4.0 RESOURCES

4.1 INTRODUCTION

This chapter describes the quantity and quality of the Green River Basin's surface water and groundwater resources. Water quantity is the volume of water the Green River Basin might draw upon to sustain the local economy for present and future generations. Water quality is discussed in terms of the suitability of the water to meet a variety of uses. This chapter characterizes the Basin's total hydrologically available water supply irrespective of existing uses, institutional constraints, and speculations for how water resources might be put to future beneficial use. The results described in this chapter pertain to physical availability, which is different from legal or permitted availability, which is discussed in Chapter 7, Availability.

4.2 GENERAL

The Green River is the main drainage of the Green River Basin and a major tributary of the Colorado River. All the water draining to this river originates as precipitation, most of which evaporates from the surface or infiltrates the soil where it is stored and transpired by vegetation (annual evapotranspiration exceeds annual precipitation in this semiarid region). Precipitation and snowmelt, including glacier melt, that is not evaporated or stored in the soil profile either runs off, feeding rivers, streams, and lakes, or percolates downward through the soil profile to become groundwater. Surface water in the form of streams, lakes and reservoirs and groundwater resources in local and regional aquifers are the subject of this chapter.

4.3 SURFACE WATER RESOURCES

4.3.1 Quantity

Surface water quantity is recorded by U.S. Geological Survey (USGS) stream gaging stations at numerous locations as shown on Figure 4-1. At any given location, the flow recorded by a gage reflects depletions by upstream uses. Consumptive uses in the Basin are discussed in Section 5. Streamflow at any given location in the Basin varies from season to season and year to year as a function of the variability of precipitation in the region. For the purposes of this planning report, surface water quantity estimates were divided into three groups: dry years, average years, and wet years. For simplicity, it is assumed that the lowest 20% of the years (in terms of annual streamflow) are dry years, the highest 20% of the years are wet years, and the remaining years are considered normal years.

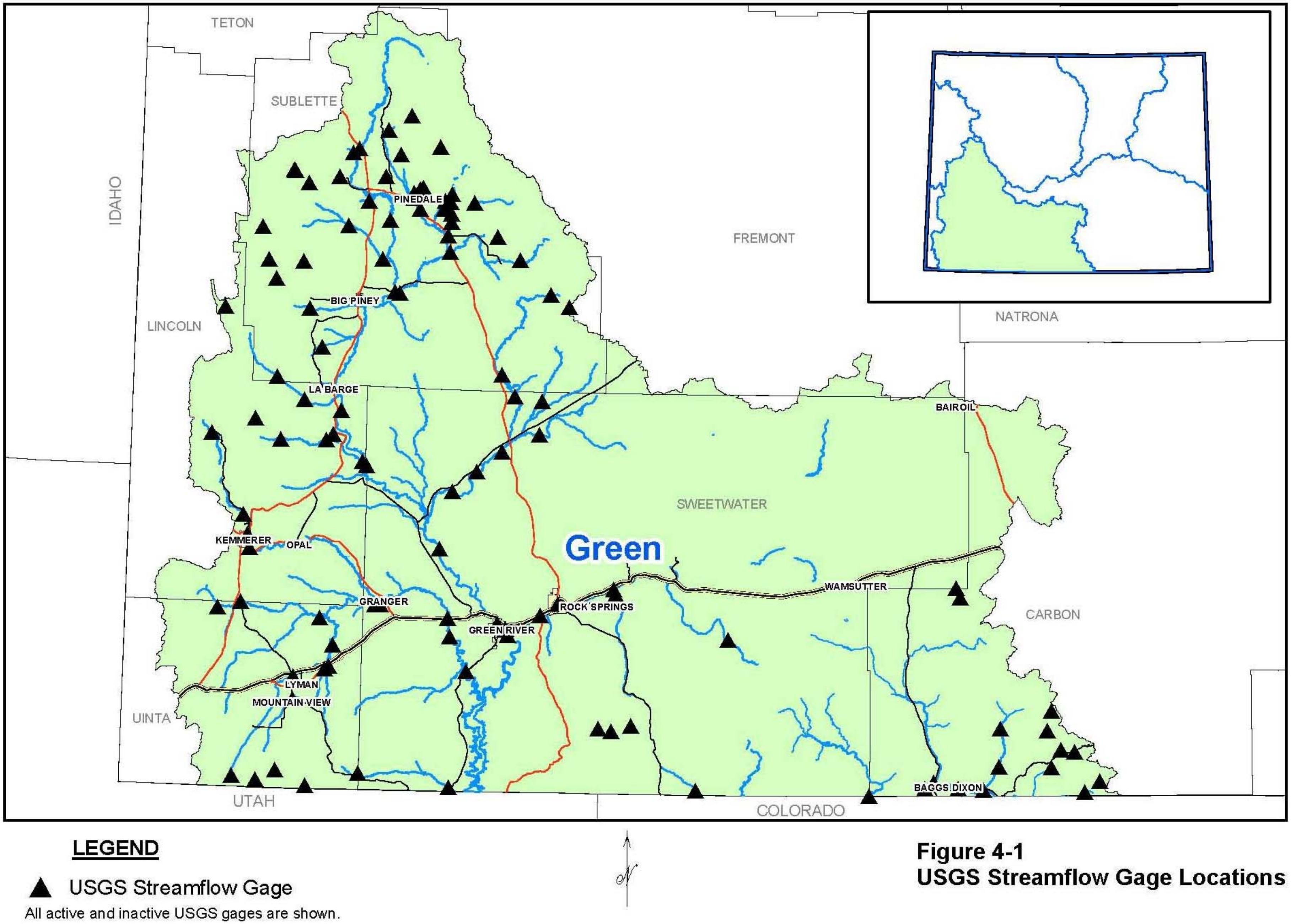


Figure 4-1
USGS Streamflow Gage Locations

Table 4-1 presents estimates of total surface water flow generated by the Green River Basin for dry, average and wet years. As the table shows, average year water supplies are about 235,000 acre-feet less than reported in the previous basin plan.

Table 4-1 - Total Surface Water Flow – Average Depletions Compared to Dry, Wet and Normal Flow Years

Sector of Water Use[1]	**Depletions Acre-Feet**		
Agricultural[2]	389,324		
Municipal[3]	21,859		
Domestic[4]	0		
Industrial[5]	56,833		
Recreational	non-consumptive		
Environmental	non-consumptive		
In-State Reservoir Evaporation[6]	121,300		
Total Depletions	**589,316**		
	Flow Leaving Green River Basin (Acre-Feet)[7]		
River	**Dry Year**	**Normal Year**	**Wet Year**
Green River	595,000	1,138,000	1,806,000
Little Snake River	177,000	407,000	642,000
Black's Fork River	67,000	195,000	398,000
Henry's Fork River	24,000	52,000	118,000
Total	**863,000**	**1,792,000**	**2,964,000**
Total Streamflow Volume plus Average Depletion	**1,452,316**	**2,381,316**	**3,553,316**
GRBP I Green River Total[8]	1,543,000	2,617,000	3,746,000
Change since 2001	-90,684	-235,684	-192,684

[1] Depletion estimates for each water use sector are from Chapter 5

[2] Agricultural surface water depletions consist of the irrigation depletion estimate, 396,246 ac-ft/yr, less the WSGS estimate for groundwater use for irrigation, 7,800 ac-ft/yr, plus one half of total stock use assuming that approximately 50% stock use is groundwater and the remaining 50% is surface water.

[3] Municipal use of 6,578 from Table 5-8 and 15,281 Cheyenne Diversions from Table 5-10.

[4] No domestic depletions from Table 5-8.

[5] Industrial depletion from Table 5-13.

[6] Evaporation estimate from 2001 Green River Basin Water Plan.

[7] From Table 2 in “Available Surface Water Determination,” tech. memo, AECOM, 2010.

[8] GRBP I Total Flow is from the 2007 Wyoming Framework Water Plan, Vol. 1, WWC Engineering

Streams in the Basin show wide fluctuations in seasonal flow in addition to annual fluctuations. A major portion of the annual stream flows is made up of snowmelt runoff occurring during the months of April, May, June, and July. The snow accumulates, particularly in the mountains, over the winter months. The average monthly flow of the Green River at Warren Bridge ranges from less than 10,000 acre-feet in the winter to over 100,000 acre-feet in June. This reach demonstrates the natural flow variation that is typical of Green River Basin streams when there is no control from large storage reservoirs or major diversions.

4.3.2 Water Quality

Water quality refers to a water's physical, chemical, radiological, biological, and bacteriological properties. The concentrations of dissolved and suspended components dictates the use-suitability of a water body, and sometimes institutional limits on concentrations of various components impose restrictions on use of certain water bodies for certain purposes. Water quality can be impacted by natural environmental processes and human activities. The success of a water development project is dependent upon the ability of the resource to meet the quality needs of the proposed use(s) without adversely affecting the water quality for other uses.

The complex geology of the Green River Basin influences the water quality characteristics of its streams. Streams which originate in the bedrock core of the mountains are generally clear and low in dissolved solids, while plains-area streams originate in softer, sedimentary rocks and are generally higher in dissolved and suspended solids. In the Green River Basin water quality analyses and regulations often focus on a project's tendency to increase salinity by concentration (e.g., by consuming water through evapotranspiration without consuming salts) or by salt loading (i.e., by adding to the total salt load of the streams) because of salinity concerns in the Colorado River Basin, particularly the lower basin.

Water salinity in the Colorado River Basin increases in a downstream direction. Some of this increase is natural, as the river flows from the mountainous areas of the upper basin toward the arid Southwest. Phreatophytes along the streams and evaporation from the water surface deplete water but leave the dissolved salts in the stream. Over the last century or so, increased use of water for irrigation, municipal and industrial uses and construction of large reservoirs have reduced streamflows and increased dissolved-solids levels in the river.

Concentrations of dissolved solids, phosphorus, suspended sediment, bacteria, and algae are generally lower in streams originating in the mountains compared to the concentrations found in streams originating on the plains. Invertebrates and fish found in the mountain streams are different from those in streams originating in the plains, partly as a result of the water quality differences. The water quality of streams originating in the mountains generally deteriorates as they flow across the plains and these water quality changes result from natural and man-made causes. Natural causes include increased availability of fine materials for transport and dissolution, less shading of the water by riparian vegetation, and less runoff per unit area in the plains than in the mountains to dilute salts. Man-made causes include irrigation return flow, livestock grazing, municipal sewage effluent, and industrial discharge.

Several stream segments in the Green River Basin are listed as impaired or threatened in Wyoming's Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report). These impaired waters require that a total maximum daily load (TMDL) not be exceeded. TMDLs must be established for each impairing pollutant in a stream and this measure of the ability of a water body to assimilate pollution while continuing to meet its designated uses helps in thorough watershed management, planning, as well as keeping solutions cost-effective. The primary sources of impairment are habitat degradation, pathogens and trace metals. Table 4-2 summarizes the 2010 303(d) List of Waters Requiring TMDLs and Figure 4-2 shows the stream segments affected.

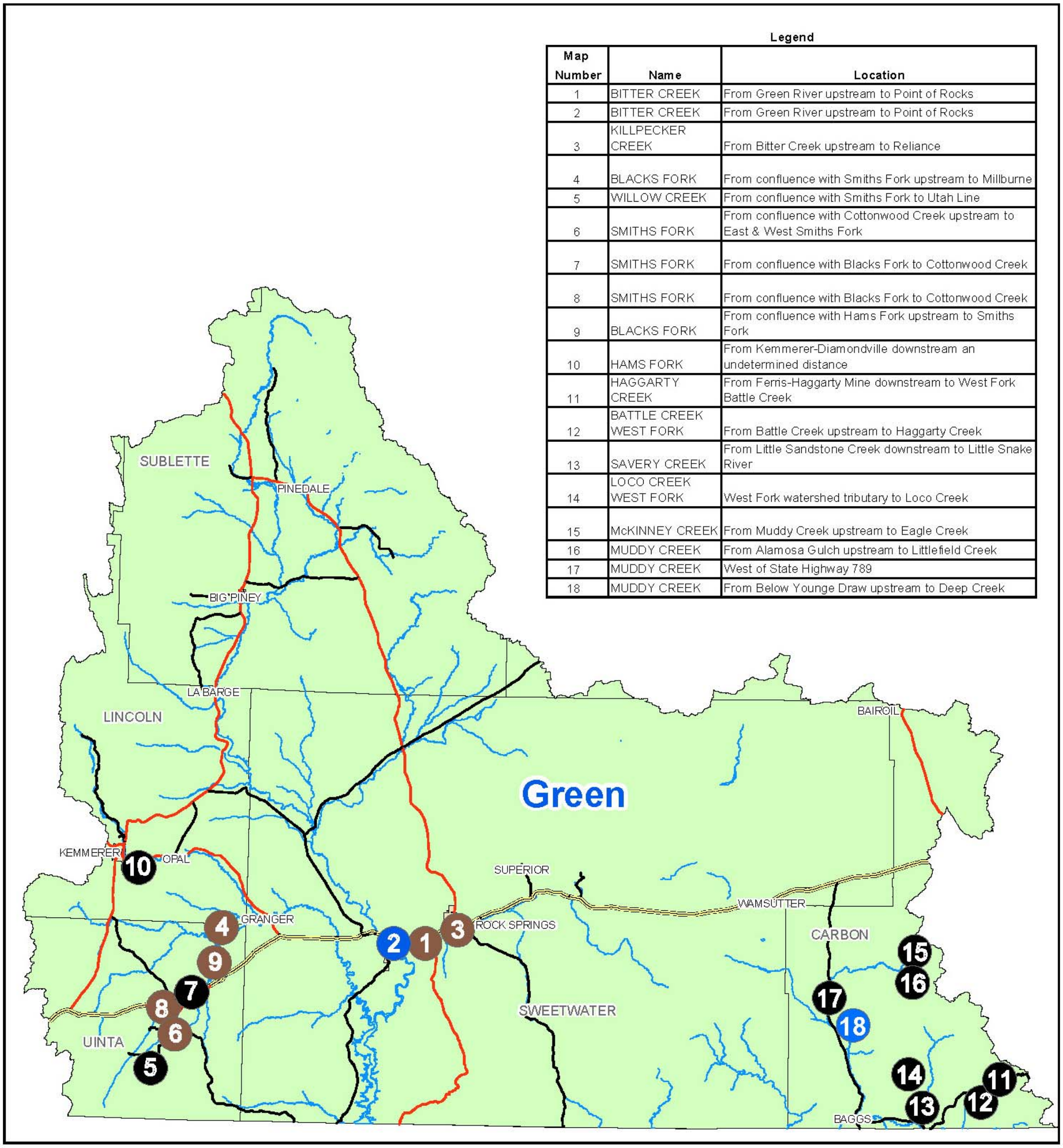
Table 4-2 2010 303(d) List of Waters Requiring TMDLs

Basin*	303(d) ID	Name	Class	Location	Miles/ Acres	Uses	Use Support	Cause(s)	Source(s)	List Date
GR	WYGR140401050506_01	Bitter Creek	2C	From Green River upstream to Point of Rocks	21.6	Recreation	Not Supporting	Fecal Coliform	Unknown	2000
GR	WYGR140401050506_01	Bitter Creek	2C	From Green River upstream to Point of Rocks	21.6	Aquatic Life, Non- Game Fish	Not Supporting	Chloride	Natural Sources, Unknown	2002
GR	WYGR140401050808_01	Killpecker Creek	3B	From Bitter creek upstream to Reliance	6.9	Recreation	Not Supporting	Fecal Coliform	Unknown	2000
GR	WYGR140401070106_01	Blacks Fork	2AB	From confluence with Smiths fork upstream to Millburne	24	Recreation	Not Supporting	E.coli	Unknown	2000
GR	WYGR140401070205_01	Willow Creek	2AB	From confluence with Smiths Fork upstream to Utah Line	48.5	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1998
GR	WYGR140401070208_00	Smiths Fork	2AB	From confluence with Cottonwood Creek upstream to east and West Smiths Fork	29.6	Recreation	Not Supporting	Fecal Coliform	Unknown	2002
GR	WYGR140401070208_01	Smiths Fork	2AB	From confluence with Blacks Fork to Cottonwood Creek	3.6	Aquatic Life, Cold Water Fish	Not Supporting	Habitat	Unknown	2000
GR	WYGR140401070208_01	Smiths Fork	2AB	Form confluence with Blacks Fork to Cotton wood Creek	3.6	Recreation	Not Supporting	E.coli	Unknown	2002
GR	WYGR140401070403_01	Blacks Fork	2AB	From confluence with Ham's Fork upstream to Smiths Fork	44.1	Recreation	Not Supporting	E.coli	Unknown	2000
GR	WYGR140401070701_01	Hams Fork	2AB	From Kemmerer-Diamondville downstream an undetermined distance	7.8	Aquatic Life, Cold Water Fish	Not Supporting	pH	Municipal WWTF	1996
LS	WYLS140500030109_01	Haggarty Creek	2AB	From Ferris-Haggarty Mine downstream to West Fork Battle Creek	5.9	Aquatic Life, Cold Water Fish	Not Supporting	Cd, Cu, Hg	Hardrock Mining	1996
LS	WYLS140500030109_02	Battle Creek West Fork	2AB	From Battle Creek upstream to Haggarty Creek	4.6	Aquatic Life, Cold Water Fish	Not Supporting	Cu	Hardrock Mining	2000
LS	WYLS140500030408_01	Savery Creek	2AB	From Little Sandstone Creek downstream to Little Snake River	11.4	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1998
LS	WYLS140500030408_02	Loco Creek West Fork	2AB	West Fork watershed tributary to Loco Creek	2.8	Aquatic Life, Cold Water Fish	Threatened	Habitat, Nutrients, Temp.	Grazing	1996
LS	WYLS140500040102_01	McKinney Creek	2AB	From Muddy Creek upstream to Eagle Creek	5.1	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040103_01	Muddy Creek	2AB	From Alamosa Gulch upstream to Littlefield Creek	11.4	Aquatic Life, Cold Water Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040104_01	Muddy Creek	2C	West of State Highway 789	15.4	Aquatic Life, Non-Game Fish	Threatened	Habitat	Grazing	1996
LS	WYLS140500040308_01	Muddy Creek	2C	From below Young Draw upstream to Deep Creek	7.5	Aquatic Life	Not Supporting	Se, Cl	Unknown	2010

* GR-Green River Basin; LS-Little Snake River Basin

Legend

Map Number	Name	Location
1	BITTER CREEK	From Green River upstream to Point of Rocks
2	BITTER CREEK	From Green River upstream to Point of Rocks
3	KILLPECKER CREEK	From Bitter Creek upstream to Reliance
4	BLACKS FORK	From confluence with Smiths Fork upstream to Millburne
5	WILLOW CREEK	From confluence with Smiths Fork to Utah Line
6	SMITHS FORK	From confluence with Cottonwood Creek upstream to East & West Smiths Fork
7	SMITHS FORK	From confluence with Blacks Fork to Cottonwood Creek
8	SMITHS FORK	From confluence with Blacks Fork to Cottonwood Creek
9	BLACKS FORK	From confluence with Hams Fork upstream to Smiths Fork
10	HAMS FORK	From Kemmerer-Diamondville downstream an undetermined distance
11	HAGGARTY CREEK	From Ferris-Haggarty Mine downstream to West Fork Battle Creek
12	BATTLE CREEK WEST FORK	From Battle Creek upstream to Haggarty Creek
13	SAVERY CREEK	From Little Sandstone Creek downstream to Little Snake River
14	LOCO CREEK WEST FORK	West Fork watershed tributary to Loco Creek
15	McKINNEY CREEK	From Muddy Creek upstream to Eagle Creek
16	MUDDY CREEK	From Alamosa Gulch upstream to Littlefield Creek
17	MUDDY CREEK	West of State Highway 789
18	MUDDY CREEK	From Below Younge Draw upstream to Deep Creek



Source: Wyoming Water Quality Assessment and Impaired Waters List (2010 Integrated 305(b) and 303(d) Report)

LEGEND

Fecal Coliform

Chloride

Other (Phosphate, pH, Habitat, Metals, Oil, Ammonia, and Temp)

N

Figure 4-2
2010 303(d) Waters With Water Quality Impairments

4.4 GROUNDWATER RESOURCES

4.4.1 Groundwater Overview

In the Green River Basin, groundwater resources occur within both unconsolidated deposits and bedrock formations and show a wide range of variability in quality and quantity available. Groundwater information presented in this section comes mainly from the Wyoming State Geological Survey's *Available Groundwater Determination, tech. memo, 2010.*

Groundwater originates when rainfall, snowmelt, stream flow, and, in some areas, irrigation water infiltrate into geologic materials, a process called groundwater "recharge". Over time, groundwater travels through the subsurface and returns to the surface as discharge. Between the points of recharge and discharge, groundwater flow may be straightforward or quite complex. Because groundwater is continually returning to the surface as springs and as diffuse gains to perennial streams, streamflow records include varying quantities of groundwater. In the absence of storm runoff or snowmelt, most of the flow in the Basin's streams is supplied from groundwater. In general, shallow groundwater flow (less than 300-500 feet beneath the surface) follows topography and is discharged to stream and river drainages.

Groundwater enters and leaves the state in the subsurface, but no estimates of rates or locations have been compiled. It is simply understood that more groundwater leaves the state than surface water. Although the area through which groundwater flow leaves the state is vastly larger than that through which surface water exits, groundwater velocities are typically measured in feet per day, whereas surface velocities are typically measured in feet per second.

In areas of shallow groundwater, groundwater levels commonly rise in response to spring precipitation and snowmelt and fall to annual lows in midwinter due to the absence of recharge. In aquifers remote from surface influence, there may be little or no annual fluctuation, but groundwater levels may still rise and fall in response to long-term climate cycles. Individual well hydrographs vary widely, as a function of local hydrogeologic and groundwater conditions and groundwater use rates.

Within the Green River Basin, most of the water-saturated portions of the geologic bedrock formations and unconsolidated deposits will yield groundwater to wells. Groundwater in bedrock formations flows predominantly through permeable rocks and fractures from aquifer recharge areas located along the margins of the Basin towards the center of the Basin and down-gradient to the south-southwest into Utah. Shallow groundwater flow in the Green River Basin is predominantly controlled by topography and stream drainage patterns. The Great Divide Basin has an internal drainage and the groundwater flow, like the surface water flow, is towards the center of the Basin.

Four major regional aquifer systems have been identified in the Green River Basin based upon the four geologic eras: the Cenozoic, Mesozoic, Paleozoic, and Precambrian (ordered youngest to oldest). These four major aquifer systems are described below.

- **Cenozoic Major Aquifer System**- is the youngest and most heavily used group of aquifers in the Basin. The water-saturated portions of this system include unconsolidated gravel and sand alluvial deposits, tertiary sedimentary rocks such as sandstone, conglomerate, and conglomeratic sandstone, and coal beds. This system includes Quaternary-age sands and gravels associated with major river courses and the very productive Tertiary-age aquifers. The Tertiary and overlying Quaternary aquifers make up 83 percent of the surficial geology of the Green River Basin.

- **Mesozoic Major Aquifer System-** is the second most utilized aquifer system in the Basin. This system consists of water-bearing sandstone, conglomerate, conglomeratic sandstone, and carbonate beds separated by confining shale units. This system includes the Mesaverde-Adaville aquifers, the Frontier aquifer, Upper Jurassic-Lower Cretaceous age aquifers, and the Sundance-Nugget aquifer system.

- **Paleozoic Major Aquifer System-** is the third most used aquifer system in the Basin. The water-bearing units in this system consist of mainly carbonates and sandstones. This system includes the Madison Limestone and the Flathead aquifer.

- **Precambrian Major Aquifer System-** is the oldest and least used system of aquifers. This unit is comprised of old crystalline crustal rocks forming the deepest bedrock beneath the Basin and are only exposed at or near the surface in the cores of mountain uplifts at the rim of the Basin. The most productive water wells in this unit are located in mountainous outcrop zones; elsewhere this unit does not support large-yielding wells.

4.4.2 Aquifer Classification

Aquifers are formations, groups of formations, or parts of a geologic formation that contain sufficient water-saturated highly-permeable material to yield significant quantities of water to wells and springs. Classification of a body of geologic material as an "aquifer" depends on how much water is yielded for a specific user or purpose. A hydrogeologic formation capable of adequately supplying the modest water needs of a single rural residence is considered an aquifer for that purpose, even though it may be entirely inadequate to meet the needs of a large agricultural operation. Several classes of aquifers are described in this section based on the state-wide framework plan (WWC Engineering, 2007), and Figure 4-4 illustrates the aerial distribution of the primary water-bearing units in the Green River Basin.

Major Aquifers

Alluvial

These aquifers consist of highly permeable sand and gravel beds in alluvial deposits located along rivers and streams and include some of the best-yielding aquifers in the Basin, with wells producing anywhere from 10 to 500 gallons per minute (gpm). The productivity of these aquifers is greatly reduced in areas where the deposits are thin or contain abundant clay or silt.

Generally, the most productive alluvial aquifers are in the upper reaches of major streams where the alluvial materials are predominantly coarse gravel and sand. The alluvial deposits tend to become finer-grained as the streams progress away from the mountains into the interior basins. Where the alluvial aquifer is associated with an active stream, interception of groundwater headed for the stream or induced infiltration from the stream may provide most of the available groundwater to wells; stream depletion rates may approach pumping rates over relatively short time periods. Where closely associated with surface streams, alluvial aquifer quality tends to be good due to the low salinity of water in the stream and good hydraulic communication between the stream and the aquifer.

Sandstone

These aquifers consist of consolidated rock formations composed mostly of permeable sandstone and conglomerates. These aquifers have the potential to develop large quantities of good quality groundwater although water quality is highly variable in the main water-bearing Tertiary aquifers. Most of the deposits and formations in this group include zones of poor production due to local clay content or lack of fractures.

The major sandstone aquifers generally crop out on the flanks of the Green River Basin's mountain ranges, and commonly dip into the Basin, where they may provide useful water supplies even considerable distances from the outcrop areas shown in Figure 4-3. In the Basin interior, the sandstone aquifers tend to be widespread and gently dipping. The most productive formations of this group are the thick, Tertiary-age sandstones, where local faulting and fracturing enhance permeability and therefore water productivity. However, not all sandstone layers are thick and continuous. There are also many discontinuous layers and lenses that require penetration of a substantial number of individual beds to produce the desired amount of water. Major sandstone and conglomerate aquifers include the Battle Spring formation, Wasatch Formation, Fort Union Formation, Mesaverde Group, Cloverly Formation, and Nugget Sandstone.

Limestone

These aquifers consist of bedrock formations composed of a majority of carbonates (limestone or dolomite/dolostone) and have the potential to develop large quantities of good quality groundwater. The productivity of these aquifers is almost entirely dependent upon fractures and karstic solution features, created by deformation and groundwater circulation, both of which are the most developed along the Basin's margin. More than with any other major aquifers, local conditions are the key to successful groundwater development. Major carbonate aquifers include the Tensleep Sandstone, Weber Sandstone, and Flathead Formation as well as the Madison Limestone and Bighorn Dolomite.

Formations	Standard Map Symbols[1]	Dominant Lithology	Basins of Occurrence[2] BE	GR	NE	PL	PT	SS	WB	Thickness, ft 100	200	300	500	1,300	2,500	3,000	>5,000	Yields, gpm 5	10	15	20	100	250	1,000	>1,000	TDS, mg/L 100	300	500	1,000	3,000	>4,000
Alluvium	Qa, Qt	sand, gravel, silt, clay	●	●	●	●	●	●	●	■	■															■	■	■	■	■	■
Ogallala	Tmu	sandstone, siltstone, gravel				●				■	■	■										■	■	■	■	■	■	■			
Teewinot and Salt Lake	Tte, Tsl	tuff, limestone, claystone						●		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Arikaree, North Park, Splitrock	Tmo, Tm, Tmu	sandstone (tuffaceous)			●	●				■	■	■	■					■	■	■	■	■	■	■			■	■			
Bridger, Battle Springs, Fowkes	Tb, Tbs, Tf	sandstone, conglomerate	●	●						■	■	■	■	■	■	■															
Wasatch, Wind River	Tw, Twdr, Twk, Twm, Twmo	siltstone, sandstone, shale	●	●	●	●	●		●			■	■	■	■					■	■	■	■			■	■	■	■	■	■
Fort Union - various members	Tfu, Tfl, Tflt, Tftr	sandstone, siltstone, coal		●	●		●							■	■	■					■	■	■					■	■	■	■
Lance	Kl	sandstone, siltstone			●		●						■	■	■	■		■	■	■	■	■	■					■	■	■	
Fox Hills	Kfh, Kfl, Kfb	sandstone, shale			●		●			■	■	■	■					■	■	■	■	■	■	■				■	■	■	
Mesaverde and related rocks	Kmv, Kav, Kal, Ke, Kr, Kbl	sandstone, shale, coal	●	●													■														
Cloverly/Dakota	KJ, KJs, Kg	sandstone, siltstone	●	●	●		●			■	■	■						■	■	■	■	■	■				■	■	■	■	
Nugget	JЋn	sandstone	●	●				●					■																		
Casper, Tensleep, Minnelusa, Hartville	P₽c, P₽cf, P₽h, P₽m, PM, P₽M	sandstone & limestone, shale	●	●	●	●	●	●	●	■	■	■	■	■	■						■	■	■	■		■	■	■	■	■	
Madison, Bighorn	Mm, MD, MDO, MDe, MDg, MO, OЄ, Ob, Pzr	limestone, dolomite	●	●	●	●	●	●	●				■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	
Flathead	Єr	sandstone	●	●					●		■																				
Non-alluvial Deposits	Ql, Qg, QTg, Qls, Qs	landslide debris, glacial deposits	●	●	●	●	●	●	●	■								■	■	■	■					■	■	■			
Arikaree	Tmo, Tmu	sandstone (tuffaceous)					●			■	■	■	■					■	■	■	■	■	■	■							
Willwood	Twl	sandstone, siltstone, mudstone							●								■	■	■	■	■										
Ft Union	Tfu	sandstone, claystone, coal				●			●								■				■	■	■				■	■	■	■	■
Evanston	Tke	conglomerate, sandstone	●	●										■	■	■															
Lance, Fox Hills	Kl, Klm	sandstone, shale, siltstone		●		●			●								■	■	■	■	■	■	■				■	■	■	■	■
Medicine Bow	Kmb	sandstone, shale				●											■											■	■	■	
Mesaverde	Kmv	sandstone, shale				●	●		●				■	■	■	■					■	■	■			■	■	■	■		
Frontier	Kf, Kfl	sandstone and shale	●	●		●	●	●	●				■	■	■	■		■	■	■	■					■	■	■	■	■	
Cloverly (Dakota), Morrison	KJ, K , KJs, KJg	sandstone, shale				●			●	■	■	■	■					■	■	■	■	■				■	■	■	■	■	■
Sundance, Nugget and related rocks	Js, Jsg, JЋ, JЋn	sandstone, siltstone, gypsum			●	●			●				■	■	■			■	■	■	■	■	■			■	■	■	■	■	
Twin Creek and Thaynes	JЋnd, Jst	limestone, shale	●	●				●						■	■																
Spearfish	ЋPs	shale, siltstone			●								■							■											
Phospohoria, Minnekahta	Pp, Pmo, MzPz	limestone, siltstone, sandstone	●	●	●			●	●			■						■	■	■	■	■	■	■							
Bighorn, Flathead	DO, Єr	dolomite, limestone, shale, sandstone							●						■			■	■	■	■	■	■	■	■						
Gallatin, Gros Ventre, Flathead	Єr	limestone, sandstone, shale				●	●						■													■	■	■			
Quaternary Deposits	Qg, Qls, Qs, Qu	sand, gravel, silt, boulders							●	■								■	■	■	■	■	■	■	■						
Volcanic rocks	Qb, Qr, Thr, Ti, Tii, Tcv, Tts, Twi, Tll, Tt, Ts, Ttp, Twp, Taw, Tv	lava flows, mudflows, ash, tuff, breccia						●	●								■	■													
Camp Davis, Colter, Hoback	Tcd, Tc, Th	conglomerate, mudstone						●									■	■	■												
White River	Twr, Twru, Twrb, Twrc	siltstone, claystone			●	●	●							■	■					■	■	■	■			■	■	■	■		
Wagon Bed, Crandall	Twb, Teml, Tcr, TKu	sandstone, siltstone, mudstone				●			●				■					■	■										■	■	
Hanna	Tha	shale, sandstone, coal				●											■				■	■	■					■	■	■	■
Ferris	TKf	sandstone, shale, conglomerate				●											■	■	■	■	■	■	■				■	■	■	■	■
Sohare, Harebell	Kso, Ksb, Kha, Kb	sandstone, shale, siltstone						●									■	■	■	■	■										
Aspen, Bear River	Ka, Kbr, Kg	shale, sandstone, siltstone						●								■	■	■	■	■	■										
Sundance	Js, Jsg	shale					●					■																			
Chugwater and related rocks	Ћc, JЋgc, JЋgn, Ћcd, ЋPcg, ЋPg	siltstone, sandstone, gypsum							●					■	■			■	■	■	■										
Woodside and Dinwoody	JЋad, Ћcd	siltstone, shale	●	●				●			■	■	■	■	■																
Amsden	P₽Ma, P₽M	shale							●			■																			
Indian Meadows	Tim	claystone							●			■																			
Meetsetse and Lewis	Km, Kle, Kml	siltstone, claystone, shale	●	●			●		●					■	■																
Cody, Pierre, Steele, Niobrara, Baxter, Carlisle	Kc, Kp, Ks, Kn, Knc, Kcl, Kgb, Kgbm, Kh, Kba	shale	●	●	●	●	●	●	●								■														
Thermopolis, Mowry, Aspen	Kmt, KJk, Kmr, Kgb, Kgbm, Kns, Ka, Kbr	shale	●	●	●	●	●		●						■																
Chugwater, Goose Egg	Ћc, Ћcd, ЋPs, ЋPcg, ЋPg	siltstone, sandstone, gypsum				●	●					■																	■	■	
Precambrian rocks		granite, gneiss, schist	●	●	●	●	●	●	●								■									■	■				

[1] Map symbols for the Geologic Map of Wyoming (Love and Christiansen, 1985)

[2] BE - Bear; GR - Green; NE - Northeast Wyoming; PL - Platte; PT - Powder/Tongue; SS - Snake/Salt; WB - Wind/Bighorn

LEGEND

Major Aquifer - Alluvial
Major Aquifer - Sandstone
Major Aquifer - Limestone
Unclassified
Minor Aquifer
Marginal Aquifer
Major Aquitard

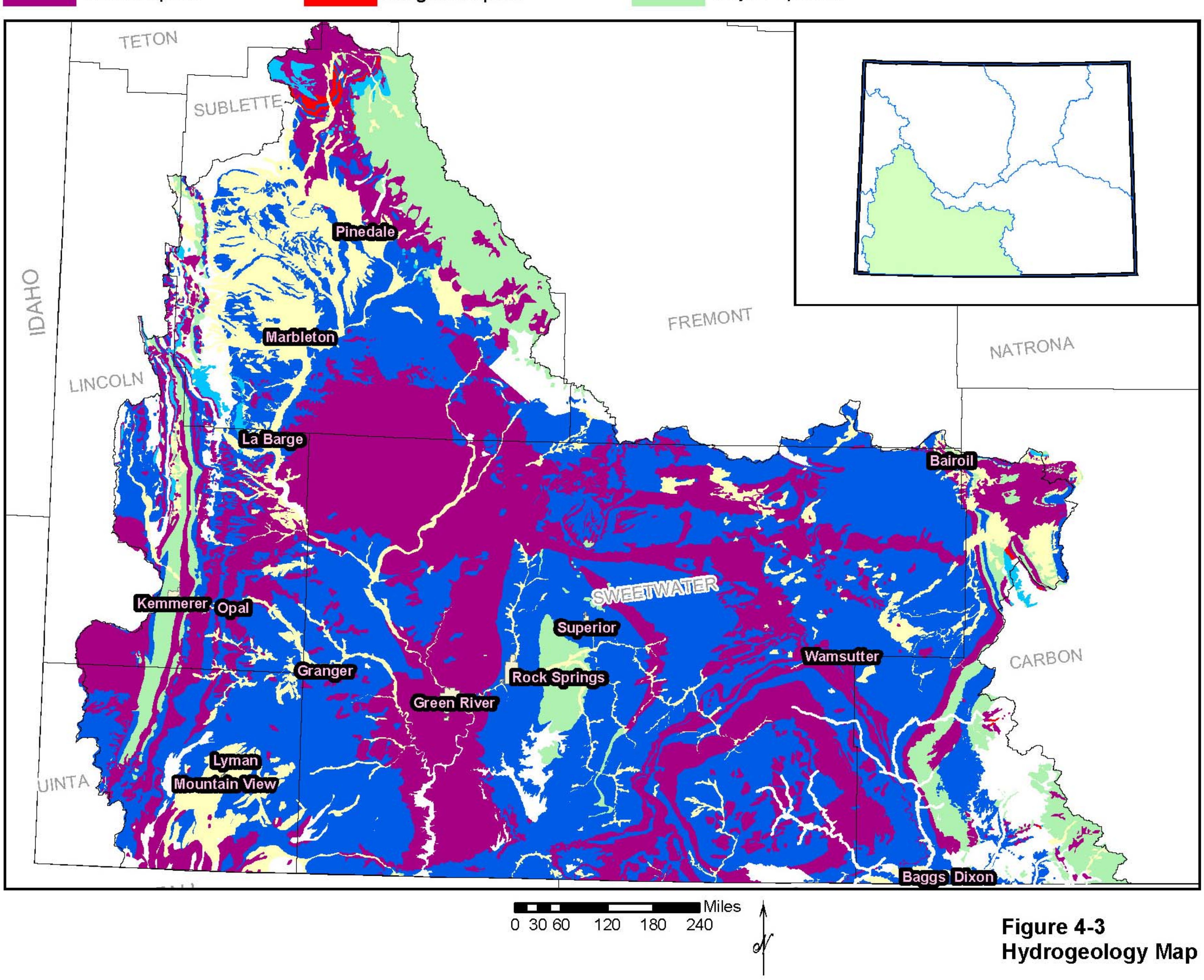


Figure 4-3
Hydrogeology Map

Minor Aquifers

Minor aquifers often have thinner beds that are less permeable and less laterally extensive as compared to major aquifers, but commonly provide useful groundwater supplies for small uses such as domestic and stock water supplies. These geologic units typically have lower yielding wells (50 gpm or less) and the groundwater quality from these aquifers is variable, largely as a function of distance from a recharge source. Productivity is largely a function of the thickness and texture of sandstone units, although fracture enhancement of permeability can make the difference between unacceptable and acceptable production rates. Examples of minor aquifers include Quaternary non-alluvial deposits, the Frontier, Evanston, Lance, and Phosphoria formations as well as the Twin Creek Limestone, Fox Hills Sandstone and the Thaynes Limestone.

Marginal Aquifers

Most geologic formations can provide useful groundwater supplies under the right conditions, particularly if the demands are small, as for stock and domestic use. Marginal aquifers are typically bedrock formations with very low yielding wells (1-5 gpm) and very little potential for developing moderate to large quantities of good quality groundwater. These aquifers are generally suitable for low-yielding domestic or stock wells. Examples of marginal aquifers include the Woodside and Dinwoody formations.

Major Confining Units (Aquitards)

These formations are typically poor producers of groundwater and the water is usually of poor quality. The sedimentary forms of these geologic units are predominantly composed of a high percentage of shale and show little potential for producing useable quantities of groundwater. Many of these low permeability, confining units are composed of thick, laterally extensive sequences of marine shale. Because of their clay content, these rocks are less brittle than sandstone or granite and are thus less susceptible to the permeability enhancement of fractures. These thick confining units act as regional seals between aquifers and greatly decrease permeability for vertical groundwater flow.

The crystalline rocks of the Precambrian aquifer system which form the mountain cores and underlie the entire Green River Basin are typically a major basal confining unit as they are located beneath sedimentary rock formations in the structural basins. The absence of fractures and nature of these types of Precambrian basement rocks makes them virtually impermeable.

Examples of confining units include the Cody, Steele, Baxter, Thermopolis, Mowry, and Aspen shales as well as the Niobrara Formation and deeply buried Precambrian basement rock units.

Unclassified

These geologic materials are present in limited areas without adequate hydrogeologic data available for classifying the geologic unit.

Aquifer Location

Aquifers are most convenient to use when they are near the surface where water is shallow (less than 500 feet deep) and usually has the best quality. Figure 4-3 shows where specific aquifer groups are present near the surface, called aquifer outcrops. Most of the water-bearing aquifer bedrock formations in the Green River Basin crop out in the highland and mountainous margins of the Basin and are covered by younger formations towards the lowland centers of the Basin. Thus groundwater is commonly available from productive basin-margin aquifers for some miles basinward of the outcrops depicted on Figure 4-3, albeit at increasing depth.

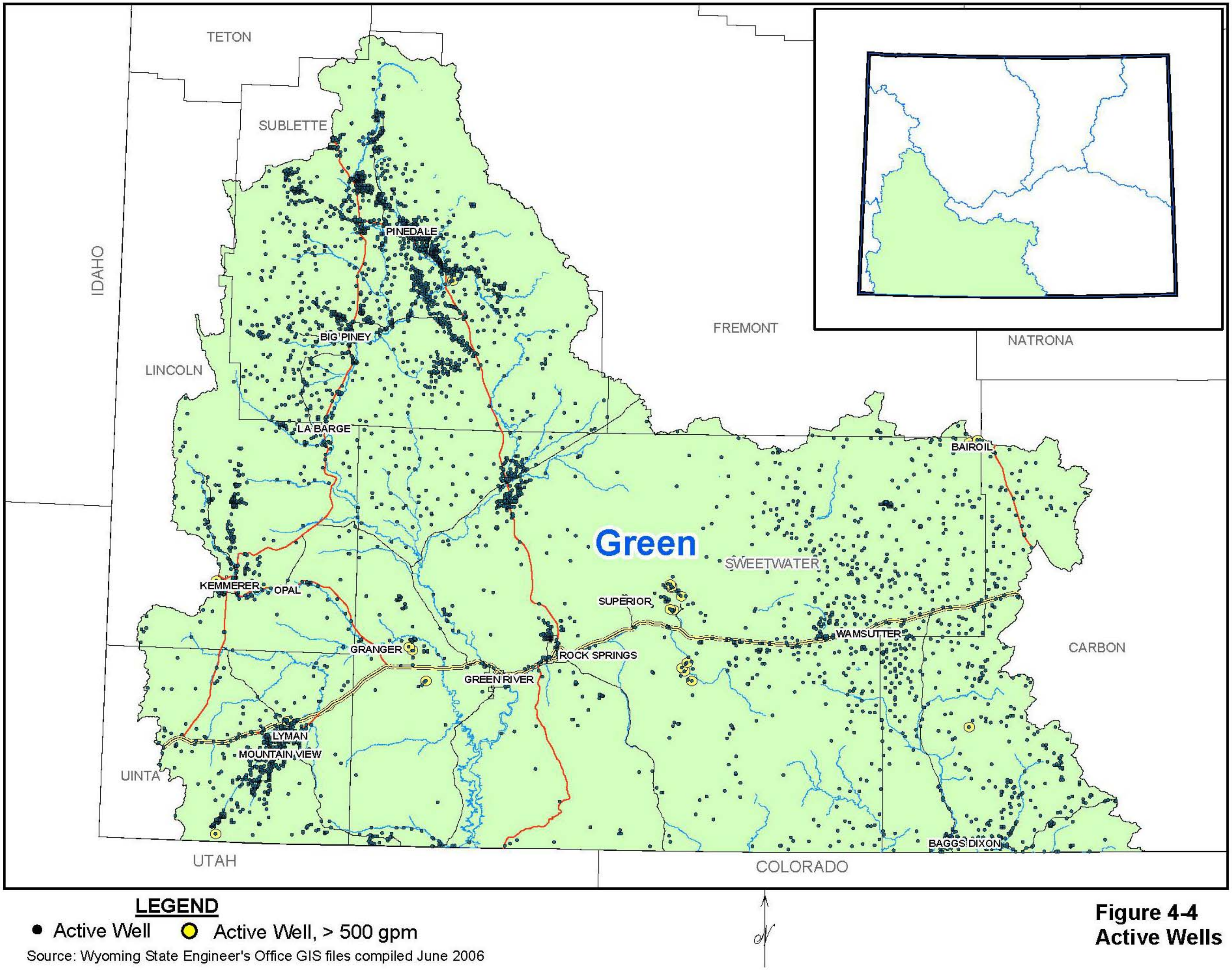
Where a productive aquifer is overlain and underlain by a confining unit (considered to be impermeable or characterized by very low permeabilities) the water contained therein is under pressure, producing artesian conditions which may result in flowing wells where the confining unit is punctured. Many aquifers of the Green River Basin are confined, including many in the Mesozoic aquifer system due to the numerous confining layers of shale present in this system.

For consolidated bedrock aquifers, geologic structures such as folds and faults are as important as rock type in providing useful supplies of groundwater. The rocks are generally fractured in these geologic structures. The fractures provide secondary permeability in rocks that have very little inherent or primary permeability and serve as conduits of flow that can increase groundwater productivity. In the Green River Basin, major belts of faulting occur along the mountains where deformation has taken place due to mountain-building. Large-scale fracturing in the interior of the Basin is much less prevalent, and grain size and degree of cementation of aquifer materials plays the primary role in determining aquifer productivity.

Optimum conditions for the development of groundwater reflect the conjunction of favorable aquifer formations, good permeability within those formations (primarily due to coarse-grained materials and/or fractures in the rock) and recharge conditions that provide suitable groundwater quality.

4.4.3 Historical Aquifer Performance

There has been relatively little development of the groundwater resources of the Green River Basin. Figure 4-4 shows all water wells for which permitted yield is greater than zero excluding coalbed methane (CBM) also known as coalbed natural gas wells. Areas of low well density reflect either small populations or lack of available water from low-producing aquitards such as the shale located just east of Rock Springs. Highlighted wells on Figure 4-4 indicate production rates of 500 or more gallons per minute, an indication of high aquifer productivity.



LEGEND

● Active Well ○ Active Well, > 500 gpm

Source: Wyoming State Engineer's Office GIS files compiled June 2006

Figure 4-4
Active Wells

These wells mark aquifers with adequate permeabilities, depth, quality, and convenience of location to serve the Basin's major needs. As of December 2007, more than 13,000 groundwater permits had been issued by the Wyoming State Engineer's Office in the Basin. Most of these wells are less than 300 feet deep (88.6%) and yield 25 gallons per minute (gpm) or less (95.2%). There are 19 permitted groundwater wells with yields listed as more than 500 gallons per minute in the Green River Basin.

4.4.4 Groundwater Quality

Most activities which affect the quality of groundwater in Wyoming are regulated by the Wyoming Department of Environmental Quality (WDEQ), Water Quality Division (WQD), while the U.S. Environmental Protection Agency (USEPA) Region 8 office headquartered in Denver, Colorado, regulates the public water systems located within the state. Each agency has established groundwater standards, which are revised and updated as needed.

The State of Wyoming through the WDEQ/WQD has classified groundwater of the state in the *Water Quality Rules and Regulations, Chapter 8—Quality Standards for Wyoming Groundwaters,* according to these criteria:

- Class I Groundwater of the State—Groundwater quality that is suitable for domestic use.
- Class II Groundwater of the State—Groundwater quality that is suitable for agricultural use where soil conditions and other factors are adequate for such use.
- Class III Groundwater of the State—Groundwater quality that is suitable for livestock watering.
    - Class Special III (A) Groundwater of the State—Groundwater quality that is suitable for fish and aquatic life.
- Class IV Groundwater of the State—Groundwater quality that is suitable for industrial use.
    - Class IV(A) Groundwater of the State—Groundwater quality that has a total dissolved solids (TDS) concentration that is 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 the Safe Drinking Water Act (SDWA) provisions as a potential future drinking water source with water treatment.
    - Class IV(B) Groundwater for the State—Groundwater quality that exceeds a TDS concentration of 10,000 mg/l.
- Class V Groundwater of the State—Groundwater quality as found in close association with commercial deposits of hydrocarbons (oil and gas)(Class V Hydrocarbon Commercial) and/or other minerals (Class V Mineral Commercial), or is a geothermal energy source (Class V Geothermal).
- Class VI Groundwater of the State—Groundwater quality which may be unusable or unsuitable for use.

Groundwater quality in the Green River Basin is highly variable, even within a single geologic unit. The Basin lies largely on sediments derived from prehistoric seas, so soils naturally contain salts which are dissolved by groundwater. Water quality in any given geologic unit tends to be better near outcrop areas where recharge occurs and deteriorates as the distance from these areas increases (and also as residence time increases). The water quality of a given geologic unit also usually deteriorates with depth. Groundwater quality concerns in most of the Green River Basin aquifers will generally limit new water well construction to depths of 1,000 feet or shallower, especially for the Tertiary, Mesozoic, and Paleozoic aquifers. This indicates that groundwater development for these aquifers is generally limited to aquifer outcrop areas or within a distance of one to three miles of these outcrops.

Total Dissolved Solids (TDS) concentration is a useful measure of a water's suitability for human, agricultural, environmental and industrial uses (See Chapter 3 for TDS standards). TDS concentrations in groundwater of most geographic regions within the Green River Basin tend to exceed the USEPA Secondary Maximum Contaminant Levels (SMCL). SMCLs are a measure of non-enforceable guidelines regulating contaminants that may cause cosmetic effects such as skin or tooth discoloration or aesthetic effects such as color, taste, and odor in drinking water. Large TDS concentrations can adversely affect the taste and odor of drinking water, as well as having a negative effect on crop production when used for irrigation and may cause scale buildup in pipes and boilers. High TDS concentrations can negatively affect fish and wildlife.

Other water quality constituents sometimes found in quantities higher than USEPA and WDEQ water quality standards in the Green River Basin include sulfate, chloride, fluoride, iron and manganese. These constituents may affect the taste and appearance of water as well as causing mild to moderate health problems and crop productivity declines. Trace elements and radioactive contaminants were also found in levels higher than USEPA and WDEQ water quality standards in certain areas of several aquifers in the Green River Basin, making some of these aquifers unsuitable for domestic, livestock, irrigation uses, and fish and wildlife.

Contamination of groundwater resources from point sources such as underground storage tank leaks or industrial releases are a concern. Many locations of former underground storage tanks for gasoline, diesel fuel, or oil have experienced past subsurface leaks from the tanks and/or associated underground pipelines into groundwater. Energy development activities have the potential to contaminate the local groundwater resource, such as has apparently occurred with some volatile organic compounds (VOC) detections in some multiple-use water wells located near Pinedale in Sublette County.

In some areas of the Green River Basin, groundwater contamination is natural and related to the elevated concentrations of water quality constituents from natural sources. Examples of naturally occurring contamination include uranium and other radioactive elements present in the Tertiary Formations in the Great Divide Basin and high levels of inorganic constituents like selenium or fluoride.

Figure 4-5 shows an aquifer sensitivity map of the Green River Basin. Higher sensitivity areas are considered to be more susceptible to shallow groundwater contamination due to the increased permeability of these geologic units and also the relatively shallow depth to groundwater in these areas. Contamination released at the ground surface or in the shallow subsurface (such as underground gasoline/diesel storage tanks) is likely to migrate downward from the shallow depth soils/formations to contaminate the shallowest groundwater underlying a site. Groundwater contamination tends to follow the direction of local groundwater flow from a contaminant point source. Groundwater contamination may be sourced from a specific site (point source) or multiple sources (nonpoint sources).

4.4.5 Groundwater Associated with Energy Development

The Atlantic Rim Coalbed Natural Gas (CBNG) development and associated natural gas field development north of Baggs in western Carbon County is underway with up to 1,800 CBNG and 200 conventional natural gas wells planned for construction. Coalbed natural gas development involves pumping groundwater to lower pressures in the target coal beds and allow the desorption and production of the natural gas from the coals. The groundwater pumping due to CBNG development in the eastern Green River Basin is projected to be approximately 11,760 to 21,168 acre-feet per year. The majority of the groundwater that is produced during the Atlantic Rim CBNG development is planned to be re-injected into other subsurface geologic formations. As of December 2007, more than 13,000 groundwater permits had been issued by the Wyoming State Engineer’s Office (WSEO) for the Green River Basin. Of this total number, CBNG wells numbered about 7.7 percent or approximately 1,000 wells. CBNG wells permitted by the Wyoming Oil and Gas Conservation Commission (WOGCC) are shown in Figure 4-6. The coal beds of the Mesaverde Group in the eastern Washakie Basin show an area of planned drawdown as part of the Atlantic Rim CBNG development north of Baggs, Wyoming. The Mesaverde coal aquifer is not of drinking water quality and the production water is planned to be re-injected into other formations in the area.

Besides CBNG production, both petroleum (oil and natural gas) and oil shales exist and are potential energy resources in the Green River Basin. The Tensleep Sandstone aquifer in the northeastern Great Divide Basin shows an area of localized drawdown due to petroleum field development in the area. The Tensleep groundwater in this area is not of drinking water quality and contains hydrocarbon compounds.

The projected water quantities required (Available Groundwater Determination, tech. memo, 2010) for developing oil shale resources in the Basin, such as for a 50,000-barrel per day production facility, are estimated as:

Oil shale surface extraction method	13,400-20,100 acre-ft/year
Oil shale underground method	6,800-10,600 acre-ft/year
Oil shale in-situ retorting method	3,000-5,700 acre-ft/year
Oil shale modified in-situ method	5,000-8,000 acre-ft/year

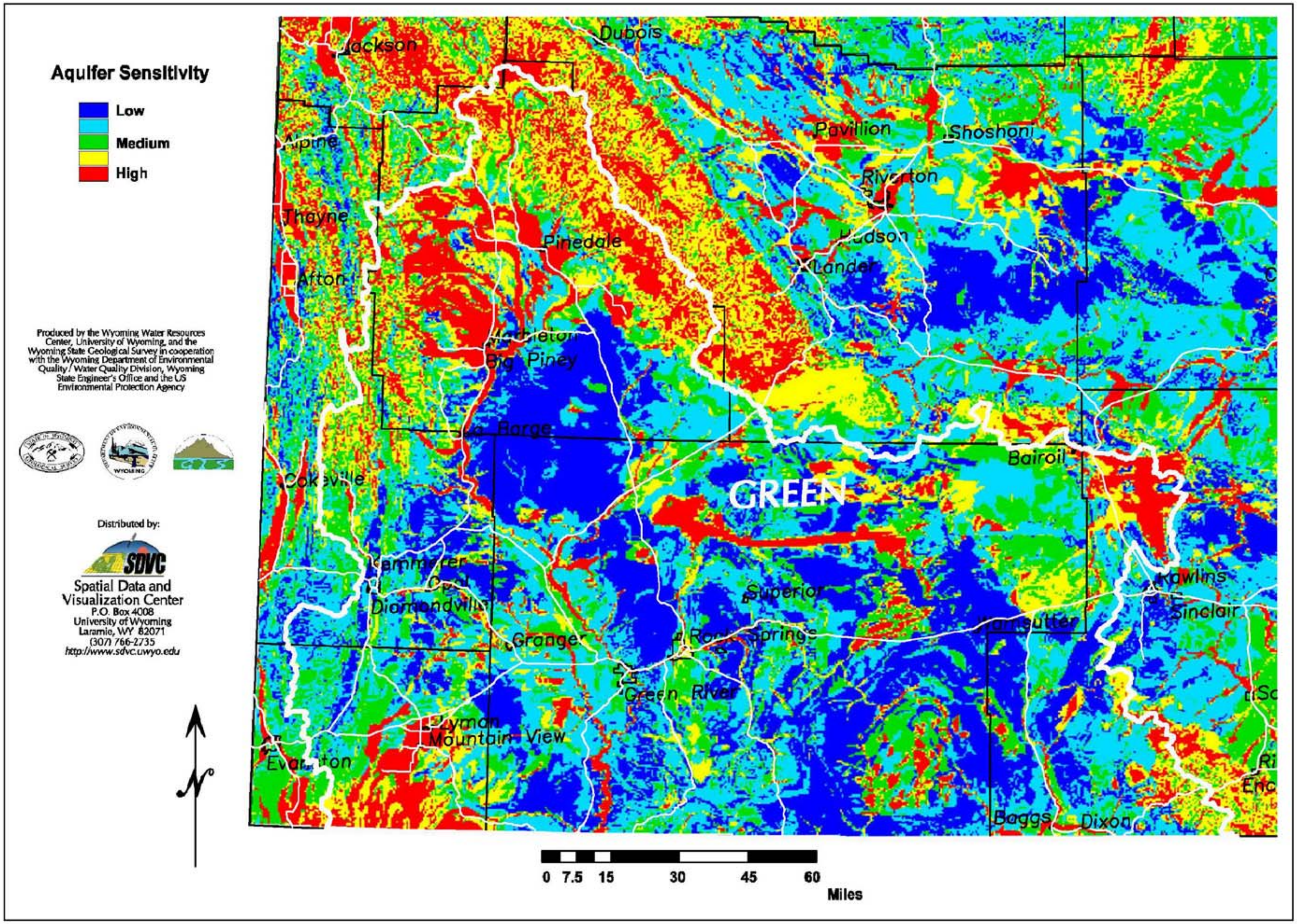
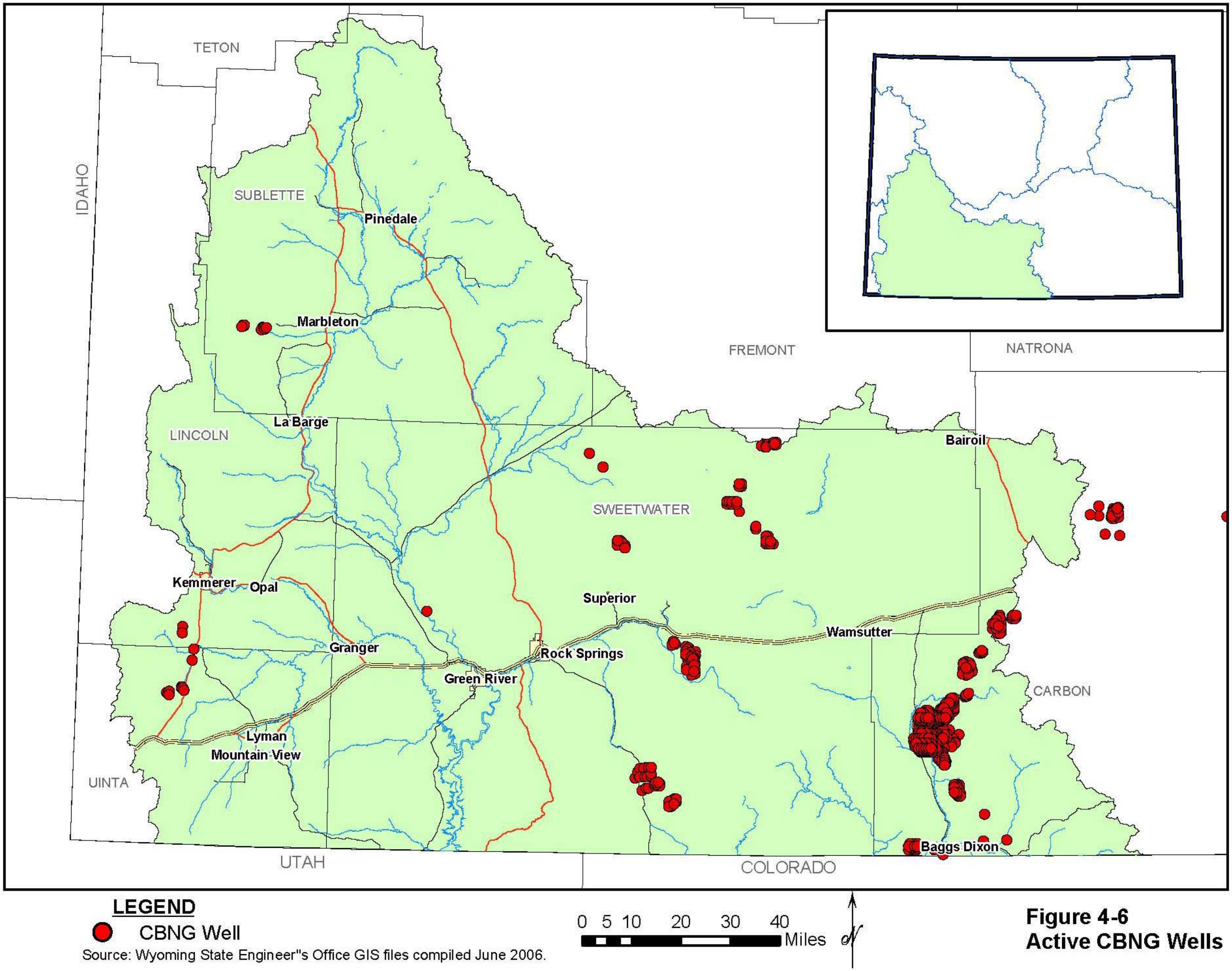


Figure 4-5
Aquifer Sensitivity



Source: Wyoming State Engineer''s Office GIS files compiled June 2006.

Figure 4-6
Active CBNG Wells

There is also an interest in developing new underground coal gasification resources in Wyoming. The projected water quantities required (Available Groundwater Determination, tech. memo, 2010) for developing underground coal gasification for a 250-million cubic feet per day production facility are estimated as:

Coal gasification Lurgi process	5,600-9,000 acre-ft/year
Coal gasification synthane process	6,694-10,500 acre-ft/year
Coal gasification synthoil process	9,655-13,000 acre-ft/year

Future energy development of both oil shale and coal gasification resources would require obtaining new water supplies from surface water and groundwater sources in the Green River Basin. Also, both oil shale and underground coal gasification pilot testing have contaminated groundwater resources within the State of Wyoming. The future development of these unconventional energy resources in the Green River Basin will depend on economics, permitting through the WDEQ and adequate pre-project planning to monitor for and remediate any potential groundwater contamination.

4.5 REFERENCES

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