics and constituents measured at concentrations greater than livestock-use standards were sulfate (25%) and TDS (25%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: TDS (93%), chloride (87%), and sulfate (47%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (87%), chloride (73%), pH (7% less than lower limit and 20% greater than upper limit), and sulfate (20%).

#### *Green River Basin*

The chemical composition of groundwater in the Rock Springs Formation of the Mesaverde Group in the Green River Basin was characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations indicated that most produced water was briny (50% of samples) and remaining waters ranged from slightly to moderately saline (supplementary data tables). TDS concentrations ranged from 1,690 to 147,000 mg/L, with a median of 37,100 mg/L.

Concentrations of some characteristics and constituents in the Rock Springs Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water analyses could be compared

to health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (83%), sulfate (83%), and pH (17% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS (83%), chloride (83%), and sulfate (83%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (83%), chloride (50%), sulfate (33%), and pH (17% exceeded upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Rock Springs Formation of the Mesaverde Group in the Great Divide/Washakie/Sand Wash basins 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 5b**. TDS concentrations varied and indicated that most waters were very saline (63% of samples) and remaining waters ranged from moderately saline to briny (supplementary data tables). TDS concentrations ranged from 7,480 to 154,000 mg/L, with a median of 18,000 mg/L.

Concentrations of some characteristics and constituents in the Rock Springs Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%),

iron (100%), TDS (100%), sulfate (25%), and pH (12% less than lower limit and 25% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS (100%), chloride (100%), and sulfate (25%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (100%), chloride (100%), pH (12% less than lower limit and 25% greater than upper limit), and sulfate (12%).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Rock Springs Formation of the Mesaverde Group on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from three wells and one spring. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations indicated that most waters were slightly saline (50% of samples) and remaining waters were fresh or moderately saline (supplementary data tables). TDS concentrations ranged from 697 to 9,430 mg/L, with a median of 1,190 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of one produced water sample from a well. Summary statistics calculated for available constituents are listed in **Appendix 5c**. The TDS concentration (2,020 mg/L) from the produced water sample indicated that the water was slightly saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Rock Springs Formation on the Rock Springs Uplift 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 one constituent exceeded health-based standards: boron (33%). Concentrations of several characteristics

and constituents exceeded aesthetic standards for domestic use: manganese (100%), sulfate (100%), TDS (100%), and chloride (25%). One water-quality analysis was from a produced water sample, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample had a concentration of one characteristic that exceeded aesthetic standards for domestic use: TDS.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were manganese (100%), sulfate (100%), boron (33%), SAR (33%), chloride (25%), and TDS (25%). The produced water sample had a concentration of one characteristic that exceeded agricultural-use standards: TDS. One characteristic and one constituent measured at concentrations greater than livestock-use standards were TDS (25%) and sulfate (25%).

**Haystack Mountains Formation.** The chemical composition of groundwater in the Haystack Mountains Formation of the Mesaverde Group in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from three springs. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations indicated that water was fresh (supplementary data tables). TDS concentrations ranged from 284 to 403 mg/L, with a median of 350 mg/L. The chemical composition of groundwater was also 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 5b**. TDS concentrations varied and indicated that most waters were moderately saline (50% of samples) and remaining waters ranged from slightly to very saline (supplementary data tables). TDS concentrations ranged from 2,480 to 32,300 mg/L, with a median of 5,890 mg/L.

Concentrations of some characteristics and constituents in the Haystack Mountains Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental water was suitable for domestic use on the basis of health standards. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several constituents that exceeded health-based standards: arsenic (100%), cadmium (100%), lead (100%), mercury (100%), barium (50%), radium-226 plus radium-228 (50%), and selenium (33%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: manganese (100%), TDS (100%), iron (71%), aluminum (67% exceeded lower limit and 33% exceeded upper limit of range; see **Table 6-1**), chloride (62%), pH (38% exceeded upper limit), and sulfate (12%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The environmental water was suitable for agricultural and livestock use. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: boron (100%), cadmium (100%), chloride (100%), SAR (100%), TDS (100%), selenium (67%), iron (57%), manganese (50%), radium-226 plus radium-228 (50%), aluminum (33%), pH (12% exceeded upper limit), and sulfate (12%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: mercury (100%), chloride (50%), radium-226 plus radium-228 (50%), TDS (50%), pH (38% exceeded upper limit), aluminum (33%), and selenium (33%).

**Blair Formation.** The chemical composition of groundwater in the Blair Formation of the Mesav-

erde Group in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from six wells and three springs. TDS concentrations varied widely and indicated that most water ranged from fresh to moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of five produced-water samples from wells. TDS concentrations indicated that most waters were briny (80% of samples) and remaining waters were very saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Blair Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters were suitable for domestic use on the basis of health standards, but generally were unsuitable for domestic use because concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (89%), TDS (89%), manganese (29%), and iron (14%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), sulfate (80%), and pH (20% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (89%), chloride (17%), and TDS (11%). The environmental waters may be suitable for livestock use. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (80%). The

produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), sulfate (40%), and pH (20% exceeded upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Blair Formation of the Mesaverde Group in the Green River Basin was characterized and the quality evaluated on the basis of three produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations indicated that most waters were briny (67% of samples) and remaining waters were very saline (supplementary data tables). TDS concentrations ranged from 20,000 to 97,600 mg/L, with a median of 67,000 mg/L.

Concentrations of some characteristics and constituents in the Blair Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared to health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that greatly exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), and TDS (100%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and sulfate (67%).

### *Rock Springs Uplift*

The chemical composition of groundwater in the Blair Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from six wells and three springs. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations varied widely and indicated that waters ranged from fresh to moderately saline (supplementary data tables). TDS concentrations ranged from 415 to 3,720 mg/L, with a median of 1,290 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of two produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced-water samples indicated that the water was briny (supplementary data tables). TDS concentrations were 45,000 and 48,000 mg/L.

Concentrations of some characteristics and constituents in the Blair Formation on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for of water for some uses. The environmental waters were suitable for domestic use on the basis of health standards, but generally were not suitable for domestic use because concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: sulfate (89% of samples), TDS (89%), manganese (29%), and iron (14%). Some water-quality analyses were available from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses were available for comparison with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), sulfate (50%), and pH (50% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Rock Springs

Uplift. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (89%), chloride (17%), and TDS (11%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (50%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and pH (50% exceeded upper limit).

**Adaville Formation.** The chemical composition of groundwater in the Adaville Formation in the GGRB was characterized and the quality evaluated on the basis of three produced-water samples from wells. TDS concentrations indicated that most waters were fresh (67% of samples) and remaining waters were moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Adaville Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), manganese (100%), TDS (67%), chloride (33%), and sulfate (33%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (67%), sulfate (33%), and TDS (33%). The produced-water samples generally had concentrations of one characteristic and one constituent that exceeded livestock-use standards: chloride (33%) and TDS (33%).

### *Green River Basin*

The chemical composition of groundwater in the Adaville Formation in the Green River Basin was characterized and the quality evaluated on the basis of one produced water sample from a well. Individual constituent concentrations for this sample are listed in **Appendix 5a**. The TDS concentration (10,000 mg/L) indicated that water was moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Adaville Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Water-quality analyses were available from only one produced water sample, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample had concentrations of three characteristics and constituents that exceeded aesthetic standards for domestic use: chloride, sulfate, and TDS.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced water sample had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride, sulfate, and TDS. The produced water sample had concentrations of one characteristic (TDS) and one constituent (chloride) that exceeded livestock-use standards.

### *Overthrust Belt*

The chemical composition of groundwater in the Adaville Formation in the Overthrust Belt was characterized and the quality evaluated on the basis of two produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations indicated that water was fresh (supplementary data tables). TDS concentrations were 279 and 563 mg/L.

Concentrations of some characteristics and constituents in the Adaville Formation in the Overthrust Belt approached or exceeded applicable

USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100% of samples), manganese (100%), and TDS (50%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples generally had a concentration of one constituent that exceeded agricultural-use standards: chloride (50%). The produced-water samples did not have concentrations of any characteristic or constituent that exceeded livestock-use standards.

**Blind Bull Formation.** The chemical composition of groundwater in the Blind Bull Formation in the Overthrust Belt was characterized and the quality evaluated on the basis of one environmental water sample from a spring. Individual constituent concentrations are listed in **Appendix 4f**. The TDS concentration (190 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the characteristics and constituents that were determined, the quality of water from the Blind Bull Formation in the Overthrust Belt was suitable for most uses, and no characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Baxter Shale.** The chemical composition of groundwater in the Baxter Shale in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one well and four springs. TDS concentrations in the environmental water standards indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater also was characterized and the quality evaluated on the basis of 34 produced-water samples from wells. The

produced-water samples were from the Baxter Shale and equivalents in the GGRB: the Baxter, Cody, and Steele Shales and associated Niobrara Formation (the Cody, Steele, and Niobrara are described separately below). The Baxter Shale occurs in the Green River Basin and on the Rock Springs Uplift, whereas the Cody Shale occurs in the Great Divide Basin and the Steele Shale and Niobrara Formation occur in the Washakie Basin. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (67% of samples) and remaining waters ranged from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Baxter Shale in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters generally were suitable for domestic use on the basis of constituents available for comparisons with health standards, but likely are not suitable for domestic use because concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS (40%) and sulfate (20%). Some water-quality analyses for the Baxter Shale and its equivalents were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of two constituents that exceeded health-based standards: barium (60%) and zinc (17%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% exceeded lower limit), TDS (100%), iron (95%), chloride (91%), manganese (50%), sulfate (21%), and pH (9% less than lower limit and 18% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. One constituent (sulfate, 40%) was measured in the environmental water samples at concentrations greater than agricultural-use standards. No characteristic or constituent was measured at concentra-

tions greater than livestock-use standards in the environmental water samples. The produced-water samples for the Baxter Shale and its equivalents had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (97%), TDS (97%), iron (55%), sulfate (24%), zinc (17%), and pH (6% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (85%), TDS (83%), and pH (9% less than lower limit and 18% greater than upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Baxter Shale in the Green River Basin was characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (67% of samples) and remaining waters ranged from fresh to slightly saline (supplementary data tables). TDS concentrations ranged from 660 to 23,300 mg/L, with a median of 16,300 mg/L.

Concentrations of some characteristics and constituents in the Baxter Shale in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (67%), sulfate (33%), and pH (20% less than lower limit and greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had

concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (83%), TDS (83%), iron (80%), sulfate (50%), and pH (20% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (67%), TDS (67%), and pH (20% less than lower limit and greater than upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Baxter Shale on the Rock Springs Uplift was characterized and the quality evaluated on the basis of environmental water samples from one well and four springs. Summary statistics calculated for available constituents are listed in **Appendix 4d**. TDS concentrations indicated that the water was fresh (supplementary data tables). TDS concentrations ranged from 248 to 961 mg/L, with a median of 472 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of one produced water sample from a well. Individual constituent concentrations are listed in **Appendix 5c**. The TDS concentration (23,300 mg/L) in the produced water sample indicated that the water was very saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Baxter Shale on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters were suitable for domestic use on the basis of health standards. Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS (40% of samples) and sulfate (20%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced water sample had concentrations of one characteristic and one constituent that exceeded aesthetic standards for domestic use: TDS and chloride.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. One constituent in the environmental water samples was measured at concentrations greater than agricultural-use standards: sulfate (40%). No characteristic or constituent was measured at concentrations greater than livestock-use standards in the environmental water samples. The produced water sample had concentrations of one characteristic and one constituent that exceeded both agricultural-use and livestock-use standards: TDS and chloride.

**Cody Shale.** The chemical composition of groundwater in the Cody Shale in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of environmental water samples from three wells. Summary statistics calculated for available constituents are listed in **Appendix 4b**. TDS concentrations were variable and indicated that most waters were fresh (67% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 291 to 2,340 mg/L, with a median of 744 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 27 produced-water samples from wells (these may also include some water samples from the Steele Shale). Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (65% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 2,270 to 45,600 mg/L, with a median of 22,200 mg/L.

Concentrations of some characteristics and constituents in the Cody Shale in the Great Divide/Washakie/Sand Wash basins of the GGRB 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 two constituents exceeded health-based standards: radon (100%) and ammonia (67%). Concentrations of several characteristics and con-

stituents frequently exceeded aesthetic standards for domestic use: manganese (100%), TDS (67%), and sulfate (33%). Most water-quality analyses for the Cody Shale (or Steele Shale) were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of two constituents that exceeded health-based standards: barium (60%) and zinc (17%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: aluminum (100% exceeded lower limit), TDS (100%), chloride (96%), iron (94%), manganese (50%), pH (7% less than lower limit and 19% greater than upper limit), and sulfate (19%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (67%), chloride (33%), manganese (33%), SAR (33%), and TDS (33%). The produced-water samples for the Cody Shale (or Steele Shale) had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), iron (47%), sulfate (19%), zinc (17%), and pH (4% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (89%), TDS (87%), and pH (7% less than lower limit and 19% greater than upper limit).

**Steele Shale.** The chemical composition of groundwater in the Steele Shale in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of one environmental water sample from a spring. Individual constituent concentrations are listed in **Appendix 4b**. The TDS concentration (1,670 mg/L) indicated that the water was slightly saline. On the basis of the one analysis available for this spring, the water

was suitable for domestic, agricultural, and livestock use, with the exception of sulfate (aesthetic standard for domestic use and State of Wyoming agricultural-use standard exceeded) and TDS (aesthetic standard for domestic use exceeded).

**Niobrara Formation.** The chemical composition of groundwater in the Niobrara Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of one environmental water sample from a spring. Individual constituent concentrations are listed in **Appendix 4b**. The TDS concentration (492 mg/L) indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of two produced-water samples from wells. Individual constituent concentrations for both samples are listed in **Appendix 5b**. TDS concentrations in the produced-water samples indicated that the waters were very saline (supplementary data tables). TDS concentrations were 29,500 and 31,100 mg/L.

On the basis of the few characteristics and constituents analyzed, the environmental water sample is suitable for domestic, agricultural, and livestock use; the only domestic standard exceeded was manganese (aesthetic SMCL), and no State of Wyoming agricultural or livestock-use standards were exceeded. On the basis of the few characteristics and constituents analyzed in the two produced-water samples, TDS and chloride concentrations in both samples exceeded the aesthetic standard for domestic use and State of Wyoming agricultural-use and livestock-use standards. The iron concentration in one produced water sample exceeded the aesthetic standard for domestic use and the State of Wyoming agricultural-use standard.

**Hilliard Shale.** The Hilliard Shale occurs in the Green River Basin and Overthrust Belt. The chemical composition of groundwater in the Hilliard Shale in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one well and three springs in the Overthrust Belt. Summary statistics calculated for available constituents are listed in **Appendix 4f**. TDS concentrations indicated that most waters

were fresh (75% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 328 to 3,340 mg/L, with a median of 454 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of six produced-water samples from wells in the Green River Basin. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations indicated that the produced waters were very saline (supplementary data tables). TDS concentrations ranged from 10,400 to 12,700 mg/L, with a median of 10,800 mg/L.

Concentrations of some characteristics and constituents in the Hilliard Shale in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters in the Overthrust Belt were suitable for domestic use on the basis of health standards. Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS (50%) and sulfate (25%). Some water-quality analyses were from produced-water samples in the Green River Basin, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced water analyses were available for comparisons with health-based standards. The produced-water samples in the Green River Basin had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), iron (100%), TDS (100%), pH (50% less than lower limit), and sulfate (50%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards in the Overthrust Belt were chloride (25%), sulfate (25%), and TDS (25%). The produced-water samples in the Green River Basin generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron

(100%), TDS (100%), and sulfate (50%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and pH (50% less than lower limit).

**Frontier Formation.** The chemical composition of groundwater in the Frontier Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from two wells and eight springs. TDS concentrations indicated that most waters were fresh (78% of samples) and remaining waters were slightly saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 370 produced-water samples from wells. Major-ion composition in relation to TDS is shown on a trilinear diagram (**Appendix 3b, diagram D**). TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Frontier Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters were suitable for domestic use on the basis of health standards. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (56%), sulfate (40%), iron (29%), manganese (14%), pH (11% exceeded upper limit), and chloride (10%). Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples had concentrations of two constituents that exceeded health-based standards: strontium (75%) and barium (50%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (99%), iron (98%), chloride (97%), manganese (67%), aluminum (50% exceeded lower limit), pH (11% less than lower limit and 3% greater than upper limit), and sulfate (11%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (40%), SAR (25%), pH (11% exceeded upper limit), and chloride (10%). One characteristic was measured at concentrations greater than livestock-use standards: pH (11% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (99%), TDS (95%), iron (64%), manganese (33%), SAR (33%), sulfate (12%), and pH (1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (86%), TDS (82%), pH (11% less than lower limit and 3% greater than upper limit), and sulfate (1%).

#### *Green River Basin*

The chemical composition of groundwater in the Frontier Formation in the Green 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 4a**. No TDS measurement was available to classify salinity. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 310 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced waters varied widely and indicated that most waters were moderately saline (54% of samples) and remaining waters ranged from fresh to briny (supplementary data tables). TDS concentrations ranged from 284 to 85,800 mg/L, with a median of 8,600 mg/L.

Concentrations of some characteristics and constituents in the Frontier Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental waters were suitable for domestic use on the basis of health standards. The concentration of one constituent (sulfate) exceeded aesthetic standards

for domestic use. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples had concentrations of two constituents that exceeded health-based standards: strontium (75%) and barium (50%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: manganese (100%), TDS (100%), iron (99%), chloride (98%), pH (13% less than lower limit and 1% greater than upper limit), and sulfate (9%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The concentration of one constituent (sulfate) exceeded agricultural-use standards. No characteristic or constituent was measured at concentrations greater than livestock-use standards in the environmental water sample. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: manganese (100%), chloride (100%), TDS (96%), iron (64%), sulfate (11%), and pH (<1% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (87%), TDS (81%), pH (13% less than lower limit and 1% greater than upper limit), and sulfate (1%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Frontier Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of 21 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely, ranging from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,330 to 62,100 mg/L, with a median of 14,400 mg/L.

Concentrations of some characteristics and constituents in the Frontier Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. All water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100% of samples), chloride (86%), iron (50%), pH (5% less than lower limit and 19% greater than upper limit), and sulfate (11%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: SAR (100%), chloride (95%), TDS (90%), iron (50%), sulfate (11%), and pH (5% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (81%), chloride (76%), and pH (5% less than lower limit and 19% greater than upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Frontier Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of 29 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced-water samples varied, ranging from moderately saline to briny (supplementary data tables). TDS concentrations ranged from 3,830 to 65,400 mg/L, with a median of 31,800 mg/L.

Concentrations of some characteristics and constituents in the Frontier Formation on the Rock

Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), iron (100%), TDS (100%), sulfate (22%), and pH (11% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), TDS (100%), and sulfate (22%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (93%), TDS (93%), pH (11% exceeded upper limit), and sulfate (4%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Frontier Formation in the Overthrust Belt was characterized and the quality evaluated on the basis of environmental water samples from two wells and seven springs. Summary statistics calculated for available constituents are listed in **Appendix 4f**. TDS concentrations indicated that most environmental waters were fresh (78% of samples) and remaining waters were slightly saline (supplementary data tables). TDS concentrations ranged from 187 to 1,470 mg/L, with a median of 657 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 10 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

TDS concentrations ranged from 148 to 65,900 mg/L, with a median of 9,110 mg/L.

Concentrations of some characteristics and constituents in the Frontier Formation in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Environmental waters generally were suitable for domestic use on the basis of health-based standards, but some waters may not be suitable for domestic use because they exceed aesthetic standards. Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: TDS (56%), sulfate (33%), iron (29%), manganese (14%), pH (12% exceeded upper limit), and chloride (11%). Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water samples with constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (90%), chloride (80%), aluminum (50% exceeded lower limit), iron (50%), manganese (50%), and sulfate (30%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were sulfate (33%), SAR (29%), pH (12% exceeded upper limit), and chloride (11%). One characteristic was measured at concentrations greater than livestock-use standards: pH (12% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (80%), TDS (70%), and sulfate (30%). The produced-water samples generally had concentrations of one characteristic and one constituent that exceeded livestock-use standards: TDS (60%) and chloride (60%).

**Aspen Shale.** The chemical composition of groundwater in the Aspen Shale in the Overthrust Belt of the GGRB was characterized and the quality evaluated on the basis of environmental water samples from three wells and two springs. TDS concentrations indicated that most waters were fresh (80% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 334 to 5,570 mg/L, with a median of 397 mg/L.

Concentrations of some characteristics and constituents in the Aspen Shale in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental water was suitable for domestic use on the basis of health standards. Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS (40%) and chloride (20%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were chloride (40%), SAR (20%), sulfate (20%), and TDS (20%). One characteristic and one constituent were measured at concentrations greater than livestock-use standards: TDS (20%) and chloride (20%).

#### **Muddy Sandstone and Thermopolis Shale.**

The chemical composition of groundwater in the Muddy Sandstone in the GGRB was characterized and the quality evaluated on the basis of produced-water samples from 18 wells. Summary statistics calculated for available constituents are listed in **Appendices 5a, 5b, and 5d**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (50% of samples) and remaining waters ranged from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Muddy Sandstone in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality

analyses were from produced-water samples and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (94%), pH (6% less than lower limit and greater than upper limit), and sulfate (18%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (94%), TDS (94%), and sulfate (18%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (89%), TDS (83%), and pH (6% less than lower limit and greater than upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Muddy Sandstone in the Green River Basin was characterized and the quality evaluated on the basis of 11 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations varied and indicated that produced-water samples ranged from moderately saline to briny (supplementary data tables). TDS concentrations ranged from 4,510 to 36,500 mg/L, with a median of 13,600 mg/L.

Concentrations of some characteristics and constituents in the Muddy Sandstone in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared to health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-

water constituent analyses could be compared with health-based standards. All produced-water samples had concentrations of one characteristic and one constituent that exceeded aesthetic standards for domestic use: TDS (100%) and chloride (100%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. All produced-water samples generally had concentrations of one characteristic and one constituent that always exceeded agricultural-use standards: TDS (100%) and chloride (100%). The produced-water samples generally had concentrations of one constituent and one characteristic that exceeded livestock-use standards: chloride (100%) and TDS (91%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Muddy Sandstone in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of four produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations varied and indicated that most waters were very saline (50% of samples) and remaining waters were fresh or moderately saline (supplementary data tables). TDS concentrations ranged from 596 to 25,700 mg/L, with a median of 9,100 mg/L.

Concentrations of some characteristics and constituents in the Muddy Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (75%), and sulfate (50%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (75%), TDS (75%), and sulfate (50%). The produced-water samples had concentrations of one characteristic and one constituent that exceeded livestock-use standards: TDS (50%) and chloride (50%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Muddy Sandstone in the Overthrust Belt was characterized and the quality evaluated on the basis of three produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations indicated that most waters were very saline (67% of samples) and remaining waters were briny (supplementary data tables). TDS concentrations ranged from 20,000 to 64,400 mg/L, with a median of 28,800 mg/L.

Concentrations of some characteristics and constituents in the Muddy Sandstone in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), pH (33% less than lower limit and greater than upper limit), and sulfate (33%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride

(100%), TDS (100%), and sulfate (33%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and pH (33% less than lower limit and greater than upper limit).

**Bear River Formation.** The chemical composition of groundwater in the Bear River Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one well in the Green River Basin and two springs in the Overthrust Belt. Individual constituent concentrations are listed in **Appendices 4a** and **4f**. TDS concentrations indicated that waters were fresh (supplementary data tables). The TDS concentration in the well was 436 mg/L and the TDS concentration available for one spring was 283 mg/L. On the basis of the few analyses available for these environmental water samples, the waters generally were suitable for domestic, agricultural, and livestock use with the exception of one characteristic (State of Wyoming SAR agricultural-use standard exceeded) in the Green River Basin.

**Cloverly Formation.** The chemical composition of groundwater in the Cloverly Formation in the GGRB was characterized and the quality evaluated on the basis of 105 produced-water samples from wells. Major-ion composition of produced waters from the Cloverly Formation throughout the GGRB in relation to TDS is shown on a trilinear diagram (**Appendix 3b**, *diagram E*). Summary statistics calculated for available constituents are listed in **Appendices 5a**, **5b**, **5c**, and **5d**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Cloverly Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. One produced water

sample had a concentration of one constituent that exceeded health-based standards: strontium. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (95% of samples), TDS (93%), chloride (89%), sulfate (22%), and pH (14% less than lower limit and 10% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (94%), TDS (85%), iron (77%), and sulfate (25%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (73%), chloride (69%), pH (14% less than lower limit and 10% greater than upper limit), and sulfate (1%).

#### *Green River Basin*

The chemical composition of groundwater in the Cloverly Formation in the Green River Basin was characterized and the quality evaluated on the basis of 47 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples varied widely, ranging from fresh to very saline (supplementary data tables). TDS concentrations ranged from 118 to 23,200 mg/L, with a median of 9,900 mg/L.

Concentrations of some characteristics and constituents in the Cloverly Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of water for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. Strontium was measured in one produced water sample at a concentration that exceeded the health-based standard. The produced-water samples generally had concentrations of several characteristics

and constituents that exceeded aesthetic standards for domestic use: iron (100% of samples), TDS (91%), chloride (85%), sulfate (21%), and pH (20% less than lower limit and 2% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (94%), iron (87%), TDS (79%), and sulfate (23%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (68%), TDS (68%), and pH (20% less than lower limit and 2% greater than upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Cloverly Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of 22 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced waters varied widely and indicated that most waters were moderately saline (55% of samples) and remaining waters ranged from fresh to very saline (supplementary data tables). TDS concentrations ranged from 426 to 26,200 mg/L, with a median of 6,480 mg/L.

Concentrations of some characteristics and constituents in the Cloverly Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (95%), chloride (91%), iron

(80%), pH (10% less than lower limit and 15% greater than upper limit), and sulfate (14%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (95%), TDS (86%), iron (60%), and sulfate (19%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (64%), chloride (50%), and pH (10% less than lower limit and 15% greater than upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Cloverly Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of 31 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (68% of samples) and remaining waters ranged from fresh to briny (supplementary data tables). TDS concentrations ranged from 32 to 98,500 mg/L, with a median of 20,300 mg/L.

Concentrations of some characteristics and constituents in the Cloverly Formation on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of water for most uses. The water-quality analyses were from produced water, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water samples with constituent analysis could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (94%), chloride (90%), sulfate (29%), and pH (10% less than lower limit and 17% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (94%), TDS (90%), and sulfate (32%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (90%), chloride (84%), pH (10% less than lower limit and 17% greater than upper limit), and sulfate (3%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Cloverly Formation in the Overthrust Belt was characterized and the quality evaluated on the basis of five produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations from produced-water samples varied and ranged from slightly to very saline (supplementary data tables). TDS concentrations ranged from 2,700 to 27,900 mg/L, with a median of 6,330 mg/L.

Concentrations of some characteristics and constituents in the Cloverly Formation in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), iron (100%), TDS (100%), pH (20% exceeded upper limit), and sulfate (20%). For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), iron (50%), and sulfate

(20%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (60%), TDS (60%), and pH (20% exceeded upper limit).

**Gannett Group.** The chemical composition of groundwater in the Gannett Group in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from three springs, one in the Green River Basin and two in the Overthrust Belt. Individual constituent concentrations are listed in **Appendices 4a** and **4f**. TDS concentrations indicated that all waters were fresh (supplementary data tables). The spring in the Green River Basin had a TDS concentration of 226 mg/L. One spring in the Overthrust Belt had a TDS concentration of 238 mg/L; the other spring, in the Ephraim Conglomerate, is described below. On the basis of the characteristics and constituents analyzed, the quality of water from the Gannett Group in the GGRB was suitable for most uses. No characteristics or constituents in the Gannett Group approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Ephraim Conglomerate.** The chemical composition of groundwater in the Ephraim Conglomerate of the Gannett Group in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from a spring in the Overthrust Belt. Individual constituent concentrations are listed in **Appendix 4f**. The TDS concentration (196 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the few characteristics and constituents analyzed, the quality of water from the Ephraim Conglomerate in the Overthrust Belt was suitable for most uses. No characteristics or constituents in the Ephraim Conglomerate approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Morrison Formation.** The chemical composition of groundwater in the Morrison Formation in the GGRB was characterized and the quality evaluated on the basis of 18 produced-water samples from wells. Summary statistics calculated for available

constituents are listed in **Appendices 5b** and **5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (67% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Morrison Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced water and constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), sulfate (67%), and pH (24% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (72%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (89%), TDS (89%), pH (24% exceeded upper limit), and sulfate (11%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Morrison Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of two produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5b**. TDS concentrations from produced-water samples indicated that the water was very saline (supplementary data tables). TDS concentrations were 26,100 and 27,000 mg/L.

Concentrations of some characteristics and constituents in the Morrison Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), and TDS (100%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. All produced-water samples had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and sulfate (50%).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Morrison Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of 16 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (62% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 2,160 to 40,800 mg/L, with a median of 18,900 mg/L.

Concentrations of some characteristics and constituents in the Morrison Formation on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality stan-

dards and could limit suitability for most uses. The water-quality analyses were from produced-water samples and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), sulfate (62%), and pH (27% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (69%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (88%), TDS (88%), pH (27% exceeded upper limit), and sulfate (6%).

**Sundance Formation.** The chemical composition of groundwater in the Sundance Formation in the GGRB was characterized and the quality evaluated on the basis of 16 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendices 5b** and **5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (56% of samples) and remaining waters ranged from moderately saline to briny (supplementary data tables). Freethey et al. (1988, and as modified by Freethey and Cordy, 1991) mapped TDS concentrations in the combined Sundance and Nugget aquifers (Sundance aquifer composed of the Preuss Sandstone and Sundance Formation, and Nugget aquifer composed of the Nugget Formation) in the GGRB and adjacent areas (**Figure 6-7**).

Concentrations of some characteristics and constituents in the Sundance Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could

limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), iron (100%), TDS (100%), sulfate (56%), and pH (8% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), TDS (100%), and sulfate (62%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (88%), TDS (88%), sulfate (19%), and pH (8% less than lower limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Sundance Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced waters varied widely and indicated that most waters were moderately saline (50% of samples) and remaining waters ranged from very saline to briny (supplementary data tables). TDS concentrations ranged from 3,230 to 39,200 mg/L, with a median of 8,040 mg/L.

Concentrations of some characteristics and constituents in the Sundance Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic

and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), iron (100%), TDS (100%), pH (20% less than lower limit), and sulfate (17%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), TDS (100%), and sulfate (33%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (67%), TDS (67%), and pH (20% less than lower limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Sundance Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of ten produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced waters varied and indicated that most waters were very saline (80% of samples) and remaining waters were moderately saline or briny (supplementary data tables). TDS concentrations ranged from 9,470 to 37,400 mg/L, with a median of 16,900 mg/L.

Concentrations of some characteristics and constituents in the Sundance Formation on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards.

No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), and sulfate (80%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (80%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), and sulfate (30%).

**Twin Creek Limestone.** The chemical composition of groundwater in the Twin Creek Limestone in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from two springs in the Overthrust Belt. Individual constituent concentrations are listed in **Appendix 4f**. The TDS concentration (202 mg/L) available for one spring indicated that the water was fresh (supplementary data tables). On the basis of the few characteristics and constituents analyzed, the quality of water from the Twin Creek Limestone in the Overthrust Belt was suitable for most uses. No characteristics or constituents in the Twin Creek Limestone approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

**Nugget Sandstone.** The chemical composition of groundwater in the Nugget Sandstone in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one well and four springs. Major-ion composition of produced-water samples from throughout the GGRB in relation to TDS is shown on a trilinear diagram (**Appendix 3b, diagram F**). Summary statistics calculated for available constituents measured in environmental water samples are listed in **Appendices 4a, 4d, and 4f**. TDS concentrations varied and indicated that most waters were fresh (80% of samples) and remaining waters were

moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 78 produced-water samples from wells. Summary statistics calculated for available constituents measured in produced-water samples are listed in **Appendix 5a, 5b, 5c, and 5d**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Nugget Sandstone in the GGRB 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 two constituents exceeded health-based standards: ammonia (50%) and radium-226 plus radium-228 (50%). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: iron (33%), manganese (33%), chloride (20%), and TDS (20%). Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (99%), sulfate (78%), and pH (15% less than lower limit and 8% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Characteristics and constituents in environmental water samples measured at concentrations greater than agricultural-use standards were radium-226 plus radium-228 (50%), boron (33%), chloride (20%), SAR (20%), and TDS (20%). Characteristics and constituents measured at concentrations greater than livestock-use standards were radium-226 plus radium-228 (50%), chloride (20%), and TDS (20%). The produced-water samples generally

had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), TDS (99%), and sulfate (81%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (87%), chloride (82%), sulfate (27%), and pH (15% less than lower limit and 8% greater than upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Nugget Sandstone in the Green River Basin was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations are listed in **Appendix 4a**. TDS concentrations indicated that both samples were fresh (supplementary data tables). TDS concentrations were 172 and 209 mg/L. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 19 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced waters indicated that most waters were briny (68% of samples) and remaining waters were very saline (supplementary data tables). TDS concentrations were very high and ranged from 15,500 to 103,000 mg/L, with a median of 85,300 mg/L.

Concentrations of some characteristics and constituents in the Nugget Sandstone in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for all uses. No environmental water sample constituent analyses could be compared with health-based standards. No concentrations of any characteristic or constituent exceeded aesthetic standards for domestic use. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared to health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents

that exceeded aesthetic standards for domestic use: chloride (100%), TDS (100%), sulfate (89%), and pH (18% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. No concentrations of any characteristic or constituent exceeded agricultural- or livestock-use standards in the two environmental water samples. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (95%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), sulfate (26%), and pH (18% less than lower limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Nugget Sandstone in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of 25 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced-water samples varied widely, ranging from fresh to briny (supplementary data tables). TDS concentrations ranged from 894 to 95,300 mg/L, with a median of 10,300 mg/L.

Concentrations of some characteristics and constituents in the Nugget Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of water for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%

of samples), TDS (100%), chloride (96%), sulfate (78%), and pH (21% less than lower limit and greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), TDS (96%), and sulfate (78%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (64%), chloride (52%), sulfate (30%), and pH (21% less than lower limit and greater than upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Nugget Sandstone on the Rock Springs Uplift was characterized and the quality evaluated on the basis of one environmental water sample from a well. Individual constituent concentrations for the environmental water sample are listed in **Appendix 4d**. The TDS concentration (7,220 mg/L) indicated that the water was moderately saline (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 21 produced-water samples from wells. Summary statistics calculated for available constituents in produced-water samples are listed in **Appendix 5c**. TDS concentrations from produced-water samples varied and ranged from moderately saline to briny (supplementary data tables). TDS concentrations ranged from 5,000 to 95,700 mg/L, with a median of 10,200 mg/L.

Concentrations of some characteristics and constituents in the Nugget Sandstone on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of water for most uses. The environmental water sample was suitable for domestic use, but concentrations of two constituents exceeded health-based standards: ammonia and radium-226 plus radium-228. Concentrations of several characteristics and constituents

exceeded aesthetic standards for domestic use: iron, manganese, chloride, and TDS. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), TDS (100%), and sulfate (53%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. Characteristics and constituents in the one environmental water sample measured at concentrations greater than agricultural-use standards were boron, chloride, radium-226 plus radium-228, SAR, and TDS. Characteristics and constituents measured at concentrations greater than livestock-use standards were radium-226 plus radium-228, chloride, and TDS. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), TDS (100%), and sulfate (58%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (95%), TDS (95%), and sulfate (5%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Nugget Sandstone in the Overthrust Belt was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations for both springs are listed in **Appendix 4f**. TDS concentrations (107 and 198 mg/L) indicated that both environmental waters were fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 13 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (54%

of samples) and remaining waters were moderately saline or briny (supplementary data tables). TDS concentrations ranged from 7,870 to 102,000 mg/L, with a median of 16,300 mg/L.

Concentrations of some characteristics and constituents in the Nugget Sandstone in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No concentrations of any characteristic or constituent in the two environmental water samples exceeded health-based or aesthetic standards for domestic use. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), TDS (100%), and pH (15% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. No concentrations of any characteristic or constituent in the two environmental water samples exceeded agricultural-use or livestock-use standards. All the produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (100%), chloride (92%), sulfate (54%), and pH (15% less than lower limit).

**Chugwater Formation or Group.** The chemical composition of groundwater in the Chugwater Formation or Group in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from a well on the Rawlins Uplift and two produced-water samples (Great Divide/Washakie/Sand Wash basins and

Rock Springs Uplift). The TDS concentration (1,420 mg/L) indicated that the environmental water was slightly saline (supplementary data tables). Individual constituent concentrations for the environmental water sample are listed in **Appendix 4c** and individual constituent concentrations that were available for one produced water sample from the Rock Springs Uplift are listed in **Appendix 5c**. TDS concentrations indicated that the produced waters were moderately saline (supplementary data tables). TDS concentrations for the produced-water samples were 8,140 mg/L (Great Divide/Washakie/Sand Wash basins) and 5,600 mg/L (Rock Springs Uplift), indicating that the produced water was moderately saline.

Concentrations of some characteristics and constituents in the Chugwater Formation or Group in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The environmental water sample from the Rawlins Uplift was suitable for domestic use, but concentrations of two constituents exceeded health-based standards: radon and strontium. Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: TDS and sulfate. Two produced-water samples were available, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. Both produced-water samples (one in the Great Divide/Washakie/Sand Wash basins and one on the Rock Springs Uplift) had concentrations of one characteristic and one constituent that exceeded aesthetic standards for domestic use: TDS and chloride.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Sulfate was measured in the environmental water sample at a concentration greater than the agricultural-use standard. No concentration of any characteristic or constituent in the environmental water sample exceeded livestock-use standards. Both produced-water samples had concentrations of chloride and

TDS that exceeded agricultural-use and livestock-use standards. In addition, sulfate was measured in the produced water sample from the Rock Springs Uplift at a concentration greater than the agricultural-use standard.

**Ankareh Formation.** The chemical composition of groundwater in the Ankareh Formation in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from a spring in the Overthrust Belt and one produced water sample in the Green River Basin. Individual constituent concentrations for the environmental sample and produced water sample are listed in **Appendices 4f** and **5c**, respectively. The TDS concentration (546 mg/L) of the environmental water sample indicated that the water was fresh, and the TDS concentration (23,800 mg/L) from the produced water sample indicated that the water was very saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Ankareh Formation in the GGRB 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, the environmental water in the Overthrust Belt was suitable for domestic use. TDS and sulfate exceeded aesthetic standards for domestic use. One water-quality sample was from produced water in the Green River Basin, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. TDS, chloride, and sulfate in the produced water sample exceeded aesthetic standards for domestic use.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Sulfate in the environmental sample exceeded agricultural-use standards. No concentration of any characteristic or constituent exceeded livestock-use standards in the environmental water sample. The produced water sample in the Green River Basin had concen-

trations of one characteristic and two constituents that exceeded agricultural-use and livestock-use standards: TDS, chloride, and sulfate.

**Thaynes Limestone.** The chemical composition of groundwater in the Thaynes Limestone in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from one spring in the Green River Basin and two springs in the Overthrust Belt. Individual constituent concentrations for the environmental water samples in the Green River Basin and in the Overthrust Belt are listed in **Appendices 4a** and **4f**, respectively. A TDS concentration (390 mg/L) was available for one of the springs in the Overthrust Belt and indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of five produced-water samples from three wells in the Green River Basin and two wells in the Overthrust Belt. Summary statistics calculated for available constituents and individual constituent concentrations are listed in **Appendices 5a** and **5d**, respectively. TDS concentrations from all produced-water samples indicated that the waters were very saline (supplementary data tables). TDS concentrations for produced-water samples in the Green River Basin ranged from 18,400 to 25,800 mg/L, with a median of 22,400 mg/L. TDS concentrations for produced-water samples in the Overthrust Belt were 26,400 and 33,200 mg/L.

Concentrations of some characteristics and constituents in the Thaynes Limestone in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of the characteristics and constituents analyzed, the quality of water from the Thaynes Limestone in the GGRB was suitable for most uses. No characteristics or constituents in the environmental water samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Some water-quality analyses were from produced-water samples, but many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agri-

cultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural- and livestock-use standards: TDS (100% of samples), chloride (100%), and sulfate (100%).

**Woodside Shale.** The chemical composition of groundwater in the Woodside Shale in the GGRB was characterized and the quality evaluated on the basis of one produced water sample in the Green River Basin. Individual constituent concentrations are listed in **Appendix 5a**. The TDS concentration (17,000 mg/L) indicated that the water was very saline.

Concentrations of some characteristics and constituents in the Woodside Shale in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality sample was from produced-water, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced water sample had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use and livestock-use standards: TDS, chloride, and sulfate.

**Dinwoody Formation.** The chemical composition of groundwater in the Dinwoody Formation in the GGRB was characterized and the quality evaluated on the basis of two environmental water samples from two springs in the Overthrust Belt. Individual constituent concentrations of environmental water samples are listed in **Appendix 4f**. A TDS concentration (97 mg/L) was available for one spring and indicated that the water was fresh. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples from the Green River Basin. Summary statistics calculated for available constituents are listed in **Appendix 5a**.

TDS concentrations indicated that the produced-water samples were very saline (supplementary data tables). TDS concentrations ranged from 14,000 to 16,800 mg/L, with a median of 15,400 mg/L.

Concentrations of some characteristics and constituents in the Dinwoody Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No water-quality constituent analyses could be compared with health-based standards. On the basis of the characteristics and constituents analyzed in the environmental water samples, the quality of water from the Dinwoody Formation in the Overthrust Belt was suitable for most uses, and no characteristics or constituents in the environmental water sample approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Three water-quality samples were from produced-water samples in the Green River Basin, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use and livestock-use standards: TDS (100% of samples), chloride (100%), and sulfate (67% exceeded livestock-use standards; 100% exceeded the other standards).

### **Paleozoic geologic units**

The water quality of aquifers contained in Paleozoic geologic units varies greatly throughout the GGRB. Recharge to these units generally occurs where the formations crop out. Near recharge areas, water in these geologic units can be relatively fresh, and may be suitable for most uses. This is where most domestic, municipal supply, or stock wells are completed. Elsewhere, and with increasing depth (as indicated by produced-water samples) and as the water moves away from the outcrop, the water can have a TDS concentration several times that of seawater, and is not suitable for most uses or is only marginally suitable for livestock use. Only oil or gas wells are completed in Paleozoic geologic units

where they are deeply buried. Groundwater in Paleozoic aquifers is highly mineralized and unsuitable for most uses.

**Phosphoria Formation.** The chemical composition of groundwater in the Phosphoria Formation in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from two springs in the Gros Ventre Range (supplementary data tables). TDS concentrations indicated that waters were nearly fresh (1,000 mg/L) and slightly saline (1,140 mg/L) (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 12 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendices 5a, 5b, 5c, and 5d**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (50% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Phosphoria Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No constituents in the two environmental water samples exceeded health-based standards. TDS and sulfate exceeded aesthetic standards for domestic use in both environmental water samples. Some water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), sulfate (100%), TDS (100%), chloride (58%), and pH (11% less than lower limit and greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. Sulfate

was measured at concentrations greater than agricultural-use standards in both environmental water samples. No characteristic or constituent was measured at concentrations greater than livestock-use standards in the environmental water samples. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: iron (100%), sulfate (100%), TDS (100%), and chloride (83%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (75%), chloride (50%), sulfate (33%), and pH (11% less than lower limit and greater than upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Phosphoria Formation in the Green River Basin was characterized and the quality evaluated on the basis of one produced water sample. Individual constituent concentrations are listed in **Appendix 5a**. The TDS concentration (16,200 mg/L) indicated that the water was very saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Phosphoria Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Many characteristic and constituent analyses were not available for the one produced water sample, and most constituents could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use and livestock-use standards: TDS, chloride, and sulfate.

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Phosphoria Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of one produced water sample. Individual constituent concentra-

tions are listed in **Appendix 5b**. The TDS concentration (5,260 mg/L) from the produced water sample indicated that the water was moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Phosphoria Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Many characteristic and constituent analyses were not available for the one produced water sample in the Great Divide/Washakie/Sand Wash basins, and most constituents could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water sample had concentrations of two characteristics and one constituent that exceeded aesthetic standards for domestic use: pH (exceeded upper limit), TDS, and sulfate.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. TDS and sulfate exceeded agricultural-use standards. The produced water sample had concentrations of two characteristics and one constituent that exceeded livestock-use standards: pH (exceeded upper limit), TDS, and sulfate.

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Phosphoria Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations indicated that most waters were very saline (83% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 5,500 to 18,200 mg/L, with a median of 16,600 mg/L.

Concentrations of some characteristics and constituents in the Phosphoria Formation in the Rock Springs Uplift approached or exceeded applicable

USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality samples were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), sulfate (100%), TDS (100%), and chloride (83%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. All produced-water samples had concentrations of three constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), iron (100%), sulfate (100%), and TDS (100%). The produced-water samples had concentrations of one characteristic and two constituents that exceeded livestock-use standards: TDS (100%), chloride (67%), and sulfate (33%).

#### *Gros Ventre Range*

The chemical composition of groundwater in the Phosphoria Formation in the Gros Ventre Range, located north of the Hoback Basin in northwestern Sublette County (**Figure 6-1**; see also **Figure 5-5**), was characterized and the quality evaluated on the basis of two environmental water samples from two springs. Individual constituent concentrations are listed in **Appendix 4g**. TDS concentrations indicated that the waters were fresh (1,000 mg/L) and slightly saline (1,140 mg/L) (supplementary data tables).

Concentrations of some characteristics and constituents in the Phosphoria Formation in the Gros Ventre Range approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No constituents in the two environmental water samples exceeded health-based standards. TDS and sulfate exceeded aesthetic standards for domestic use in both environmental water samples.

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Gros Ventre Range. Sulfate was the only constituent measured in the environmental water samples at concentrations greater than agricultural-use standards. No characteristic or constituent was measured at concentrations greater than livestock-use standards in the environmental water samples.

#### *Overthrust Belt*

The chemical composition of groundwater in the Phosphoria Formation in the Overthrust Belt was characterized and the quality evaluated on the basis of four produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations indicated that most waters were slightly saline (75% of samples) and remaining water was briny (supplementary data tables). TDS concentrations ranged from 2,330 to 276,000 mg/L, with a median of 2,720 mg/L.

Concentrations of some characteristics and constituents in the Phosphoria Formation in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality samples were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: sulfate (100%), TDS (100%), chloride (25%), and pH (25% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS (100%), sulfate (100%), and chloride (75%). The produced-water samples had concentrations of two

characteristics and one constituent that exceeded livestock-use standards: pH (25% less than lower limit), TDS (25%), and chloride (25%).

**Tensleep Sandstone.** The Tensleep Sandstone is equivalent to the Weber Sandstone and Morgan Formation on the Rock Springs Uplift and in the Green River Basin, and to the Wells Formation in the Overthrust Belt (these units are described below). The chemical composition of groundwater in the Tensleep Sandstone in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from a spring on the Rawlins Uplift. Individual constituent concentrations for the environmental water sample are listed in **Appendix 4c**. The TDS concentration (334 mg/L) indicated that the water was fresh. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 71 produced-water samples from wells. Major-ion composition in relation to TDS for produced waters throughout the GGRB is shown on a trilinear diagram (**Appendix 3c, diagram A**). Summary statistics calculated for available constituents in produced-water samples are listed in **Appendices 5b, 5c, and 5d**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (55% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). Lindner-Lunsford et al. (1989, and as modified by Geldon, 2003b) mapped TDS concentrations in the Tensleep-Weber aquifer (composed of the Tensleep Sandstone and Weber Sandstone) in the GGRB and adjacent areas (**Figure 6-8**).

Concentrations of some characteristics and constituents in the Tensleep Sandstone in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. On the basis of the few analyses available, water from the environmental water sample was suitable for domestic, agricultural, and livestock use. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. One produced water

sample had a concentration of one constituent that exceeded health-based standards: radium-226 plus radium-228. Produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), sulfate (94%), chloride (89%), and pH (2% less than lower limit and 7% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in produced-water samples exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: radium-226 plus radium-228 (100%), TDS (99%), sulfate (94%), and chloride (93%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: radium-226 plus radium-228 (100%), TDS (76%), chloride (58%), sulfate (37%), and pH (2% less than lower limit and 7% greater than upper limit).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Tensleep Sandstone in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of 64 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (52% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,980 to 94,800 mg/L, with a median of 10,400 mg/L.

Concentrations of some characteristics and constituents in the Tensleep Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. One produced water

sample had a concentration of one constituent that exceeded health-based standards: radium-226 plus radium-228. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), sulfate (94%), chloride (88%), and pH (2% less than lower limit and 6% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in produced-water samples exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: radium-226 plus radium-228 (100%), TDS (98%), sulfate (94%), and chloride (92%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: radium-226 plus radium-228 (100%), TDS (73%), chloride (58%), sulfate (37%), and pH (2% less than lower limit and 6% greater than upper limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Tensleep Sandstone on the Rock Springs Uplift was characterized and the quality evaluated on the basis of four produced-water samples from wells. These samples are probably from one of the geologic units that is equivalent to the Tensleep Sandstone (Weber Sandstone or Morgan Formation). Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (75% of samples) and the remaining water was briny (supplementary data tables). TDS concentrations ranged from 12,600 to 42,600 mg/L, with a median of 23,000 mg/L.

Concentrations of some characteristics and constituents in the Tensleep Sandstone in the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be

compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards: TDS (100%), chloride (100%), and sulfate (100%). All produced-water samples had concentrations of one characteristic and one constituent that exceeded livestock-use standards: TDS (100%), and chloride (100%).

#### *Rawlins Uplift*

The chemical composition of groundwater in the Tensleep Sandstone on the Rawlins Uplift was characterized and the quality evaluated on the basis of one environmental water sample from a spring. The TDS concentration (334 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the few analyses available for this sample, the water was suitable for domestic, agricultural, and livestock use.

#### *Overthrust Belt*

The chemical composition of groundwater in the Tensleep Sandstone in the Overthrust Belt was characterized and the quality evaluated on the basis of three produced-water samples from wells. These samples are probably from the Wells Formation, a geologic equivalent to the Tensleep Sandstone. Individual constituent concentrations are listed in **Appendix 5d**. TDS concentrations from produced-water samples indicated that the water was very saline (supplementary data tables). TDS concentrations ranged from 11,200 to 23,000 mg/L, with a median of 19,100 mg/L. Concentrations of some characteristics and constituents in the Tensleep Sandstone in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared

with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), sulfate (100%), TDS (100%), and pH (33% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in produced-water samples exceeded State of Wyoming standards in the Overthrust Belt. All the produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS (100%), chloride (100%), and sulfate (100%). The produced-water samples generally had concentrations of one constituent and two characteristics that exceeded livestock-use standards: sulfate (100%), TDS (100%), and pH (33% exceeded upper limit).

**Wells Formation.** The chemical composition of groundwater in the Wells Formation in the GGRB was characterized and the quality evaluated on the basis of two environmental water samples from two springs in the Overthrust Belt. TDS concentrations (100 and 131 mg/L) indicated that the waters were fresh (supplementary data tables). On the basis of the characteristics and constituents analyzed in the environmental water samples, the quality of water from the Wells Formation in the Overthrust Belt was suitable for most uses. No characteristics or constituents in the environmental water samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples from wells in the Overthrust Belt. These water samples were assigned to the Tensleep Sandstone and are discussed under “Tensleep Sandstone,” above).

**Weber Sandstone.** The chemical composition of groundwater in the Weber Sandstone in the GGRB was characterized and the quality evaluated on the basis of 15 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendices 5a, 5b, and 5c**. TDS concentrations from produced waters varied

widely and indicated that most waters were very saline (73% of samples) and remaining waters were moderately saline or briny (supplementary data tables). The Weber Sandstone is equivalent to the upper Tensleep Sandstone to the east and the upper Wells Formation to the west.

Concentrations of some characteristics and constituents in the Weber Sandstone in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability of water for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), iron (100%), TDS (100%), and sulfate (93%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. All the produced-water samples had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), iron (100%), sulfate (100%), and TDS (100%). The produced-water samples had concentrations of one characteristic and two constituents that exceeded livestock-use standards: TDS (93%), chloride (93%), and sulfate (73%).

#### *Green River Basin*

The chemical composition of groundwater in the Weber Sandstone in the Green River Basin was characterized and the quality evaluated on the basis of nine produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations from produced-water samples indicated the waters were very saline (supplementary data tables). TDS concentrations ranged from 14,000 to 19,100 mg/L, with a median of 16,800 mg/L.

Concentrations of some characteristics and constituents in the Weber Sandstone in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use and livestock-use standards in all samples: chloride, sulfate, and TDS.

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Weber Sandstone in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of two produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5b**. TDS concentrations (86,900 and 102,000 mg/L) from the produced-water samples indicated that both waters were briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Weber Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards, but the waters are unlikely to be suitable for any use due to high TDS content. All produced-water samples had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards in all samples: chloride, iron, sulfate, and TDS. Both produced-water samples generally had concentrations of two

constituents and one characteristic that exceeded State of Wyoming livestock-use standards: chloride, sulfate, and TDS.

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Weber Sandstone on the Rock Springs Uplift was characterized and the quality evaluated on the basis of four produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5c**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (50% of samples) and remaining waters were moderately saline or briny (supplementary data tables). TDS concentrations ranged from 3,390 to 72,300 mg/L, with a median of 24,600 mg/L.

Concentrations of some characteristics and constituents in the Weber Sandstone on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (100%), and sulfate (75%).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards on the Rock Springs Uplift. All produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples had concentrations of one characteristic and one constituent that exceeded livestock-use standards: TDS (75%) and chloride (75%).

**Morgan Formation.** The chemical composition of groundwater in the Morgan Formation in the

GGRB was characterized and the quality evaluated on the basis of five produced-water samples from wells. Individual constituent concentrations are listed in **Appendices 5a** and **5c**. TDS concentrations indicated that most waters were briny (80% of samples) and the remaining water was moderately saline (supplementary data tables). The Morgan Formation is equivalent to the lower Tensleep Sandstone to the east and the lower Wells Formation to the west.

Concentrations of some characteristics and constituents in the Morgan Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), TDS (100%), and pH (40% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. All produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: chloride (100%), TDS (100%), pH (40% less than lower limit), and sulfate (20%).

#### *Green River Basin*

The chemical composition of groundwater in the Morgan Formation in the Green River Basin was characterized and the quality evaluated on the basis of three produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5a**. TDS concentrations indicated that most waters were briny (67% of samples) and the remaining water was moderately saline (supplementary data tables). TDS concentrations ranged from 8,460 to 97,900 mg/L, with a median of 43,400 mg/L.

Concentrations of some characteristics and constituents in the Morgan Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), TDS (100%), and pH (67% less than lower limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. All produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of one constituent and two characteristics that exceeded livestock-use standards: chloride (100%), TDS (100%), and pH (67% less than lower limit).

#### *Rock Springs Uplift*

The chemical composition of groundwater in the Morgan Formation on the Rock Springs Uplift was characterized and the quality evaluated on the basis of two produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5c**. TDS concentrations (38,300 and 85,700 mg/L) indicated that both waters were briny (supplementary data tables) and unsuitable for most uses.

Concentrations of some characteristics and constituents in the Morgan Formation on the Rock Springs Uplift approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. No produced-water constituent analyses could be compared with health-based standards. Both produced-water samples had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards: chloride (100% of samples), sulfate (100%), and TDS (100%). The produced-water samples generally had

concentrations of one characteristic and two constituents that exceeded State of Wyoming livestock-use standards: TDS (100%), chloride (100%), and sulfate (50%).

**Amsden Formation.** The chemical composition of groundwater in the Amsden Formation in the GGRB was characterized and the quality evaluated on the basis of ten produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendices 5a** and **5b**. TDS concentrations indicated that most waters were very saline (80% of samples) and remaining waters were moderately saline (supplementary data tables).

Concentrations of some characteristics and constituents in the Amsden Formation in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), TDS (100%), and pH (50% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (100%), TDS (100%), and pH (20% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (100%), sulfate (80%), pH (50% exceeded upper limit), and chloride (30%).

### *Green River Basin*

The chemical composition of groundwater in the Amsden Formation in the Green River Basin was characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5a**. TDS concentrations indicated that water was very saline (supplementary data tables) and unsuitable for most uses. TDS concentrations ranged from 12,300 to 24,600 mg/L, with a median of 21,000 mg/L.

Concentrations of some characteristics and constituents in the Amsden Formation in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared to health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100% of samples), sulfate (100%), TDS (100%), and pH (83% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Green River Basin. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (100%), TDS (100%), and pH (33% exceeded upper limit). The produced-water samples generally had concentrations of several characteristics and constituents that exceeded livestock-use standards: sulfate (100%), TDS (100%), pH (83% exceeded upper limit), and chloride (17%).

### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Amsden Formation in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of four produced-water

samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations indicated that the water ranged from moderately to very saline (supplementary data tables) and was unsuitable for many uses. TDS concentrations ranged from 5,950 to 17,400 mg/L, with a median of 11,600 mg/L.

Concentrations of some characteristics and constituents in the Amsden Formation in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural-use and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards: chloride (100% of samples), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded State of Wyoming livestock-use standards: TDS (100%), chloride (50%), and sulfate (50%).

**Round Valley Limestone.** The chemical composition of groundwater in the Round Valley Limestone in the GGRB was characterized and the quality evaluated on the basis of one produced water sample from a well on the Rock Springs Uplift. Individual constituent concentrations are listed in **Appendix 5c**. The TDS concentration (88,900 mg/L) indicated that the water was briny (supplementary data tables) and was unsuitable for most uses.

Concentrations of some characteristics and constituents in the Round Valley Limestone in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses, and many characteristic and constituent analyses were not available and could not be compared with the standards. No

produced-water constituent analyses could be compared with health-based standards. The produced water sample had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use and livestock-use standards: chloride, sulfate, and TDS.

**Madison Limestone (Formation).** The chemical composition of groundwater in the Madison Limestone in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from a spring in the Overthrust Belt. Individual constituent concentrations for the environmental water sample are listed in **Appendix 4f**. The TDS concentration (199 mg/L) indicated that the water was fresh (supplementary data tables) and suitable for most uses. The chemical composition of groundwater was also characterized and the quality evaluated on the basis of 32 produced-water samples from wells. Major-ion composition in relation to TDS for produced waters from the Madison Limestone throughout the GGRB is shown on a trilinear diagram (**Appendix 3c, diagram B**). Individual constituent concentrations for the Madison Limestone in the Green River Basin and Overthrust Belt are listed in **Appendices 5a** and **5d**, respectively. Summary statistics calculated for available constituents in produced-water samples in the Great Divide/Washakie/Sand Wash basins are listed in **Appendix 5b**. TDS concentrations from produced waters were highly variable and indicated that most waters were very saline (47% of samples) and remaining waters were slightly saline to briny (supplementary data tables). Lindner-Lunsford et al. (1989; and as modified by Geldon, 2003b) mapped TDS concentrations in the lower zone of the Madison aquifer (composed of the Madison Formation) in the GGRB and adjacent areas (**Figure 6-9**).

Concentrations of some characteristics and constituents in the Madison Limestone waters in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for of water for most uses. No characteristics or constituents in the environmental water sample approached or exceeded applicable USEPA or State of Wyoming domestic,

agriculture, or livestock water-quality standards. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), sulfate (97%), chloride (94%), and pH (7% less than lower limit and 4% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in the produced-water samples exceeded State of Wyoming standards in the GGRB. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (97%), sulfate (97%), TDS (97%), and pH (4% less than lower limit). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (78%), chloride (66%), sulfate (16%), and pH (7% less than lower limit and 4% greater than upper limit).

#### *Green River Basin*

The chemical composition of groundwater in the Madison Limestone in the Green River Basin was characterized and the quality evaluated on the basis of two produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5a**. TDS concentrations indicated that the produced-water samples were very saline (20,800 mg/L) and briny (76,800 mg/L) (supplementary data tables), and unsuitable for most uses.

Concentrations of some characteristics and constituents in the Madison Limestone in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared

with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. Both produced-water samples had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards: chloride (100% of samples), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded State of Wyoming livestock-use standards: TDS (100%), chloride (100%), and sulfate (50%).

#### *Great Divide/Washakie/Sand Wash basins*

The chemical composition of groundwater in the Madison Limestone in the Great Divide/Washakie/Sand Wash basins was characterized and the quality evaluated on the basis of 27 produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations from produced waters varied widely and indicated that most waters were very saline (44% of samples) and remaining waters ranged from slightly saline to briny (supplementary data tables). TDS concentrations ranged from 1,200 to 54,500 mg/L, with a median of 9,490 mg/L.

Concentrations of some characteristics and constituents in the Madison Limestone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for many uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: iron (100%), TDS (100%), chloride (96%), sulfate (96%), and pH (9% less than lower limit and 5% greater than upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (100%), sulfate (96%), TDS (96%), and pH (5% less than lower limit). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (78%), chloride (67%), pH (9% less than lower limit and 5% greater than upper limit), and sulfate (7%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Madison Limestone in the Overthrust Belt was characterized and the quality evaluated on the basis of one environmental water sample from a spring. Individual constituent concentrations for the environmental water sample are listed in **Appendix 4f**. The TDS concentration (199 mg/L) indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendix 5d**. TDS concentrations from produced waters indicated that most waters were very saline (67% of samples) and the remaining water was slightly saline (supplementary data tables). TDS concentrations ranged from 2,900 to 25,300 mg/L, with a median of 22,000 mg/L.

Concentrations of some characteristics and constituents in the Madison Limestone in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. No characteristics or constituents in the environmental water sample approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared

with health-based standards. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS (100%), sulfate (100%), and chloride (67%).

For agricultural and livestock use, concentrations of some characteristics and constituents in the produced-water samples exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples generally had concentrations of one characteristic and two constituents that exceeded agricultural-use standards: TDS (100%), sulfate (100%), and chloride (67%). The produced-water samples had concentrations of one characteristic and two constituents that exceeded livestock-use standards: TDS (67%), sulfate (67%), and chloride (33%).

**Darby Formation.** The chemical composition of groundwater in the Darby Formation in the GGRB was characterized and the quality evaluated on the basis of one environmental water sample from one spring in the Overthrust Belt. Individual constituent concentrations are listed in **Appendix 4f**. The TDS concentration (537 mg/L) indicated that the water was fresh (supplementary data tables). On the basis of the one sample available, the water was suitable for domestic, agricultural, and livestock use with the exception of the concentration of one constituent: TDS (exceeded aesthetic standard for domestic use).

**Bighorn Dolomite.** The chemical composition of groundwater in the Bighorn Dolomite in the GGRB was characterized and the quality evaluated on the basis of environmental water samples from three springs. Summary statistics calculated for available constituents are listed in **Appendices 4a** and **4f**. TDS concentrations indicated that waters from the springs were fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of six produced-water samples from wells. Summary statistics calculated for available constituents are listed in **Appendices 5a** and **5d**. TDS concentrations from produced waters varied widely and indicated that most waters were slightly saline (50% of samples) and remaining waters ranged

from moderately saline to briny (supplementary data tables).

Concentrations of some characteristics and constituents in the Bighorn Dolomite in the GGRB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No characteristics or constituents in the environmental water samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: TDS (100%), sulfate (67%), chloride (50%), and pH (33% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents in the produced-water samples exceeded State of Wyoming standards in the GGRB. The produced-water samples had concentrations of several characteristics and constituents that exceeded agricultural-use standards: chloride (83%), sulfate (83%), TDS (50%), and pH (17% exceeded upper limit). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: pH (33% exceeded upper limit), TDS (50%), chloride (33%), and sulfate (33%).

#### *Green River Basin*

The chemical composition of groundwater in the Bighorn Dolomite in the Green River Basin was characterized and the quality evaluated on the basis of one environmental water sample from a spring. Individual constituent concentrations are listed in **Appendix 4a**. The TDS concentration (287 mg/L) indicated that the water was fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples

from wells. Individual constituent concentrations are listed in **Appendix 5a**. TDS concentrations from produced waters varied and indicated that most waters were slightly saline (67% of samples) and the remaining water was briny (supplementary data tables). TDS concentrations ranged from 1,050 to 66,200 mg/L, with a median of 1,850 mg/L.

Concentrations of some characteristics and constituents in the Bighorn Dolomite in the Green River Basin approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No characteristics or constituents in the environmental water sample approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS (100%), chloride (67%), pH (67% exceeded upper limit), and sulfate (67%).

For agricultural and livestock use, concentrations of some characteristics and constituents in the produced-water samples exceeded State of Wyoming standards in the Green River Basin. The produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), sulfate (100%), pH (33% exceeded upper limit), and TDS (33%). The produced-water samples had concentrations of one characteristic and two constituents that exceeded livestock-use standards: pH (67% exceeded upper limit), TDS (33%), chloride (33%), and sulfate (33%).

#### *Overthrust Belt*

The chemical composition of groundwater in the Bighorn Dolomite in the Overthrust Belt was characterized and the quality evaluated on the basis

of two environmental water samples from two springs. Individual constituent concentrations are listed in **Appendix 4f**. TDS concentrations (227 and 290 mg/L) indicated that the waters were fresh (supplementary data tables). The chemical composition of groundwater was also characterized and the quality evaluated on the basis of three produced-water samples from wells. Individual constituent concentrations are listed in **Appendix 5d**. TDS concentrations from produced-water samples ranged from slightly to very saline (supplementary data tables). TDS concentrations ranged from 1,500 to 30,500 mg/L, with a median of 5,790 mg/L.

Concentrations of some characteristics and constituents in the Bighorn Dolomite in the Overthrust Belt approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No characteristics or constituents in the environmental water samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards. Most water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. The produced-water samples had concentrations of one characteristic and two constituents that exceeded aesthetic standards for domestic use: TDS (100% of samples), sulfate (67%), and chloride (33%).

For agricultural and livestock use, concentrations of some characteristics and constituents in the produced-water samples exceeded State of Wyoming standards in the Overthrust Belt. The produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (67%), sulfate (67%), and TDS (67%). The produced-water samples had concentrations of one characteristic and two constituents that exceeded livestock-use standards: TDS (67%), chloride (33%), and sulfate (33%).

**Cambrian geologic units.** The chemical composition of groundwater in the undifferentiated Cambrian rocks in the GGRB was characterized and the quality evaluated on the basis of nine produced-water samples in the Great Divide/Washakie/Sand Wash basins. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations indicated that most waters were very saline (67% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 3,900 to 33,500 mg/L, with a median of 13,700 mg/L.

Concentrations of some characteristics and constituents the undifferentiated Cambrian rocks in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for many uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples generally had concentrations of several characteristics and constituents that exceeded aesthetic standards for domestic use: chloride (100%), sulfate (100%), TDS (100%), and pH (12% exceeded upper limit).

For agricultural and livestock use, concentrations of some characteristics and constituents exceeded State of Wyoming standards in the Great Divide/Washakie/Sand Wash basins. All produced-water samples had concentrations of two constituents and one characteristic that exceeded agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples had concentrations of several characteristics and constituents that exceeded livestock-use standards: TDS (89%), chloride (78%), pH (12% exceeded upper limit), and sulfate (11%).

**Flathead Sandstone.** The chemical composition of groundwater in the Flathead Sandstone in the GGRB was characterized and the quality evaluated on the basis of six produced-water samples in the

Great Divide/Washakie/Sand Wash basins. Summary statistics calculated for available constituents are listed in **Appendix 5b**. TDS concentrations indicated that most waters were very saline (83% of samples) and remaining waters were moderately saline (supplementary data tables). TDS concentrations ranged from 3,930 to 17,700 mg/L, with a median of 12,500 mg/L.

Concentrations of some characteristics and constituents the Flathead Sandstone in the Great Divide/Washakie/Sand Wash basins approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The water-quality analyses were from produced-water samples, and many characteristic and constituent analyses were not available and could not be compared with health-based, aesthetic, or State of Wyoming agricultural and livestock-use standards. No produced-water constituent analyses could be compared with health-based standards. All produced-water samples generally had concentrations of two constituents and one characteristic that exceeded aesthetic standards for domestic use and State of Wyoming agricultural-use standards: chloride (100%), sulfate (100%), and TDS (100%). The produced-water samples generally had concentrations of one characteristic and one constituent that exceeded State of Wyoming livestock-use standards: TDS (83%) and chloride (83%).

### **Precambrian geologic units**

The chemical composition of groundwater in the undifferentiated Precambrian rocks in the GGRB was characterized and the quality evaluated on the basis of two environmental water samples, one from a spring in the Green River Basin and one from a spring in the Great Divide/Washakie/Sand Wash basins. Individual constituent concentrations are listed in **Appendices 4a** and **4b**, respectively. Low TDS concentrations (272 and 188 mg/L) indicated that both waters were fresh (supplementary data tables). On the basis of analyses available for the spring in the Green River Basin, the water was suitable for domestic, agricultural, and livestock use with the exception of two characteristics: pH (upper limit exceeded) and SAR (agricultural-use standard exceeded). On the basis of analyses avail-

able for the spring in the Great Divide/Washakie/  
Sand Wash basins, the quality of water from that  
Precambrian geologic unit was suitable for most  
uses.

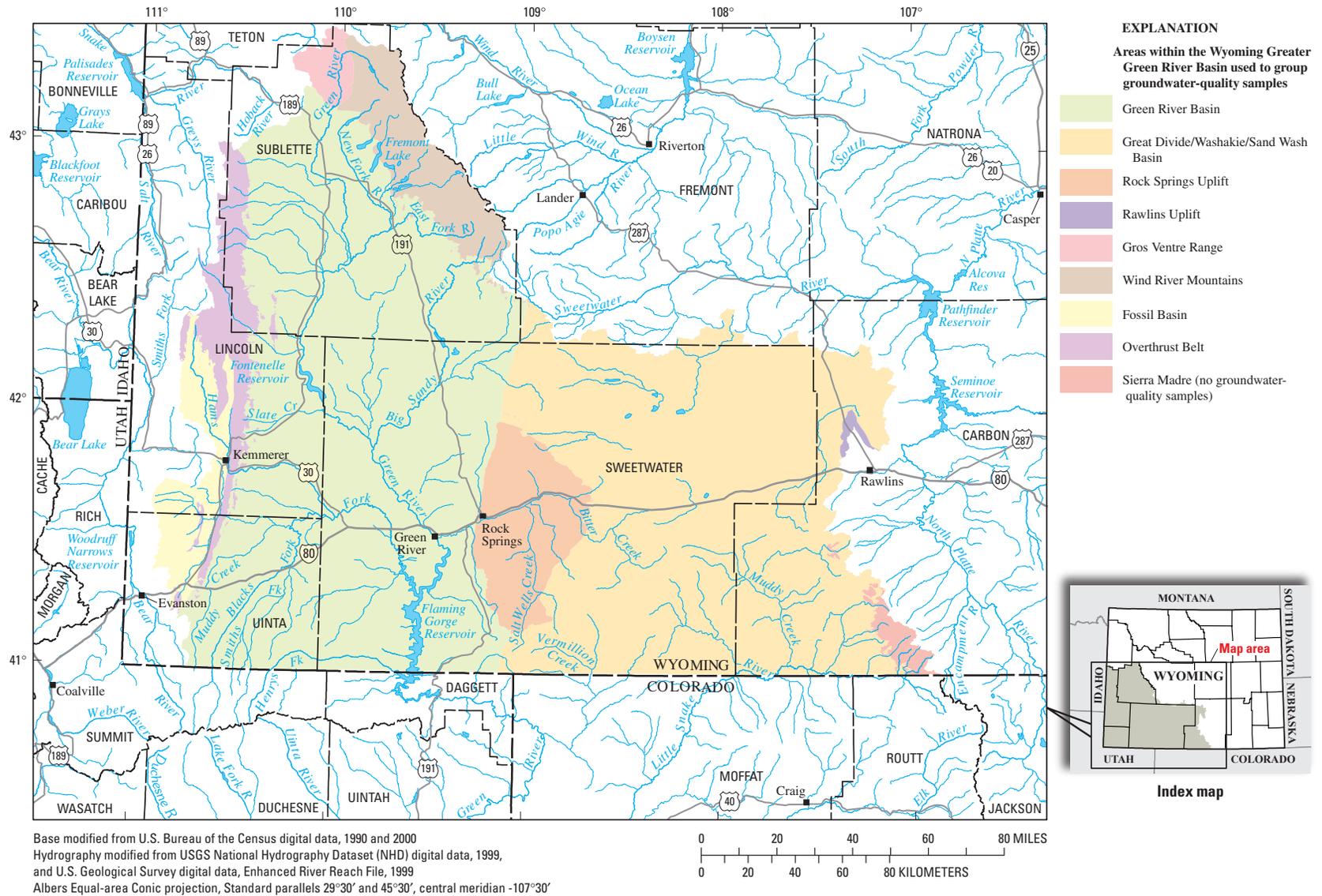


Figure 6-1. Location of geographic regions used to group groundwater-quality samples, Wyoming Greater Green River Basin.

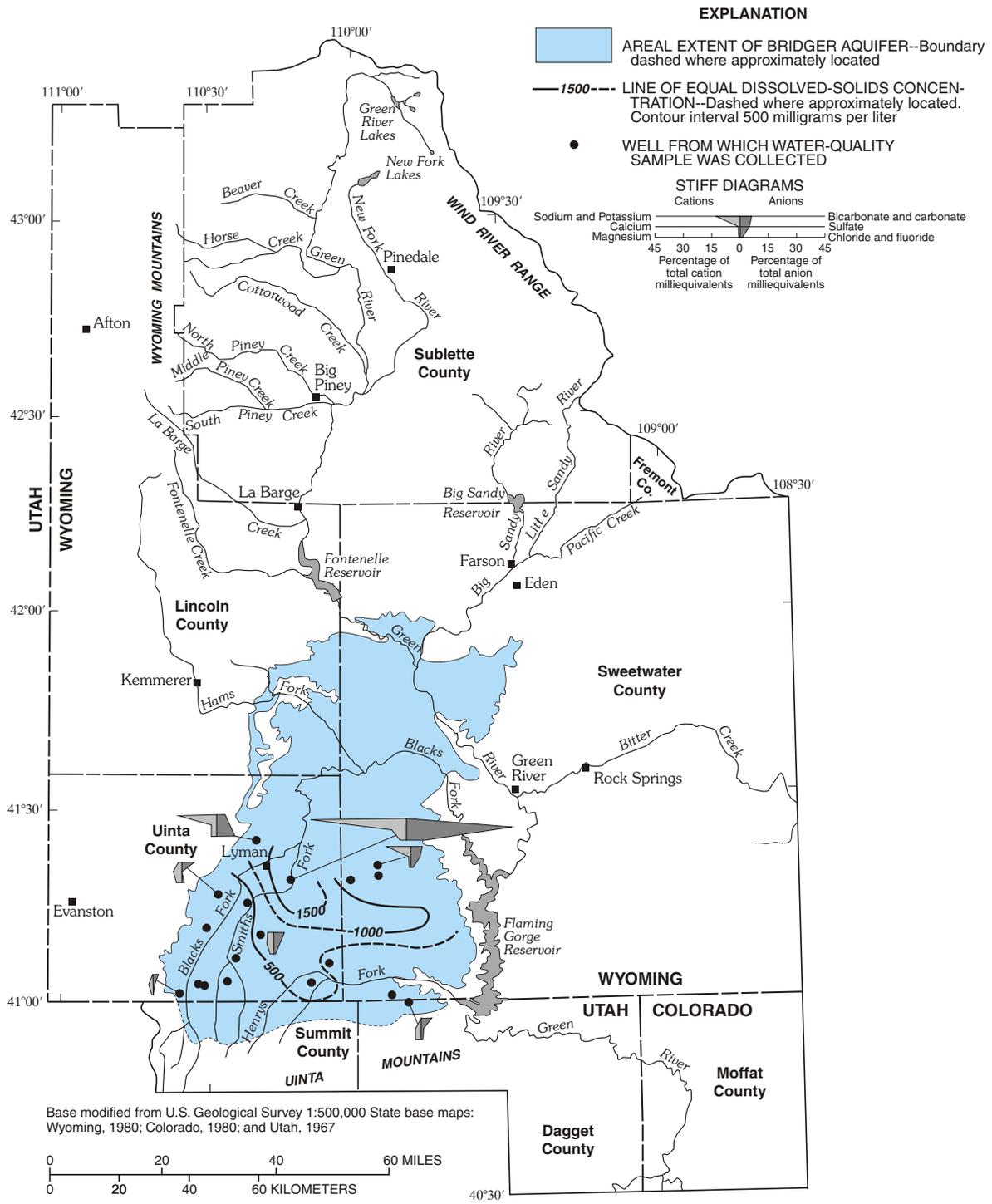


Figure 6-2. Dissolved-solids concentration and Stiff diagrams, Bridger aquifer, Green River Basin lower Tertiary aquifer system. Modified from Naftz (1996).

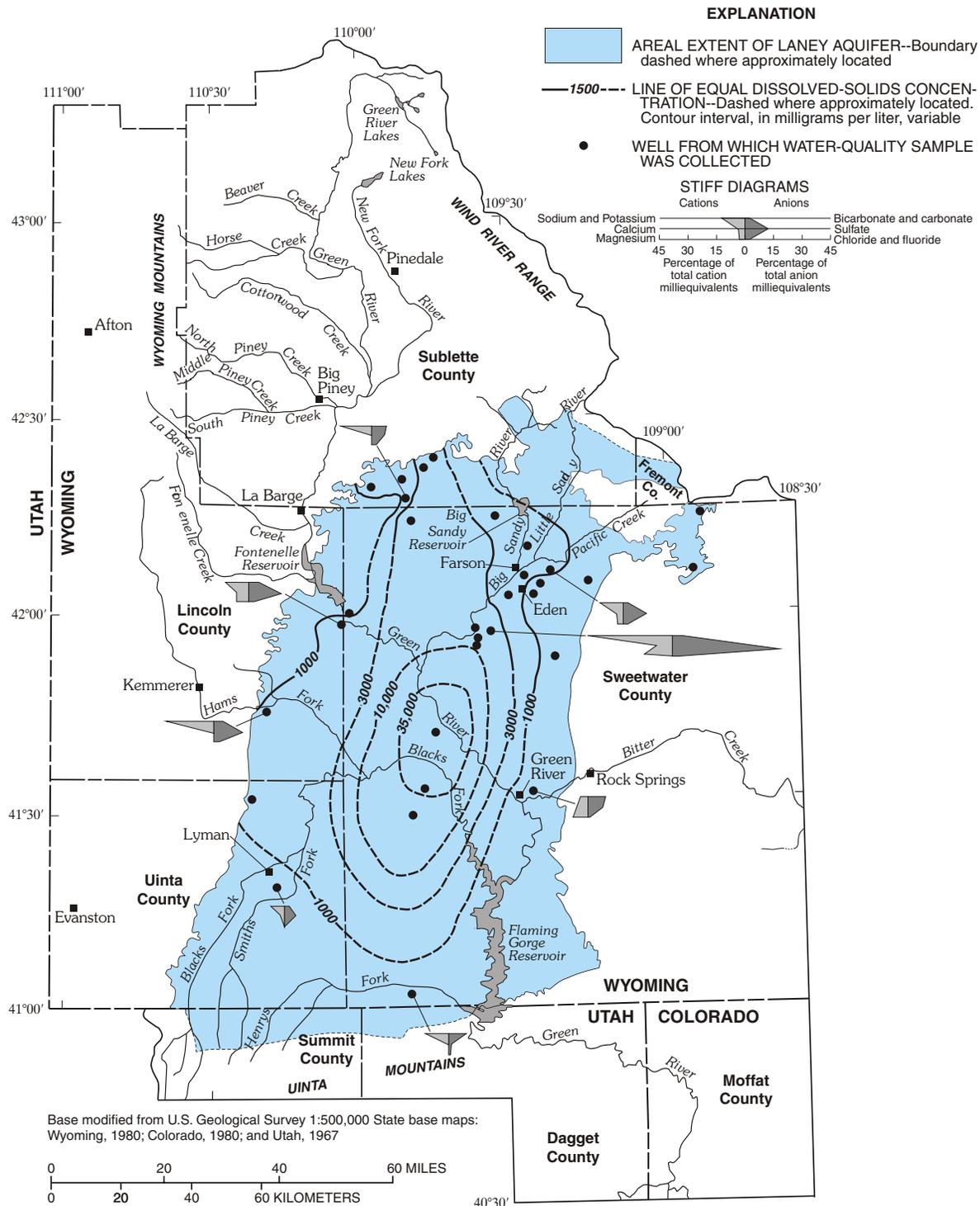


Figure 6-3. Dissolved-solids concentration and Stiff diagrams, Laney aquifer, Green River Basin lower Tertiary aquifer system. Modified from Nafiz (1996).

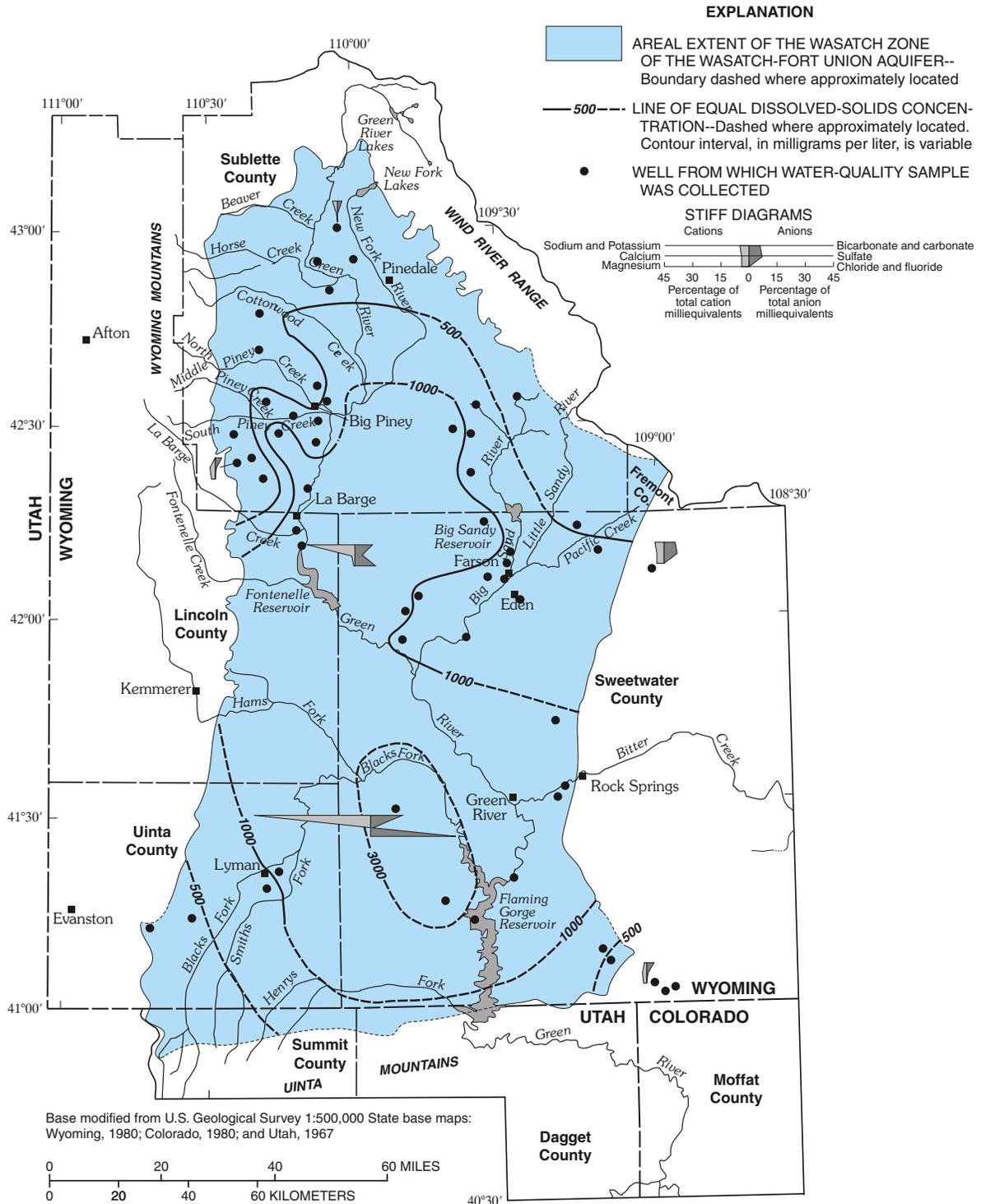


Figure 6-4. Dissolved-solids concentration and Stiff diagrams, Wasatch zone of the Wasatch-Fort Union aquifer, Green River Basin lower Tertiary aquifer system. Modified from Naftz (1996).

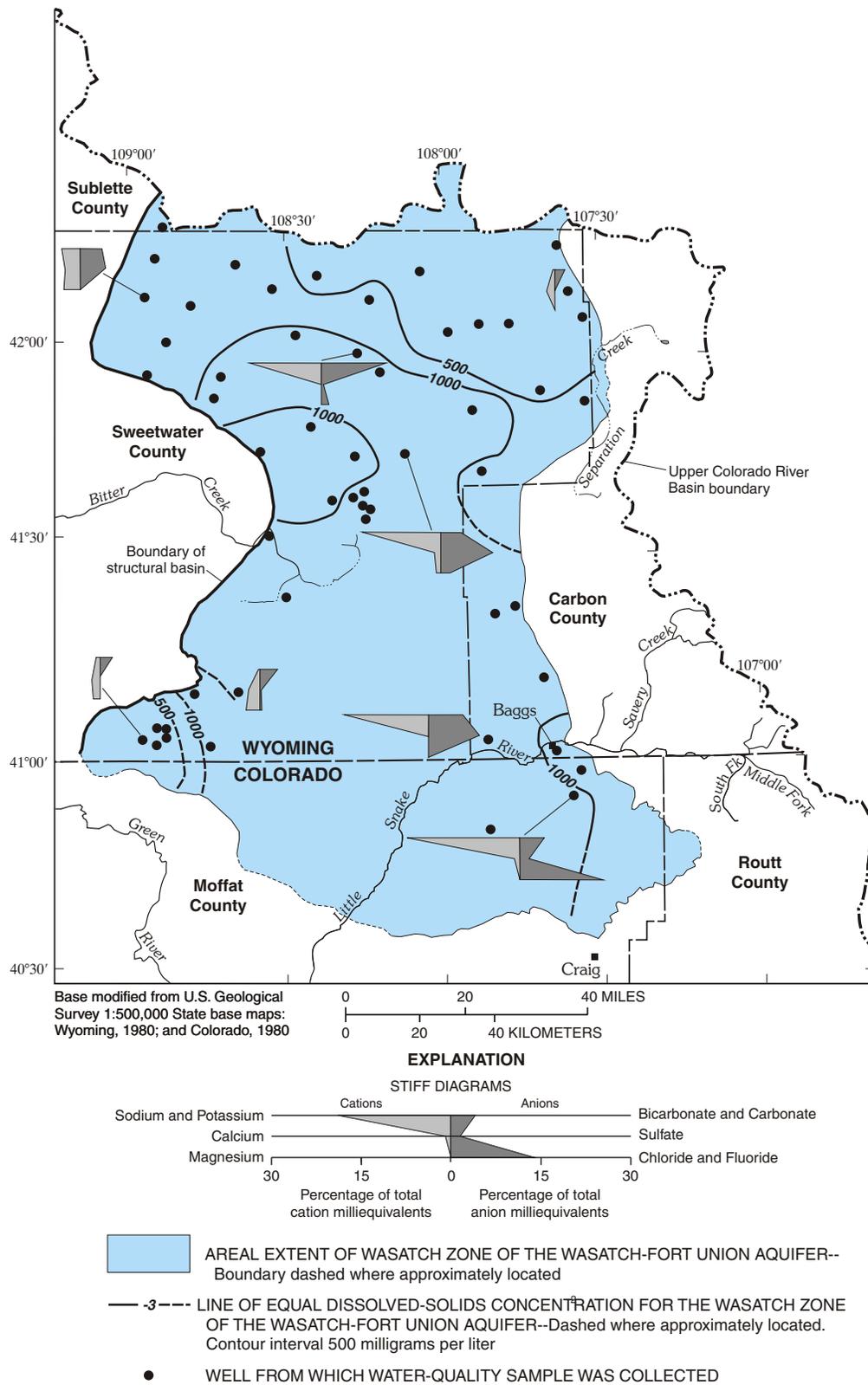


Figure 6-5. Dissolved-solids concentration and Stiff diagrams, Wasatch zone of the Wasatch-Fort Union aquifer, Great Divide/Washakie/Sand Wash basins lower Tertiary aquifer system. Modified from Naftz (1996).

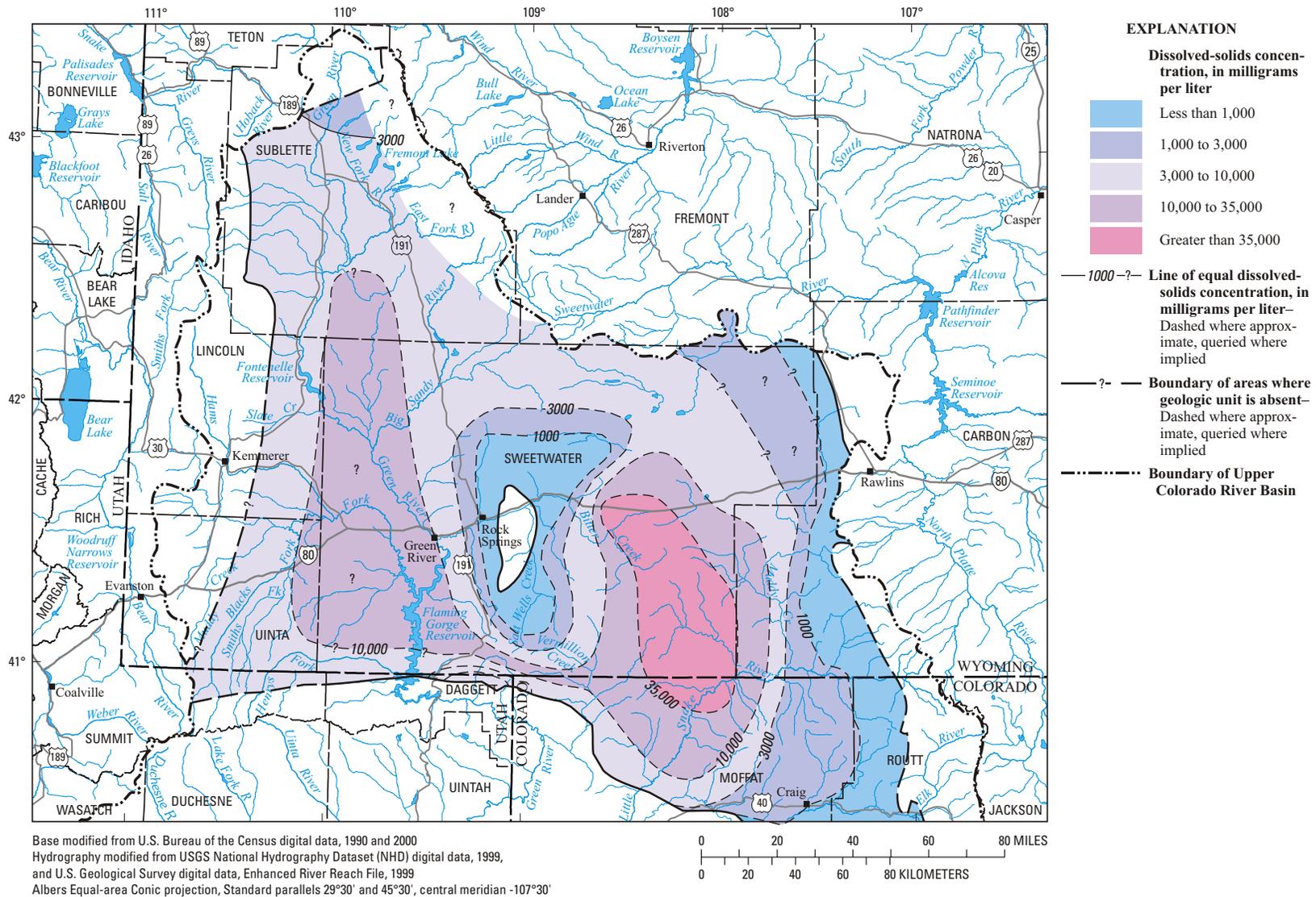


Figure 6-6. Concentration of dissolved solids, Mesaverde aquifer, Greater Green River Basin and adjacent areas to the south. Modified from Freethy et al. (1988).

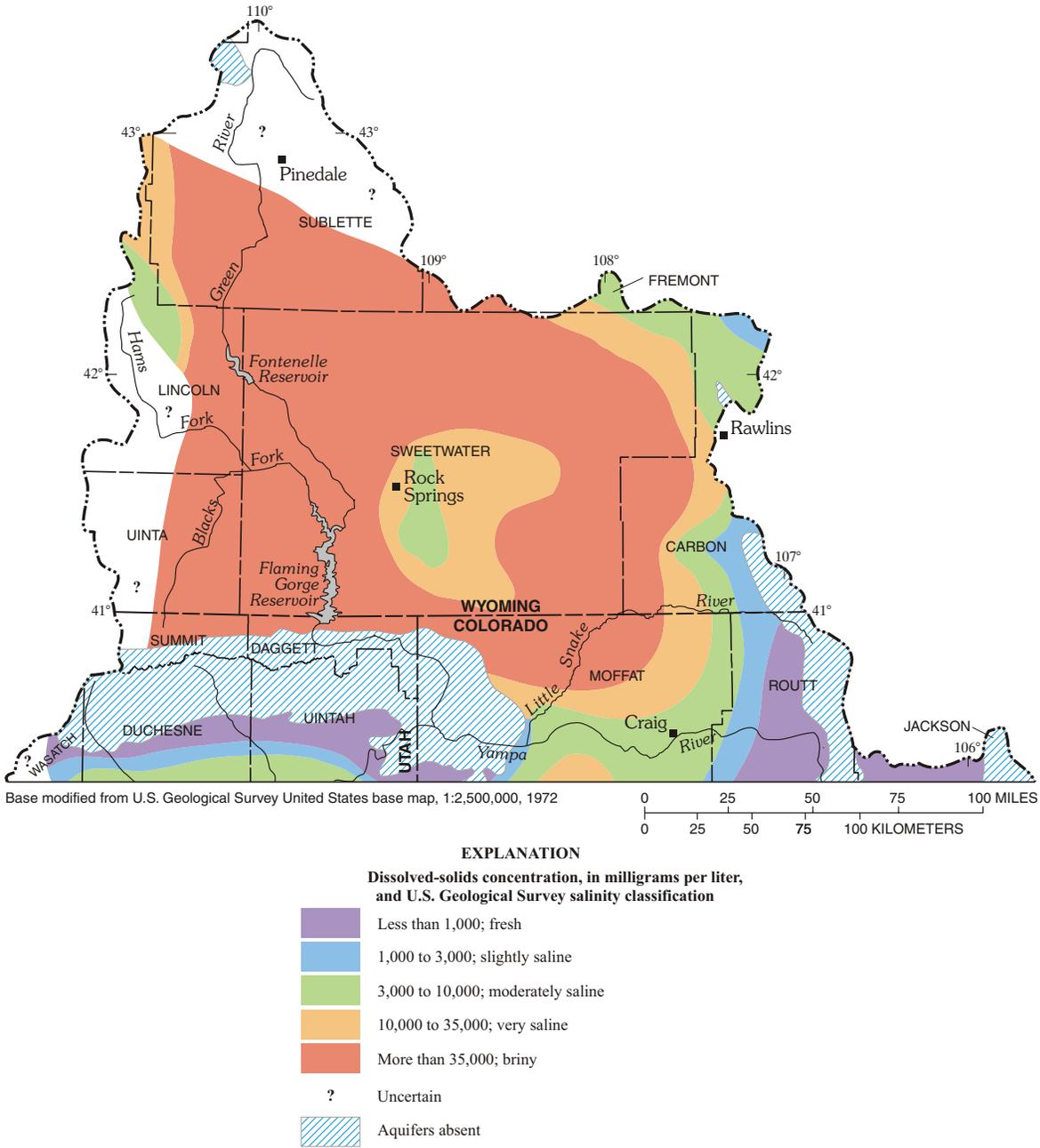


Figure 6-7. Concentration of dissolved solids, Sundance and Nugget aquifers, Greater Green River Basin and adjacent areas to the south. Modified from Freethy et al. (1988) and Freethy and Cordy (1991).

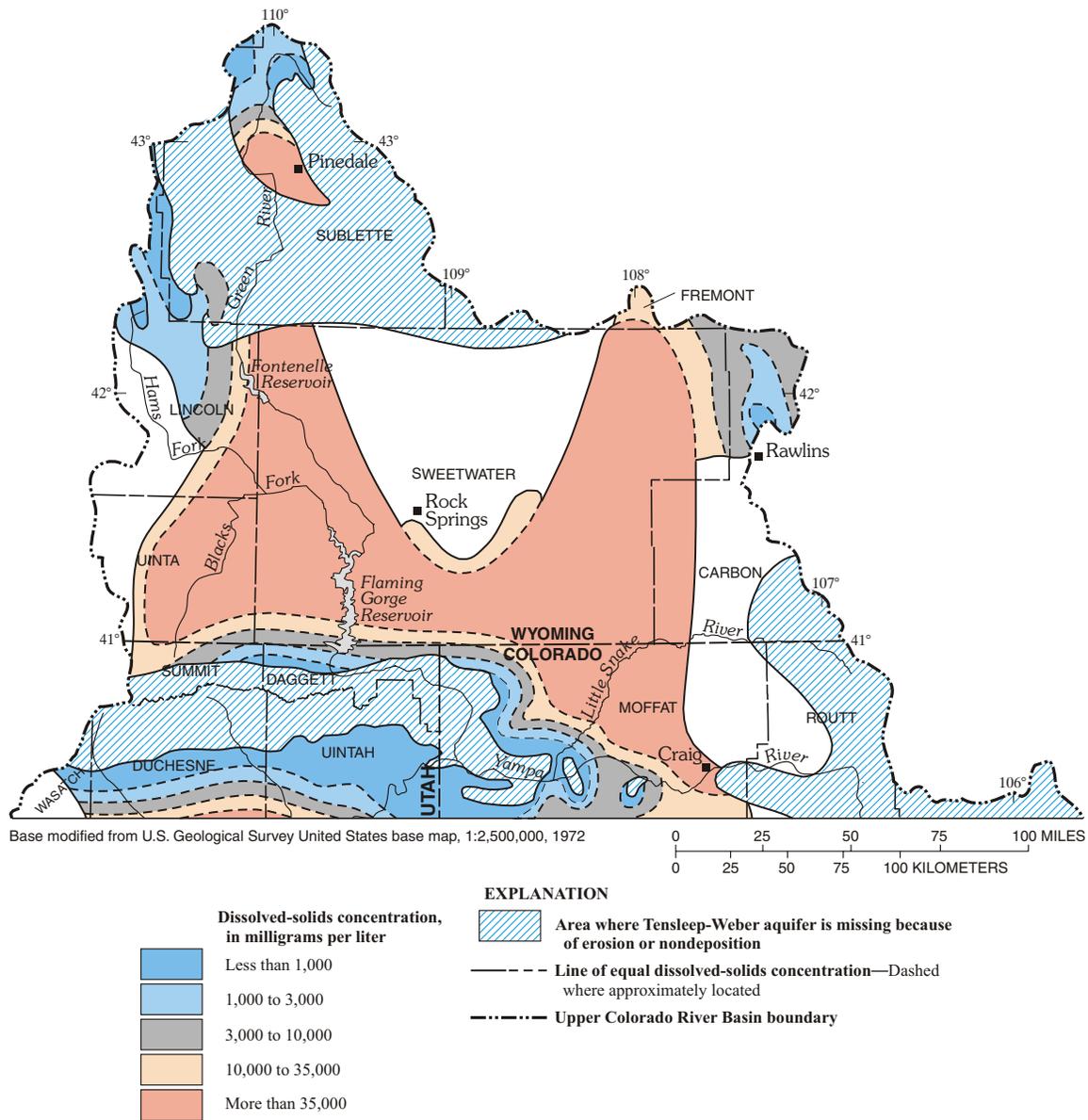


Figure 6-8. Concentration of dissolved solids, Tensleep-Weber aquifer, Greater Green River Basin and adjacent areas to the south. Modified from Lindner-Lunsford et al. (1989) and Geldon (2003b).

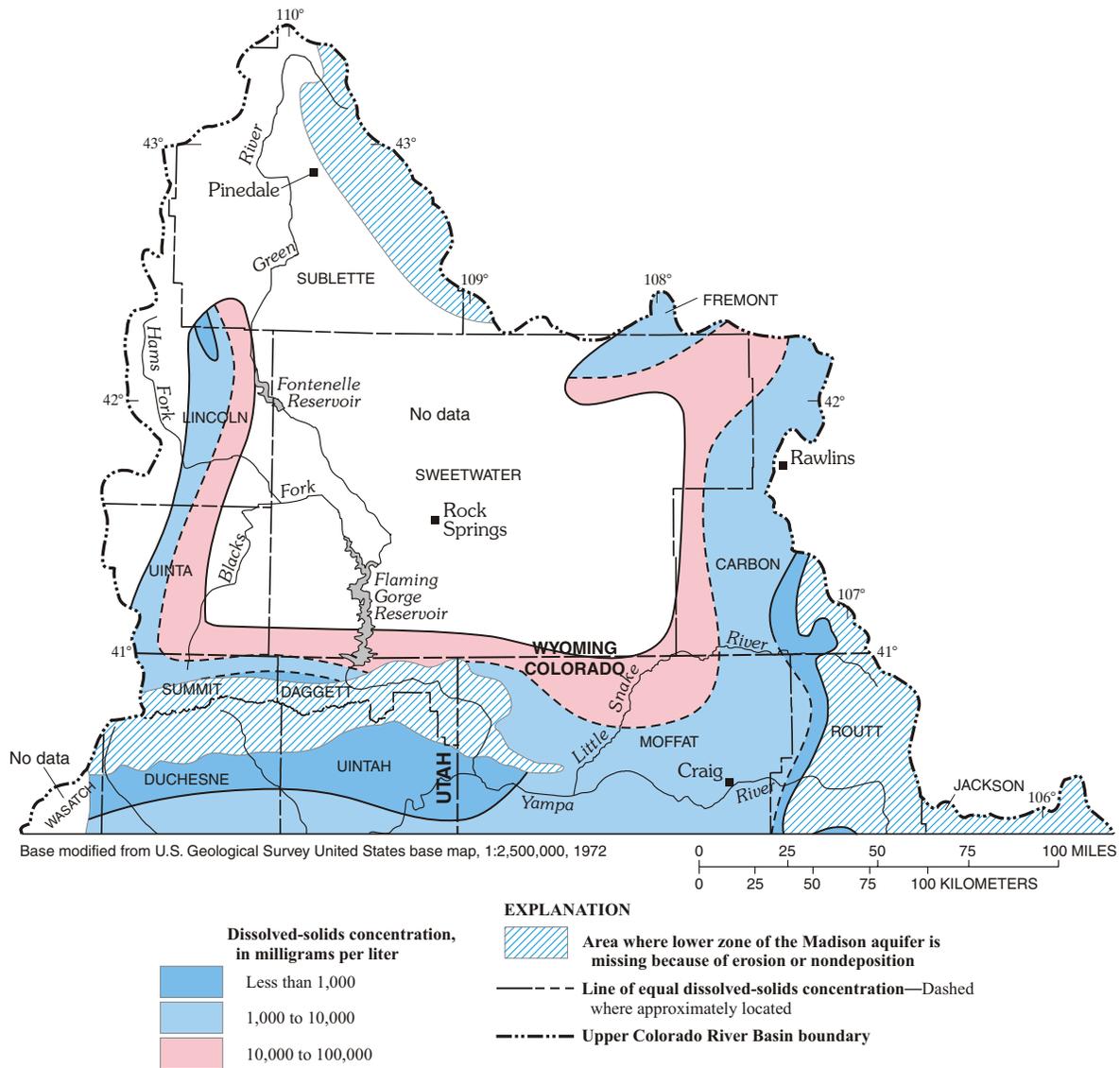


Figure 6-9. Concentration of dissolved solids, lower zone of the Madison aquifer, Greater Green River Basin and adjacent areas to the south. Modified from Lindner-Lunsford et al. (1989) and Geldon (2003b).