Chapter 8

Groundwater development and basinwide water balance

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This chapter discusses groundwater development, withdrawals, consumptive uses, and depletions in the Powder/Tongue/Northeast River basins (NERB).

The terms "withdrawal" and "consumptive use" are used throughout this chapter. A groundwater withdrawal is simply the removal of a volume of water from a well or a spring at its source. Throughout this study, "use" has essentially the same meaning as "withdrawal." The "consumptive use" of a water resource, however, diminishes the amount of water available for other uses and effectively removes that water as a useable resource from the drainage basin. Consumptive processes include plant and animal growth, evaporation, transpiration by plants, and some industrial processes (Sharp, 2007). Evaporation and transpiration combined (referred to as evapotranspiration) constitute the largest consumptive loss of water resources in most river basins. The U. S. Geological Survey (USGS) defines groundwater depletion as, "long-term water-level declines caused by sustained groundwater pumping" (USGS, 2019). However, this chapter also looks at groundwater "depletion" as the volume of pumped groundwater that is unlikely to return to its source aquifer in any substantial amount.

Relatively few uses are wholly consumptive or non-consumptive. Most uses are partially consumptive; meaning some of the water is lost while the remainder returns to the system. For example, evapotranspiration and plant growth consume a large fraction of the groundwater used for irrigation, but smaller portions return to the basin as flow to surface water and as recharge to groundwater. Other examples of partially consumptive uses (with the associated consumptive constituent noted in parentheses) include livestock watering (animal growth and evaporation), reservoir storage (evapotranspiration), and domestic wastewater treatment such as discharge from sewage or septic systems (evapotranspiration). Other uses, such as industrial wastewater storage and disposal in lined evaporation pits, are wholly consumptive.

In a similar manner, only a minor fraction of water withdrawn from wells is returned to a basin's groundwater system. The amount of water lost from groundwater storage is a depletion. In the example above, the groundwater lost to evapotranspiration and surface outflows represents a depletion; only a small amount of the withdrawn water re-enters the ground surface below irrigated fields and return flow channels as recharge. In the same way, a minor portion of the 922,000 ac-ft of groundwater withdrawn (WOGCC, 2018) in the Powder River Basin during coalbed methane development (2002–2018) was returned to groundwater storage. Much of the produced water was lost to evapotranspiration and outflows into neighboring states when it was discharged into unlined on-channel evaporation/infiltration pits or into streams. Depletions also reduce groundwater discharges to streamflow thereby reducing available surface water resources (Barlow and Leake, 2012). Groundwater depletions are well documented near past and current coalbed methane fields (Taboga and others, 2015; 2017).

Information for this chapter was compiled from multiple sources:

- Previous and current water plans for the Powder/Tongue and Northeast basins (HKM Engineering, 2002a, b; RESPEC, 2019a, b)
- Numerous previous local and regional studies (app. B, chap. 7)
- Groundwater permit data provided by the Wyoming State Engineer's Office (SEO), the Montana Department of Natural Resources and Conservation (MDNRC), the South Dakota Department of Environment and Natural Resources (SDDENR), and the Nebraska Department of Natural Resources (NDNR)
- The SEO 2016 Hydrographers' Annual Reports Water Division 1 and 2 (Wyoming State Engineer's Office, 2016) available at: http://seo.wyo.gov/documents-data/hydrographer-reports
- Produced groundwater data from the Wyoming Oil and Gas Conservation Commission (WOGCC, 2018)

8.1 INFORMATION FROM PREVIOUS WATER PLANS

The Wyoming Statewide Framework Water Plan (WWC Engineering and others, 2007) lists estimated groundwater withdrawals and consumptive uses, compiled from the 2002 Powder/Tongue and Northeast basins plans and the associated technical memoranda (HKM, 2002a, b). There are, however, minor differences in the volumes reported between the plans and the various technical memoranda, which is likely due to the estimation methods used. Additionally, RESPEC Company LLC (RESPEC) provided groundwater withdrawal and consumptive-use data from their recent Powder/Tongue River Basin Level 1 Study (2019a) and Northeast River Basin Level 1 Study (2019b).

8.2 GROUNDWATER WITHDRAWAL AND CONSUMPTIVE-USE ESTIMATIONS IN THIS MEMORANDUM AND BASINWIDE WATER BALANCE

In the absence of direct measurements, groundwater withdrawals and consumptive uses must be estimated. This is more complex than it would appear because multiple estimations of the same parameter may be made using different methods and assumptions. Still, the methods used must provide reasonably conservative estimations of withdrawals and consumptive uses based on rational assumptions. The tables, shown below, present ranges of probable withdrawals and consumptive uses in multiple formats. In some cases, the tables provide conservative estimations for comparison. For example, compare the SEO permitted irrigation and livestock withdrawals in table 8-1a to science-based estimates of actual withdrawals (RESPEC, 2019a, b).

The water resources of any river basin are not composed of static volumes of standing water. Unlike an area's mineral reserves, water is a dynamic resource. It enters a basin as precipitation or as surface water, and groundwater inflows and exits as effluent flow or as evapotranspiration (see definition, chap. 5). It is important to understand the transient nature of water resources. For this reason, the Wyoming State Geological Survey (WSGS) generated a basin-wide water balance (tables 8-2a and 8-2b) to provide a sense of the magnitude, origin, and fate of water resources in the NERB.

8.2.1 Groundwater withdrawal and consumptive-use estimations

Tables 8-1a through 8-1e summarize groundwater withdrawal and consumptive-use estimates from the SEO and previous Wyoming Water Development Commission (WWDC) river basin plans (HKM Engineering, 2002a, b; WWC Engineering and others, 2007; RESPEC, 2019a, b) for principal SEO listed water right withdrawals. Consumptive-use estimates from the median economic growth and normal water-demand year scenario are shown for each withdrawal (Agricultural, Municipal/Rural Domestic Water Systems, Industrial, and Miscellaneous). These use sectors combine principal SEO-listed water right uses:

- Agricultural uses (irrigation and stock watering (table 8-1a)
- Municipal and rural domestic supplies are combined (table 8-1b)
- Industrial uses (table 8–1c)
- Other diverse uses (table 8–1d) that involve miscellaneous, monitoring, testing, and multi-use wells hereinafter referred to as minor uses

Additionally, consumptive-use estimates are provided from the 2019 Powder/Tongue and Northeast Basin plans (RESPEC, 2019a, b) for comparison to the values prorated from the technical memoranda of the 2002 Powder/Tongue and Northeast Basin plans (HKM, 2002a, b). The values developed for tables 8-1a through 8-1e and tables 8-2a through 8-2d are typically shown to a precision of three significant figures. Percentages are typically carried to one decimal place in the tables; in some cases, small percentages are carried to two decimal places (table 8-2c).

Estimates of total withdrawal and consumptive-use volumes for the six use sectors listed above are shown in tables 8-1a through 8-1d and are aggregated in table 8-1e. Irrigation and stock watering withdrawals are combined as agricultural uses in table 8-1a, and public supply and rural domestic withdrawals are combined in table 8-1b. Total average annual groundwater withdrawal during 2002–2018 is estimated at 189,000 ac-ft, and the highest estimated value for annual consumptive use is 150,000 ac-ft (table 8-1e). Water-use categories, amounts, and estimation methods are discussed in more detail later in this chapter. Minor uses are not included in the totals shown in table 8-1e because only SEO-permitted withdrawal data (table 8-1d) are available, and minor uses were not addressed in previous water plans.

For other uses, potential volumes calculated from SEO allocated well yields are provided for comparison to consumptive-use estimates obtained from previous water basin plans or from data compiled and processed by the WSGS. The large differences between SEO allocated well yields and actual use estimates show that the volumes of groundwater used constitute, in most cases, a minor fraction of what has been allocated to permitted water right holders. For example, the total irrigation withdrawal calculated from SEO-permitted yields for "likely existing wells" (157,000 ac-feet/yr in table 8-1a) assumes continuous year-round operation of the permitted irrigation wells. Although the value is clearly an overestimate, it does provide a useful upper limit of groundwater withdrawals for irrigation readily compared to estimates of actual consumptive uses, in this case 12,600 ac-feet/yr in table 8-1a. Estimates shown for agricultural withdrawals and consumptive uses of groundwater are aggregate values for both irrigation and stock watering provided in previous reports (RESPEC, 2019a, b). Irrigation

consumptive uses in those reports are based on actual crop-specific consumptive uses specified in Pochop and others (1992) applied to crop-distribution data obtained from the agricultural industry in the target basins. The methods used are explained in appendices of the 2002 and 2019 Powder/Tongue and Northeast basin plans (HKM, 2002a, b; RESPEC, 2019a, b).

Table 8-1a. Groundwater withdrawal and consumptive use estimates for agricultural use wells (irrigation and stock watering) in the Wyoming portion of the NERB.

Use	Annual withdrawal (ac-ft/yr)	Annual consumptive use (ac-ft/yr)	Percent consumptive use	Estimation method/data sources/notes
SEO permitted irrigation wells [a]	252,000	no estimate	no estimate	SEO permitted yields for irrigation wells through 10/7/15 (See table 8-6)
	157,000	no estimate	no estimate	SEO permitted yields for likely existing irrigation wells through 10/7/2015 (See table 8-6)
SEO permitted livestock wells [a]	176,000	no estimate	no estimate	Total permitted yield through 10/7/2015 (See table 8-6)
	135,000	no estimate	no estimate	Permitted yield for likely existing stock wells through 10/7/2015 (See table 8-6)
Agricultural uses [b, c]	7,940 livestock	7,940	100.0%	Irrigation and livestock use estimates are aggregated as agricultural uses. Mean annual crop consumptive use of groundwater for 1971–1998 in NERB is 80% of withdrawals Stock use considered 100% consumptive
	15,800 irrigation	12,600	79.7%	

[a] Wyoming State Engineer's Office, 2017

[b] RESPEC, 2019a, b

[c] C. McCutcheon, written commun., 2017

Table 8-1b. Groundwater withdrawal and consumptive use estimates for municipal and domestic use wells in the Wyoming portion of the NERB.

Use	Annual withdrawal (ac-ft/yr)	Annual consumptive use (ac-ft/yr)	Percent consumptive use	Estimation method/notes
Permitted municipal and domestic wells [a]	185,000	no estimate	no estimate	Total permitted yield through 10/7/2015 (table 8-6)
	129,000	no estimate	no estimate	Permitted yield for likely existing wells through 10/7/2015 (table 8-6)
Municipal/community groundwater use [b]	9,590	5,260	55%	Consumptive municipal water use calculated by subtracting 4,323 ac-ft of wastewater returns from annual withdrawals
Rural domestic use [b]	3,350	3,350	100%	Rural domestic use assumed to be 100% consumptive
Total	**12,940**	**8,610**	66.5%	Combined municipal and rural domestic use

[a] Wyoming State Engineer's Office, 2018

[b] RESPEC, 2019a, b

Table 8-1c. Groundwater withdrawal and consumptive use estimates for industrial use wells in the Wyoming portion of the NERB.

Use	Annual withdrawal (ac-ft/yr)	Annual consumptive use (ac-ft/yr)	Estimation method/notes
Permitted non-CBNG industrial wells [a]	108,000	no estimate	Total permitted yield through 10/7/2015 (See table 8-6)
	31,800	no estimate	Total permitted yield for likely existing wells through 10/7/2015 (See table 8-6)
Electrical energy generation, refineries, other industry [b]	5,100	5,100	Electrical power plants, Newcastle refinery, misc. industry
Coalbed natural gas produced water [c]	61,500	61,500	CBNG production only Assumed to be 100% consumptive
Oil and gas produced water [c]	52,500	52,500	Includes no CBNG production Assumed to be 100% consumptive
Disposal well volumes [c]	-------	-3,500	Returned to groundwater storage
Injection well volumes [c]	-------	-28,200	Returned to groundwater storage
Estimated water use for coal mines [d]	33,100	33,100	Water volumes based on short tons of coal produced in the PRB multiplied by use coefficients Assumed to be 100% consumptive
Total	**152,200**	**120,500**	

[a] Wyoming State Engineer's Office, 2018

[b] HKM, 2002a, b; RESPEC, 2019a, b

[c] Wyoming Oil and Gas Conservation Commission, 2018

[d] Lovelace, 2009; USEIA, 2018

Table 8-1d. Permitted annual groundwater withdrawal rates for SEO monitor, multi-use, and other wells in the Wyoming portion of the NERB.

SEO permitted use	Annual withdrawal [a] (ac-ft/yr)	Annual consumptive use (ac-ft/yr)	Estimation method/notes (See table 8-6)
Permitted monitor wells	957	no estimate	Total permitted yield through 10/7/2015
	255	no estimate	Permitted yield for likely existing wells through 10/7/2015
Permitted "other wells"	662,000	no estimate	Total permitted yield through 10/7/2015
	123,000	no estimate	Permitted yield for likely existing wells through 10/7/2015
Permitted "multi-use wells"	1,620,000	no estimate	Total permitted yield through 10/7/2015
	921,000	no estimate	Permitted yield for likely existing wells through 10/7/2015

[a] Wyoming State Engineer's Office (2018)

Table 8-1e. Total groundwater withdrawal and consumptive use estimates for all uses in the NERB.

Use	Annual withdrawal (ac-ft/yr)	Annual consumptive use (ac-ft/yr)	Percent consumptive use	Estimation method/notes
Total permitted yield Wyoming	2,120,000	no estimate	no estimate	Permitted yield for likely existing wells through 10/7/2015 (See table 8-6)
	1,950,000	no estimate	no estimate	Permitted yield for non-CBM likely existing wells through 10/7/2015 (See table 8-6)
Total permitted and likely drilled yield Wyoming, Montana, South Dakota, and Nebraska [a,b,c,d]	2,120,000	no estimate	no estimate	1,362 WSEO permits as of 10/7/2015 262 MDNRC permits as of 04/03/15 77 SDDENR permits as of 03/09/15 1 NDNR permit as of 11/03/15 (See tables 8-6, 8-7, 8-8)
Estimated withdrawals and consumptive uses from Wyoming agricultural, municipal, domestic and industrial wells	189,000	150,000	79.4%	Totals of estimates from Tables 8-1a, 8-1b, and 8-1c

[a] Wyoming State Engineer's Office (2018)

[b] Montana Department of Natural Resources and Conservation (MDNRC, 2017)

[c] South Dakota Department of Environment and Natural Resources (SDDENR, 2017)

[d] Nebraska Department of Natural Resources (NDNR, 2017)

8.3 BASIN-WIDE WATER BALANCE

Tables 8-2a and 8-2b contain mass balance water budget calculations for the Wyoming portion of the NERB. The water balance analysis provides an estimate of basin-wide evapotranspiration. In the process, streamflow, consumptive-use, and recharge data from this and other chapters in this report are compiled into one table (table 8-2a). Armed with these estimates, first-order approximations can be made of the proportions of precipitation destined for recharge, evapotranspiration, surface water outflows, and consumptive uses from water resource development.

The analysis contained in table 8-2a is adapted from the general water budget equation (Fetter, 2001):

Evapotranspiration = (precipitation + surface inflow + imported water + groundwater inflow) – (surface water outflow + groundwater outflow + reservoir evaporation + exported water + recharge) ± changes in surface water storage ± changes in groundwater storage

The assumptions used in this water balance are:

- Water is neither imported into nor exported from the NERB
- Basin groundwater inflows plus outflows equal zero
- The water budget mass balance model examines annual fluxes of water resources in the NERB. The assumption that long-term changes in groundwater storage equal zero, used in previous groundwater memoranda (Taucher and others, 2013; Taboga and others, 2014a, b), cannot be applied because large volumes of groundwater are coproduced with oil, gas, and coal annually in the NERB (see chap. 10 of this report). A complete listing of groundwater depletions is shown in table 8-2c.

8.3.1 Precipitation

Precipitation is the ultimate source of groundwater recharge. Average annual precipitation volume in the NERB for the 30-year period of record (POR) from 1981 to 2010 was calculated using GIS software and PRISM data (http://prism.oregonstate.edu/, fig. 3-3) at 18,800,000 ac-ft.

Table 8-2a. NERB water resources mass balance.

Water balance parameters [a]		Average annual volume (ac-ft)
Precipitation (1981–2010 - figure 3-3) [b]		18,800,000
Total surface water inflows [c]	+	3,100
Total surface water outflows [c]	-	891,000
Groundwater discharged to the surface from municipal/domestic, livestock, and industrial uses[d]	+	137,000
Evaporation from reservoirs: [e]	-	47,700
Total estimated NERB recharge [f]	-	433,000
Basinwide evapotranspiration	=	**17,568,000**
Comparative estimates (ac-ft)		
Estimated evapotranspiration in the NERB from the USGS climate and land-cover data regression [g]		*17,089,000*
Estimated evapotranspiration in the NERB from the WSGS climate and land-cover data regression [h]		*17,449,000*

[a] Fetter , C.W., 2001

[b] PRISM Climate Group, 2012

[c] USGS, 2018

[d] Tables 8-1a, 8-1b, 8-1c

[e] RESPEC, 2019a, b

[f] Table 6-3

[g] Sanford and Selnick, 2013

[h] Taboga and Stafford, 2016

Table 8-2b. Water balance parameter volumes as percent of precipitation in the Wyoming portion of the NERB.

Water balance parameters[a]	Percent of precipitation [b]
Net stream outflows[c]	4.7%
Evaporation from reservoirs[d]	0.2%
Surface water and groundwater depletions from municipal/domestic, livestock, and industrial uses[d]	0.3%
Total estimated NERB recharge (table 6-3)	2.3%
Basinwide evapotranspiration	93.4%
Total	**100.9%**

[a] Fetter , C.W., 2001

[b] PRISM Climate Group, 2012

[c] USGS, 2018

[d] RESPEC, 2019a, b

8.3.2 Surface water inflows and outflows

Average annual stream inflow and outflow data for the Wyoming portion of the basin were obtained from the USGS (http://water.usgs.gov/). USGS streamflow gaging station 06429500 at Buckhorn, Wyoming, monitors inflows from Cold Spring Creek entering Wyoming from South Dakota. Annual outflow data were recovered from USGS stream gaging stations sited on effluent reaches of the Little Bighorn, Tongue, Powder, Little Powder, Little Missouri, Belle Fourche, Upper Niobrara, and Cheyenne rivers, and Redwater Creek.

8.3.3 Groundwater discharged to surface

Annual water production volumes for traditional oil and gas (TOG), coalbed methane (CBM), and injection/disposal wells were obtained from operator-supplied data as reported to the WOGCC (2018). Groundwater production volumes associated with coal mining were calculated by multiplying annual coal production (U.S. Energy Information Administration, 2018) by groundwater production rates per short ton of coal mined (Lovelace, 2009). The volume of produced groundwater discharged to the surface was calculated as mean annual groundwater produced from oil, gas, and coal development minus mean annual produced water volumes pumped into injection and disposal wells.

Groundwater depletions from municipal/domestic and livestock uses were obtained from the 2019 Powder/Tongue and Northeast basins water plans (RESPEC, 2019a, b). Irrigation uses were not considered because 99.9 percent of irrigation water is lost to evapotranspiration and return flows (Colorado State University, 2013), and the USGS (Sanford and Selnick, 2013) and WSGS (Taboga and Stafford, 2016) models calculate cropland-specific evapotranspiration rates.

8.3.4 Evaporation from reservoirs

The 2019 Powder/Tongue and Northeast basins water plans (RESPEC, 2019a, b) provided reservoir evaporation data.

8.3.5 Total estimated NERB recharge

The recharge value shown is the "best total recharge" estimate for sedimentary aquifers calculated in tables 6-2 and 6-3 from the recharge fraction data in Taboga and Stafford (2016) and PRISM (2013) precipitation data for the 1981–2010 POR.

8.3.6 Estimated basin-wide evapotranspiration

The water balance model adapted from Fetter (2001) and presented in table 8-2a places basin-wide evapotranspiration at 17,600,000 ac-ft per year. For comparison, estimates of actual evapotranspiration in the NERB are shown at the bottom of table 8-2a. These estimates were obtained using GIS based regression models developed by the USGS (Sanford and Selnick, 2013) and the WSGS (Taboga and Stafford, 2016) from environmental data. The results of the two regression models agree closely with the evapotranspiration calculated in the water balance.

8.4 MAGNITUDE, ORIGIN, AND FATE OF WATER RESOURCES IN THE NERB

Table 8-2b shows that more than 93 percent of precipitation is lost to evapotranspiration in the NERB, about 2 percent recharges the basin's aquifers, and nearly 5 percent leaves as stream outflow. Evaporation from reservoirs constitutes about 0.2 percent of total basin precipitation. Combined surface water and groundwater depletions from municipal/domestic, livestock, and industrial uses comprise 0.3 percent of precipitation. The total percentage exceeds 100 percent of precipitation because groundwater contributions to each parameter are not considered.

Table 8-2c summarizes various average annual (2002-2016) groundwater demand estimates from tables 8-1a through 8-1c as percentages of estimated recharge. Aggregated municipal and domestic consumptive uses constitute about 2 percent of recharge. Estimated total annual demands for all uses (156,700 ac-ft; table 8-1e) constitute about 36 percent of annual average recharge. Average annual industrial demand (120,000 ac-ft) represents almost 28 percent of recharge; however, recent annual industrial demand has decreased substantially (e.g. 76,500 ac-ft in 2016) as energy production declined in the Powder River Basin (WOGCC, 2018). Chapter 10 of this report examines groundwater production by the energy industry in detail.

Estimated recharge (table 8-2c) exceeds average annual withdrawals of groundwater. Estimates of total average annual groundwater use could be substantially higher and the estimates of recharge substantially lower without significantly changing these simple, comparative results.

Table 8-2d evaluates future groundwater requirements relative to recharge. The 2019 Powder/Tongue and Northeast basins water plans (RESPEC, 2019a, b) provide use factor-based projections of total combined annual withdrawals and consumptive uses for agricultural, municipal/rural domestic, recreational, and industrial uses in 2045. The analyses examines normal and maximum water demand for low-, moderate-, and high-economic-growth scenarios. Projected future annual groundwater requirements for the 25-year timeframe are determined as percentages of annual recharge estimated in chapter 6. These estimates apparently do not consider demands from the oil, gas, and coal industries, and, any estimates for the energy sector are likely to be speculative, given the rapidly changing global energy market.

Overall, groundwater consumptive uses projected for 2045 range from 9.7 percent of recharge for the low-growth scenario to 12.9 percent for the high-growth scenario. Estimated recharge volumes are likely adequate to meet not only current withdrawals (table 8-2c) but future groundwater demands as well. The potential for overutilization is location specific, both hydrologically and legally, and must be evaluated during the planning stage of any development project. Evaluating potential groundwater resources of the NERB outside of existing environmental regulations and legal restrictions is beyond the scope of this study.

Table 8-2c. Summary of groundwater use statistics as percentage of recharge in the Wyoming portion of the NERB.

Groundwater-use statistics	Annual volume (ac-ft)	Percentage of calculated recharge
Estimated recharge (ac-ft) to sedimentary aquifers[a]	433,000	-----
Average annual groundwater consumptive uses		
Agricutural uses (irrigation and stock watering)[b]	23,700	5.5%
Municipal and domestic[b]	13,000	3.0%
Industrial[b]	120,000	27.7%
Total	**156,700**	**36.2%**

[a]Table 6-3

[b]Tables 8-1a-d

Table 8-2d. Summary of future groundwater requirements as percentages of recharge.

Economic scenario	Low growth	Mid growth	High growth
Groundwater demand 2045 consumptive use (ac-ft)[a]	41,987	44,628	55,992
Percentage of estimated recharge	9.7%	10.3%	12.9%

[a] RESPEC, 2019a, b

The following sections discuss the uses that account for nearly all estimated groundwater withdrawals in the 2019 Powder/Tongue and Northeast basins water plans (RESPEC, 2019a, b) and the 2007 Statewide Framework Water Plan (WWC Engineering and others, 2007). Tables 8-6 through 8-8 show the number of groundwater permits by use for the portions of Wyoming, Montana, South Dakota, and Nebraska, respectively. The "other" category includes miscellaneous wells.

8.4.1 Agricultural uses (irrigation, livestock watering, and dairy)

Irrigation and livestock uses are aggregated as agricultural uses in this report. Previous basin water plans do not present direct measurements of groundwater volumes used for irrigation. Instead, the previous plans estimate use based on actual crop-specific consumptive uses delimited/defined in Pochop and others (1992) and applied to crop-distribution data obtained from the agricultural industry in the Powder/Tongue and Northeast basins. HKM (2002a, b — Tab D in both reports) estimated actual surface water and groundwater depletions (consumptive uses) for irrigation during wet, normal, and dry conditions.

In the NERB, most irrigation wells are in the High Plains aquifer system of the Niobrara River Basin and along the alluvium of the Tongue River (fig. 8-1). Irrigation uses are largely consumptive due to the proportion of water lost to evapotranspiration. RESPEC provided the irrigation use estimates shown in table 8-1a (RESPEC, 2019a, b). Within the NERB, the SEO has issued 319 permits solely for irrigation use. Total agricultural use permits and permitted yields are shown in tables 8-6 through 8-9. The USGS shows localized groundwater level declines of less than 50 ft in the High Plains Aquifer around Lusk and in northeastern Goshen County (McGuire, 2017).

Livestock wells are widely distributed throughout the NERB (fig. 8-2). Withdrawals and consumptive uses for livestock watering (table 8-1b) were calculated using seasonally adjusted daily water requirements for beef cattle, dairy cows, horses, sheep, goats, and pigs (C. McCutcheon, written commun., 2017). It was assumed that all livestock water use is consumptive. In the NERB, the number of permits issued solely for stock watering (tables 8-6 through 8-9) are 10,714 in Wyoming, 32 in Montana, 8 in South Dakota, and 1 in Nebraska (tables 8-6 through 8-9).

8.4.2 Municipal and rural domestic water systems

The 2019 Powder/Tongue and Northeast basins water plans (RESPEC, 2019a, b) provide municipal and rural domestic water systems data (table 8-1b). Municipal groundwater use (9,180 ac-ft/year) calculated by RESPEC shows close agreement with total annual water-use numbers (9,140 ac-ft/year) reported by public water system managers to WWDC and SEO (WWDC, 2016; Water Guy, LLC, 2017).

As of October 7, 2015, the SEO issued 109 permits for exclusive municipal use and 6,539 domestic-use permits in the NERB (table 8-6). Montana (table 8-7) and South Dakota have issued 23 and 46 domestic-use permits, respectively (table 8-8). In addition to the municipal-use permits, some of the wells that supply water to the basin's smaller communities in Wyoming (table 8-12) are permitted as multiple use or miscellaneous wells (fig. 8-7).

8.4.3 Industrial uses

Groundwater is the primary source for industrial uses in the NERB (RESPEC, 2019a, b; Lovelace, 2009; HKM, 2002a, b), due in large part to oil, gas, and coal development. The market forces and extractive technologies that drive the pace of energy resource development (and the industry's requirements for groundwater) vary widely over time. Residents of the NERB are all too familiar with the area's cycle of "boom and bust." Chapter 10 of this report discusses the magnitude and variability of groundwater production associated with energy development during 2002–2018.

Consumptive losses for oil, gas and coal production were assumed to constitute 100 percent of groundwater withdrawals minus the volumes returned to groundwater storage by injection and disposal wells. In fact, an undetermined fraction of groundwater withdrawn during

energy development infiltrates into shallow aquifers from unlined produced water storage pits and streambeds where surface discharge is permitted. The volume of produced water used consumptively during energy development has been a controversial issue in the NERB for decades.

Not all industrial uses of groundwater are ultimately extractive. Some groundwater co-produced during oil and gas development is disposed by reinjection into geologic units. Water injection into existing hydrocarbon reservoirs can extend and enhance oil production. Table 10-1 shows the annual volumes of produced water injected into wells sited in the NERB during 2002–2016; injection data was not available for 2017 and 2018 at the time of writing. Further information about enhanced oil recovery is available at the Schlumberger website, http://www.slb.com/services/technical_challenges/enhanced_oil_recovery.aspx.

Permitted yields for SEO industrial permits as well as average annual volumes of produced water and injected water for 2002–2016 are provided in table 8-1c. Figure 8-5 shows the locations of SEO permitted industrial use wells. Although CBM wells are not shown, some industrial wells in figure 8-5 are permitted for use in coalmines or building aggregate mines. Figure 10-1 shows the location of oil and natural gas wells, and coal mines where groundwater is produced in association with energy development.

8.5 INFORMATION FROM HYDROGEOLOGIC UNIT STUDIES

In addition to the withdrawal and consumptive-use data compiled from numerous sources, aquifer-specific groundwater-use information was compiled from a variety of sources for the chapter 7 discussion of hydrogeologic units in the NERB. Chapter 7 summarizes the physical, hydrogeologic, and chemical characteristics of the principal hydrogeologic units in the NERB, including the known dynamics of recharge, discharge, and groundwater circulation.

Appendix B provides a chronological summary of the locations, aquifers, focus, results, and status of groundwater development studies in the NERB sponsored by the WWDC since 1973. Many of these studies were used to compile the information presented in chapter 7.

8.6 GROUNDWATER PERMIT INFORMATION

Groundwater development proceeds primarily by installing water supply wells and, to a lesser degree, by developing natural springs. Permits allowing the appropriation of groundwater are issued and administered by the SEO, the Montana Department of Natural Resources and Conservation (MDNRC), the South Dakota Department of Environment and Natural Resources (SDDENR), and the Nebraska Department of Natural Resources (NDNR). For this study, the WSGS acquired groundwater permit data from all of these agencies. The SEO provided information for more than 66,000 groundwater permits through October 7, 2015 (table 8-6). Groundwater permit data is also listed for Montana (table 8-7), South Dakota (table 8-8), and Nebraska (table 8-9). Additional information about the groundwater permit databases is given in appendix C. Information for specific Wyoming groundwater permits can be accessed through the SEO online water rights database, http://seo.state.wy.us/wrdb/PS_WellLocation.aspx. The database is easy to use, and specific information can be queried using various search parameters (e.g., permit number, location, applicant, use).

Information on specific groundwater permits from the out-of-state agencies can be accessed online:

http://dnrc.mt.gov/divisions/water/water-rights for the MDNRC

https://denr.sd.gov/des/wr/dbwrsearch.aspx for the SDDENR

http://dnr.ne.gov/gwr/groundwaterwelldata for the NDNR

In this study, permits to appropriate groundwater in the NERB are mapped by SEO class-of-use (figs. 8-1 through 8-7). Additional groundwater permit data are tabulated in this chapter to summarize the number of permits by:

1. SEO permit status, depth range, and yield range (tables 8-3 through 8-5)
2. Class–of-use for Wyoming, Montana, South Dakota, and Nebraska (tables 8-6 through 8-9)
3. SEO municipal use, including producing hydrogeologic unit (tables 8-10 through 8-11)
4. Wyoming Department of Environmental Quality (WDEQ) Source Water Assessment Program (SWAP; table 8-12)

8.6.1 Groundwater permits by permit status

Table 8-3 presents the number of groundwater permits issued by the SEO under five permit-status categories. Table 8-3 does not include permits from Montana, South Dakota, or Nebraska. In Wyoming, the status categories are:

1. Fully Adjudicated—the well has been drilled and inspected, and a certificate of appropriation issued
2. Complete—SEO has received a notice of completion of the well
3. Unadjudicated—the well has not yet been inspected but may have been drilled
4. Incomplete—SEO has not received a notice of completion of the well
5. Undefined—a permit without a designated status. These include the following discontinued status categories:
   - Abandoned—SEO has received a notice that the well has been physically abandoned
   - Expired—the permit to appropriate groundwater has expired, generally because SEO has not received a notice that the well has been completed within the time specified in the original permit or extension(s)
   - Cancelled—the permit has been cancelled, generally by the original permit applicant

The SEO issues permits granting water rights to applicants. This does not necessarily mean that a well has been completed, and in most cases, it is not known with certainty whether a well was installed in association with a specific permit. To estimate the number of wells that have likely been completed for each use, the WSGS assumed that wells have been completed for fully adjudicated, complete, abandoned, and unadjudicated permits. In contrast, wells are likely not completed in association with incomplete and undefined permits. Table 8-3 summarizes the number of likely drilled wells for each use in the NERB. Based on these assumptions, at least 72 percent of wells permitted through 2002 are likely to have been installed (i.e., completed) compared to at least 54 percent of wells permitted after 2002.

8.6.2 Groundwater permits by depth and yield

Tables 8-4 and 8-5 show the number of SEO permits by depth range and by yield range, respectively.

Approximately 52 percent of all SEO groundwater permits for which depth data are available (table 8-4) are for wells less than 500 ft deep, and nearly 18 percent are for wells less than 100 ft deep. Almost 75 percent of SEO groundwater permits issued after 2002 were for wells more than 500 ft deep, and approximately 54 percent were for wells more than 1,000 ft deep. The incidence

Table 8-3. SEO groundwater permits in the NERB listed by permit status.

Permit status	All permits	New permits since 2002
Fully adjudicated	782	56
Complete	47,288	14,992
Unadjudicated	111	96
Incomplete	17,801	12,496
Undefined	706	207
Total permits	**66,688**	**27,847**
Probable wells drilled	*48,181–66,688 (72–100%)*	*15,144–27,847 (54–100%)*

of recent well depths greater than 500 ft is likely biased by the inclusion of CBM well permits, which constitute 68 percent of all permits issued after 2002 (table 8-6). A substantial fraction of permits (49 percent issued after 2002 and 26 percent overall) does not include well depth (table 8-4).

Of the 57,008 groundwater permits in the NERB database for which yield information is available (table 8-5), approximately 67 percent of all permits and 57 percent of wells permitted since 2002 are allowed yields of 1–25 gallons per minute (gpm). Approximately 6 percent of all permits and 7 percent of permits issued after 2002 allow yields greater than 100 gpm. Less than one-half percent of permits issued both since 2002 and in total are for yields greater than 1,000 gpm. A small portion of permits (8 percent issued after 2002 and 15 percent overall) in the SEO database do not include permitted yield.

Permitted depths and yields, and the mapped permit locations on figures 8-1 through 8-7 illustrate that most wells in the NERB are completed in Tertiary hydrogeologic units.

Table 8-4. SEO groundwater permits in the NERB listed by yield range.

Depth range (ft)	All permits		Cumulative	
	Permits	Percentage	Permits	Percentage
1–50	5,885	11.93%	5,885	11.93%
51–100	2,958	5.99%	8,843	17.92%
101–500	16,971	34.39%	25,814	52.31%
501–1000	11,460	23.22%	37,274	75.53%
> 1000	12,074	24.47%	49,348	100.00%
Total permits with depth information	49,348	--	--	--
Permits with no depth information	17,340	26.00%	66,688	--
Total permits	**66,688**	**(of total)**	**--**	**--**

Depth range (ft)	New permits since 2002		Cumulative	
	Permits	Percentage	Permits	Percentage
1–50	679	4.78%	679	4.78%
51–100	280	1.97%	959	6.75%
101–500	2,599	18.30%	3,558	25.06%
501–1000	3,007	21.18%	6,565	46.23%
> 1000	7,635	53.77%	14,200	100.00%
Total permits with depth information	14,200	--	--	--
Permits with no depth information	13,647	49.01%	27,847	--
Total permits	**27,847**	**(of total)**	**--**	**--**

Table 8-5. Wyoming SEO groundwater permits in the NERB listed by yield range.

Yield range (gpm)	All permits		Cumulative	
	Permits	Percentage	Permits	Percentage
1–25	38,147	66.92%	38,147	66.92%
26–100	15,675	27.50%	53,822	94.41%
101–500	2,642	4.63%	56,464	99.05%
501–1000	354	0.62%	56,818	99.67%
> 1000	190	0.33%	57,008	100.00%
Total permits with yield information	57,008	--	--	--
Permits with no yield information	9,680	14.52%	66,688	--
Total permits	**66,688**	**(of total)**	**--**	**--**

Yield range (gpm)	New permits since 2002		Cumulative	
	Permits	Percentage	Permits	Percentage
1–25	14,691	57.36%	14,691	57.36%
26–100	9,012	35.19%	23,703	92.54%
101–500	1,654	6.46%	25,357	99.00%
501–1000	144	0.56%	25,501	99.56%
> 1000	112	0.44%	25,613	100.00%
Total permits with yield information	25,613	--	--	--
Permits with no yield information	2,234	8.02%	27,847	--
Total permits	**27,847**	**(of total)**	**--**	**--**

8.6.3 Groundwater permits by use: tables, figures, and matrix tables

Groundwater permit information categorized by use is presented in tables 8-6 through 8-9 and figures 8-1 through 8-7, and the matrix tables contained in the figures. This information was obtained from the SEO, MDNRC, SDDENR, and NDNR. In many cases, particularly with older permits, it is not known with any certainty whether a well or spring improvement was actually installed in association with a specific permit. Furthermore, existing facilities might have been abandoned after some time and are no longer being used beneficially. Any examination of permitted uses must explain how the permit data were processed and what the data actually represent. The permit data presented in the following two sections differ between the figures and the tables.

Tables 8-6 through 8-9 show the number of groundwater permits issued in Wyoming, Montana, South Dakota, and Nebraska by permitted use, regardless of permit status (sec. 8.4.1). This means that all permits issued are listed without evaluating if a well was installed. The tables list six single primary-use categories (municipal, domestic, industrial, irrigation, stock, and monitoring), an "other" category for all other single uses, and a "multi-use" category for permits that list more than one use (approximately 7 percent of all groundwater permits in the NERB are for multiple uses). The "other" category includes permits issued for "miscellaneous uses" and for minor uses such as test wells. The number of permits given for a single use, such as the 109 municipal-use permits in table 8-6, does not include "multi-use" or "other" permits, which may also allow municipal withdrawals. Additionally, tables 8-6 through 8-9 provide total permitted yields calculated by summation of all

Table 8-6. SEO groundwater permits in the NERB listed by intended use. Coalbed methane wells include any well that lists a CBM code including multi-use wells; multi-use wells shown do not include any well with a CBM code.

Well type	WSEO code	Total number of permits	New since 2002	Total permitted yield (gpm)	Total likely yield* (gpm)
Municipal	MUN	109	26	28,492	12,162
Domestic	DOM	6,539	1,737	86,212	68,006
Industrial	IND	629	44	108,100	31,783
Irrigation	IRR	319	48	156,635	97,393
Stock	STK	10,714	2,167	109,026	83,694
Monitor	MON	7,930	1,506	595	159
Other	MIS, blank	3,387	1,939	411,102	76,707
Coalbed methane	CBM	32,248	18,880	1,459,218	840,852
Multi-use	various	4,813	1,500	312,726	105,611
Total		**66,688**	**27,847**	**2,672,105**	**1,316,366**

*Includes only wells that are fully adjudicated, complete, and unadjudicated.

Table 8-7. Montana DNRC groundwater permits in the NERB listed by intended use.

Well type	Total number of permits	New since 2002	Total permitted yield (gpm)
Municipal	0	0	0
Domestic	23	2	211
Industrial	0	0	0
Irrigation	0	0	0
Stock	32	3	340
Monitoring	109	31	924
Other	21	1	0
Coalbed methane	1	0	0
Unknown	76	1	113
Total	**262**	**38**	**1,588**

Table 8-8. South Dakota DENR groundwater permits in the NERB listed by intended use. South Dakota data does not include yield information.

Well type	Total number of permits	New since 2002	Total permitted yield (gpm)
Municipal	0	0	------
Domestic	46	20	------
Industrial	1	0	------
Irrigation	0	0	------
Stock	8	0	------
Monitoring	13	0	------
Other	9	3	------
Total	**77**	**23**	**------**

Table 8-9. Nebraska DNR groundwater permits in the NERB listed by intended use.

Well type	Total number of permits	New since 2002	Total permitted yield (gpm)
Municipal	0	0	0
Domestic	0	0	0
Industrial	0	0	0
Irrigation	0	0	0
Stock	1	1	300
Monitoring	0	0	0
Other	0	0	0
Multi-use	0	0	0
Total	**1**	**1**	**300**

allowable yields and total likely yields determined by analysis of permit status.

Figures 8-1 through 8-7 show the number of "likely drilled wells," as determined by analysis of permit status (sec. 8.4.1) for each of the six primary-use categories and miscellaneous wells. This includes permits where one use is listed. For example, the number of municipal wells is determined by counting single-use "municipal" wells and any "multi-use" permits that include "municipal" as one of the permitted uses. Thus, multi-use wells are counted several times, once for each listed use.

Matrix tables contained in each of the figures present the number of all permits issued for each use combined in all states (fig. 3-1) regardless of permit status. This includes permits that list one-use and multi-use permits, for example, "municipal" as well as "multi-use" permits that include "municipal" as one of the permitted uses would be listed as "municipal" permits.

8.6.3.1 Groundwater permits by use: Tables 8-6 through 8-11

Tables 8-6 through 8-9 show that most groundwater permits in the NERB are for coalbed methane development, followed by livestock (stock) wells, and wells designated for monitoring.

Additionally, total likely yields (permitted yields from wells that are likely to be completed) constitute about 50 percent of the total permitted yields. A comparison of total likely yields to total permitted yields for each use suggests that a higher proportion of domestic (79 percent) and stock (77 percent) wells were completed and used beneficially than other types of wells.

Tables 8-10 and 8-11 are expanded summary tables for SEO permits that include municipal uses, and table 8-12 summarizes information on SWAP wells and springs that are used for both municipal and non-community public water supply. A brief discussion of the SWAP is provided in section 8.4.3.7. The SWAP provides some information beyond what is available in the SEO groundwater permits data.

8.6.3.2 Groundwater permit location maps and matrix tables, by use

Seven maps (figs. 8-1 through 8-7) were prepared for this study to illustrate the geospatial distribution of groundwater permits by use in the NERB. Only permits for wells that were likely to have been drilled (including abandoned wells) are included on figures 8-1 through 8-7. Groundwater permits in figures 8-2 through 8-7 are mapped by their date of issue: permits issued in 2002 or earlier are shown in blue, permits issued after 2002 are shown in red. Figures have been provided for the following permitted uses:

- Irrigation (fig. 8-1)
- Livestock (fig. 8-2)
- Municipal (fig. 8-3)
- Domestic (fig. 8-4)
- Industrial-use wells (fig. 8-5)
- Monitoring (fig. 8-6)
- Miscellaneous-use and other wells (fig. 8-7)
- USGS spring locations are shown on figure 7-2

In order to evaluate "recent" groundwater development that occurred since the previous water basin plans (HKM Engineering, 2002a, b), figures 8-1 through 8-7 differentiate groundwater permits issued after 2002. As with earlier groundwater rights, most permits issued after 2002 continue to target Tertiary hydrogeologic units.

Matrix tables that correlate ranges of well depths and yields for all permits issued are also provided in figures 8-1 through 8-7. Consistent with table 8-5, the depth versus yield tables show that by far the most permits issued in the NERB are for 0–25 gpm across all depth ranges. In addition, the insert tables show that fewer wells are permitted for increasingly higher yields across all depth ranges. Because only permits for wells that were likely to have been drilled (status of fully adjudicated, complete, unadjudicated, and abandoned) are shown on figures 8-1 through 8-7, the number of permits on the insert matrix tables does not match the number of permits depicted on the maps.

Figure 5-11 shows the distribution of SWAP wells used for municipal and other public supply. Because public supply is one of the most important uses of groundwater resources, a more comprehensive compilation was performed for the SEO permit data and related WDEQ SWAP data on municipal and non-community public groundwater supplies.

8.6.3.3 Irrigation-use permits

Tables 8-6 through 8-9 list 319 groundwater permits for irrigation use (IRR) in the NERB, all located in Wyoming. Figure 8-1 shows the distribution of likely drilled irrigation wells. Most irrigation wells are located in the High Plains aquifer system of the Upper Niobrara River Basin. The depth versus yield tables in figure 8-1 show that most irrigation well permits that list depth were permitted for depths of 100–499 ft and include a wide range of yields. Table 8-6 and the matrix tables in figure 8-1 illustrate that most irrigation permits in the NERB were issued before 2003.

8.6.3.4 Livestock-use permits

Tables 8-6 through 8-9 show 10,755 groundwater permits have been issued solely for livestock use (STK) in the NERB. Figure 8-2 shows the distribution of likely drilled stock wells in the NERB issued since 2002. Stock wells are sited most densely in the eastern two-thirds of the NERB and in a broad band beginning along the upper reaches of Crazy Woman Creek and extending northwest into the Tongue River Basin. Most stock wells are completed in outcrops of Tertiary and Cretaceous units. The depth versus yield tables in figure 8-2 show that the largest number of total permits and permits issued since 2002 are for depths under 500 ft and for yields less than 25 gpm.

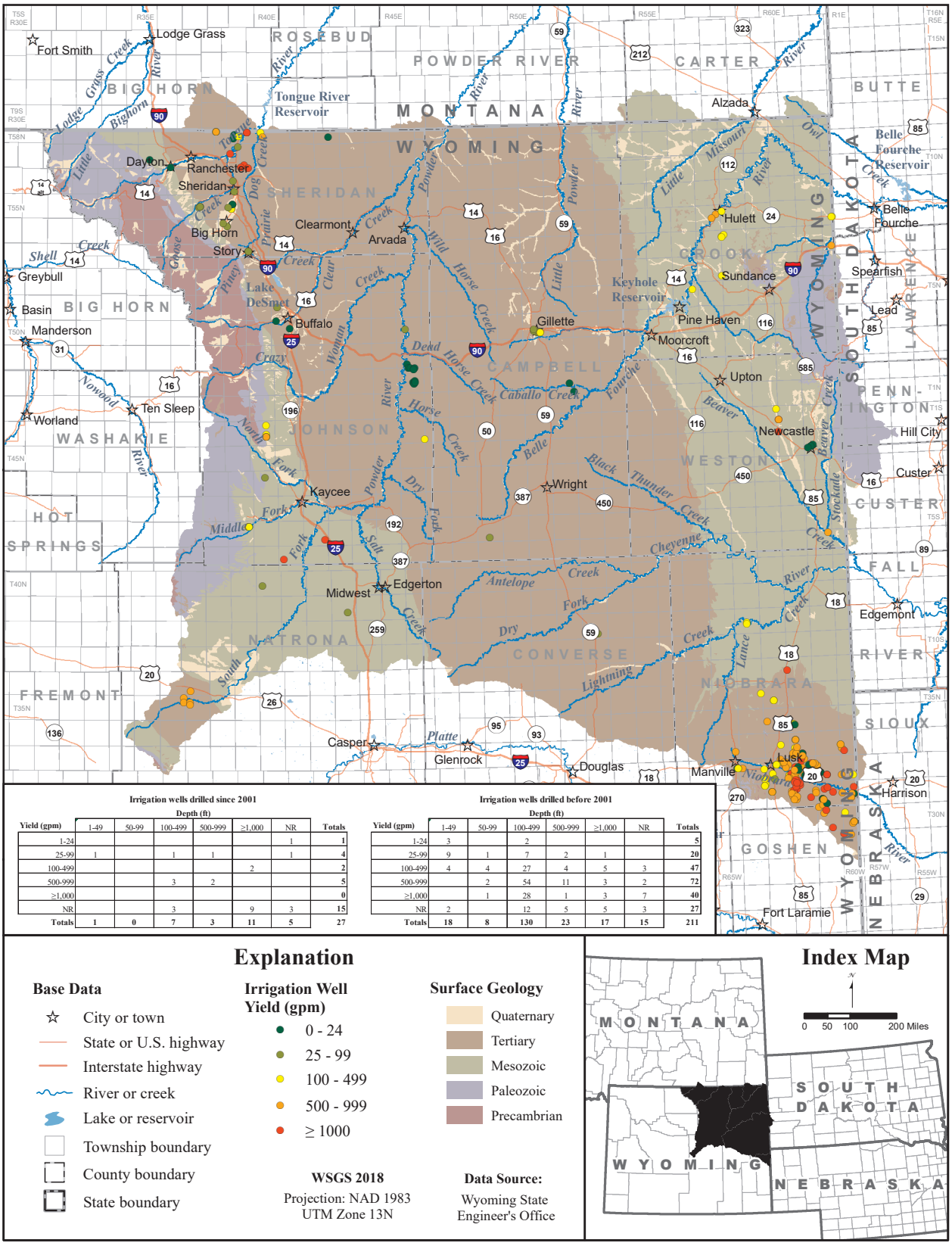


Figure 8-1. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled irrigation wells, NERB.

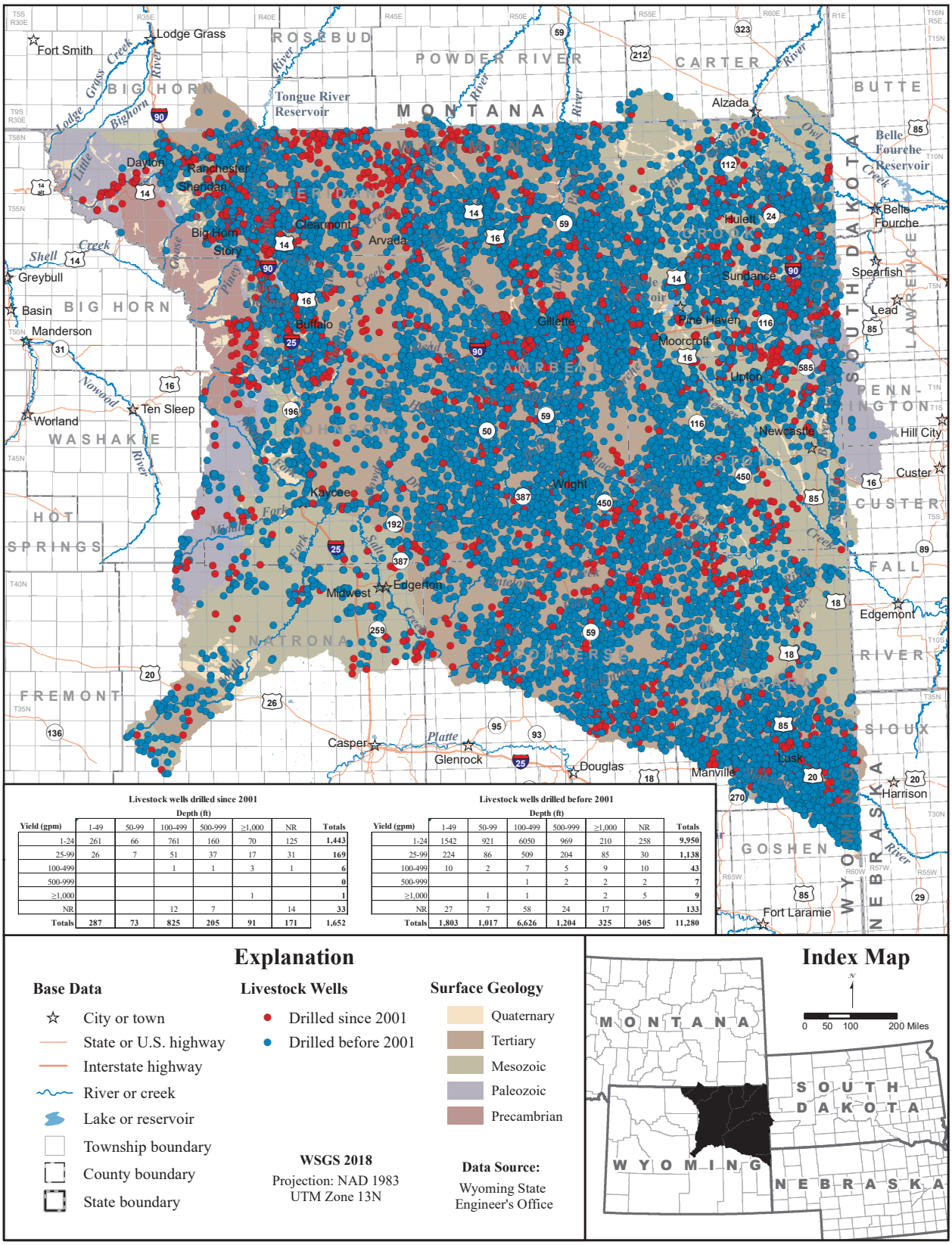


Figure 8-2. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled livestock wells, NERB.

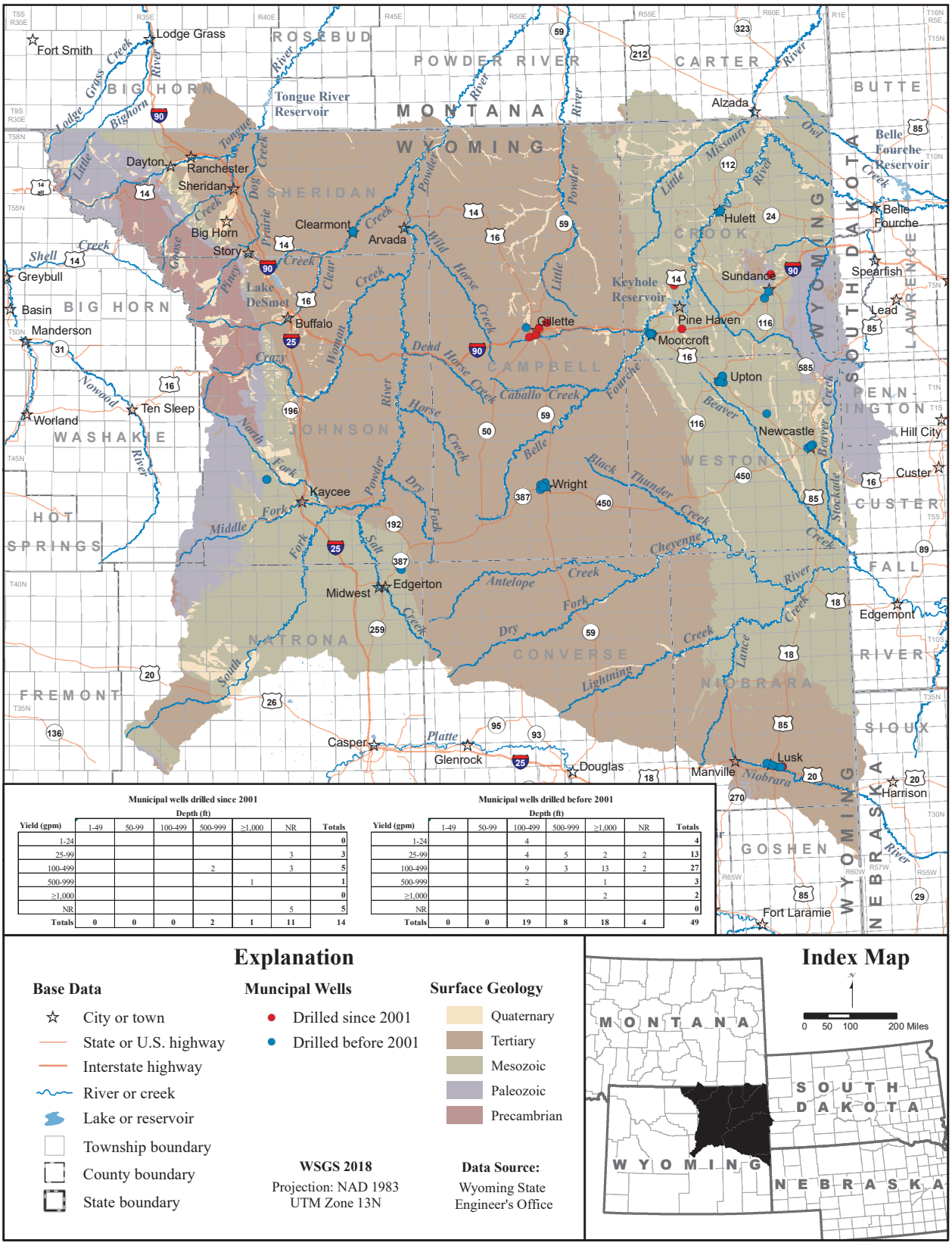
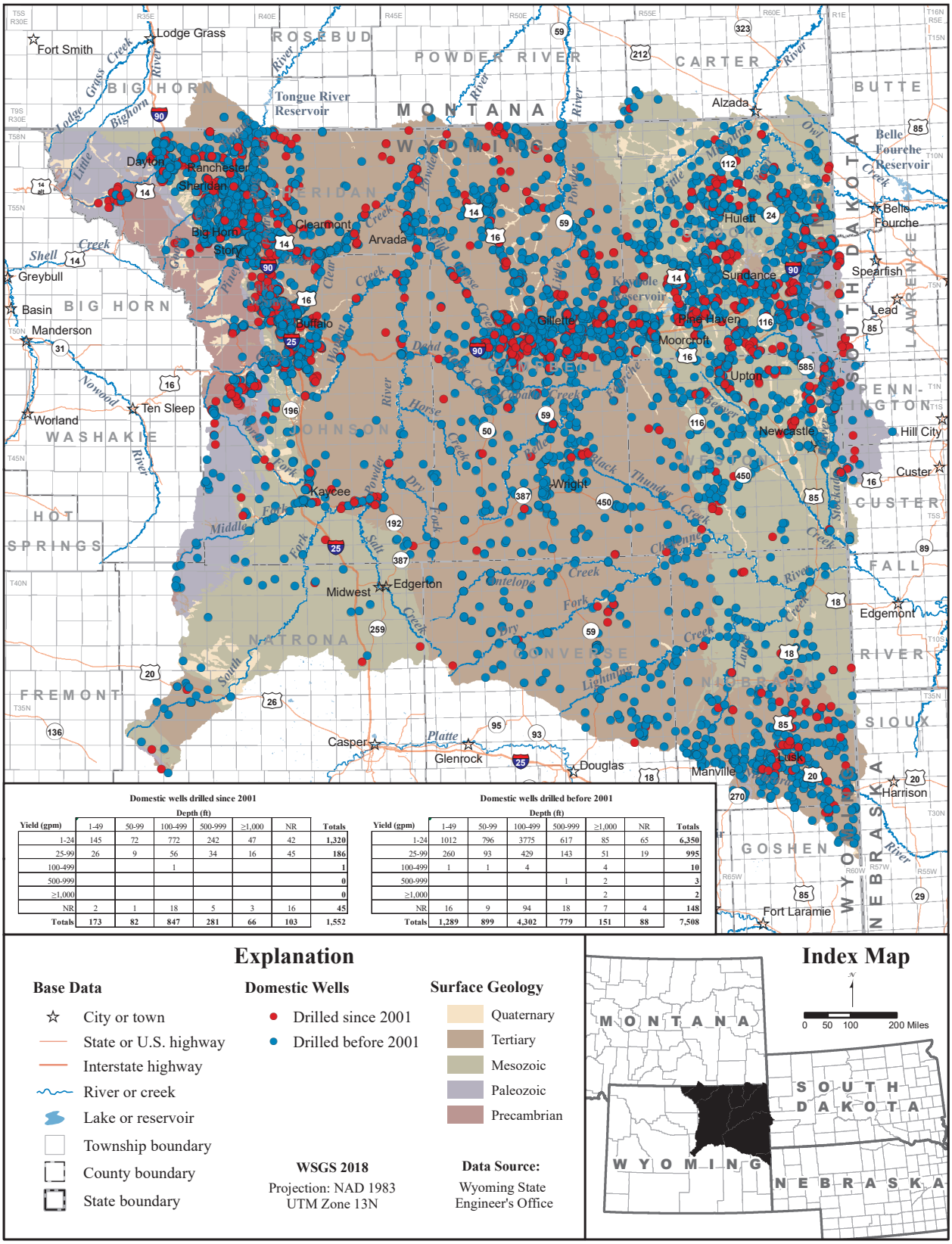


Figure 8-3. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled municipal wells, NERB.



Domestic wells drilled since 2001

Yield (gpm)	Depth (ft) 1-49	50-99	100-499	500-999	≥1,000	NR	Totals
1-24	145	72	772	242	47	42	1,320
25-99	26	9	56	34	16	45	186
100-499			1				1
500-999							0
≥1,000							0
NR	2	1	18	5	3	16	45
Totals	173	82	847	281	66	103	1,552

Domestic wells drilled before 2001

Yield (gpm)	Depth (ft) 1-49	50-99	100-499	500-999	≥1,000	NR	Totals
1-24	1012	796	3775	617	85	65	6,350
25-99	260	93	429	143	51	19	995
100-499	1	1	4		4		10
500-999				1	2		3
≥1,000					2		2
NR	16	9	94	18	7	4	148
Totals	1,289	899	4,302	779	151	88	7,508

Explanation

Base Data

- City or town
- State or U.S. highway
- Interstate highway
- River or creek
- Lake or reservoir
- Township boundary
- County boundary
- State boundary

Domestic Wells

- Drilled since 2001
- Drilled before 2001

Surface Geology

- Quaternary
- Tertiary
- Mesozoic
- Paleozoic
- Precambrian

WSGS 2018
Projection: NAD 1983
UTM Zone 13N

Data Source:
Wyoming State Engineer's Office

Index Map

Figure 8-4. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled domestic wells, NERB.

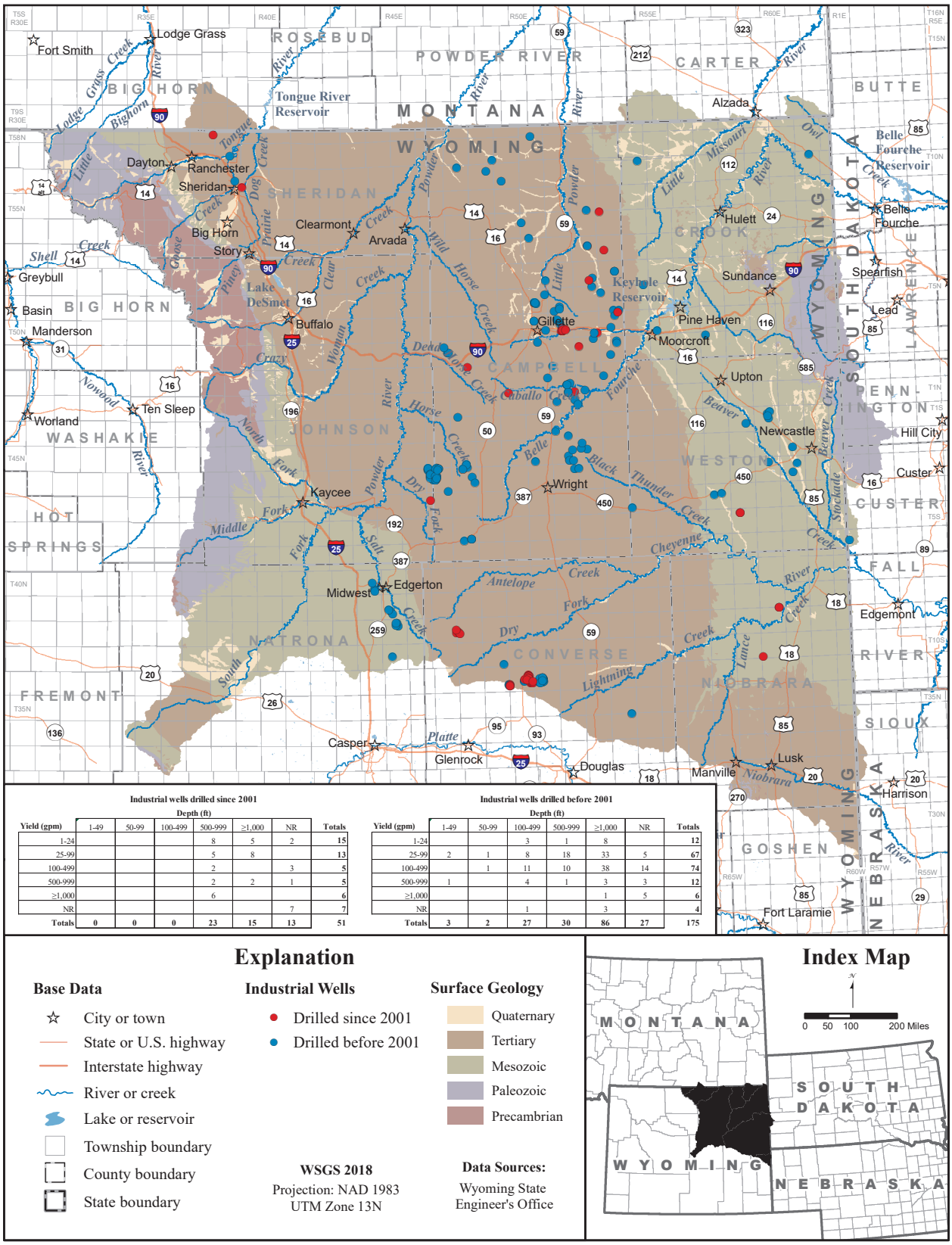


Figure 8-5. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled industrial wells, NERB.

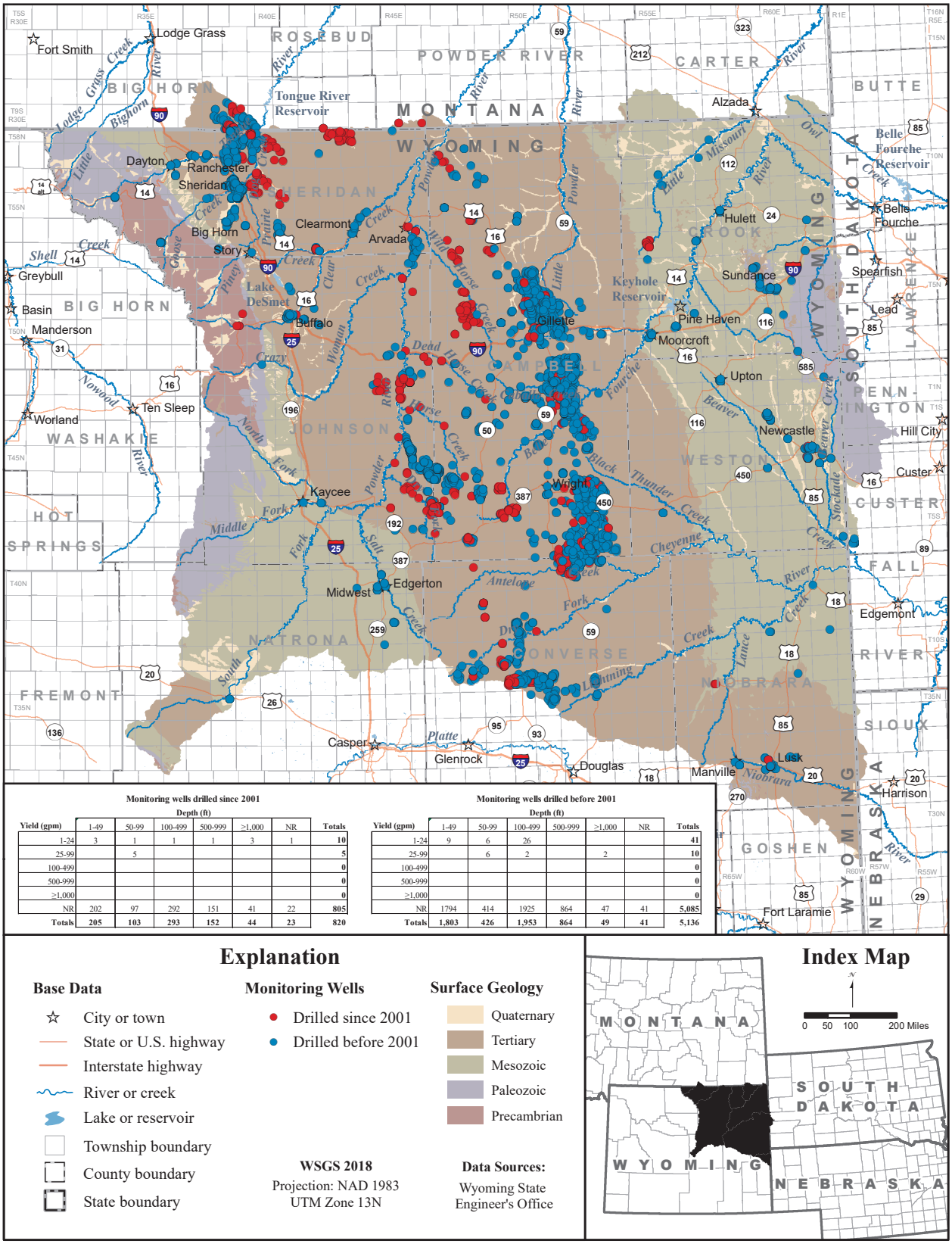


Figure 8-6. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled monitoring wells, NERB.

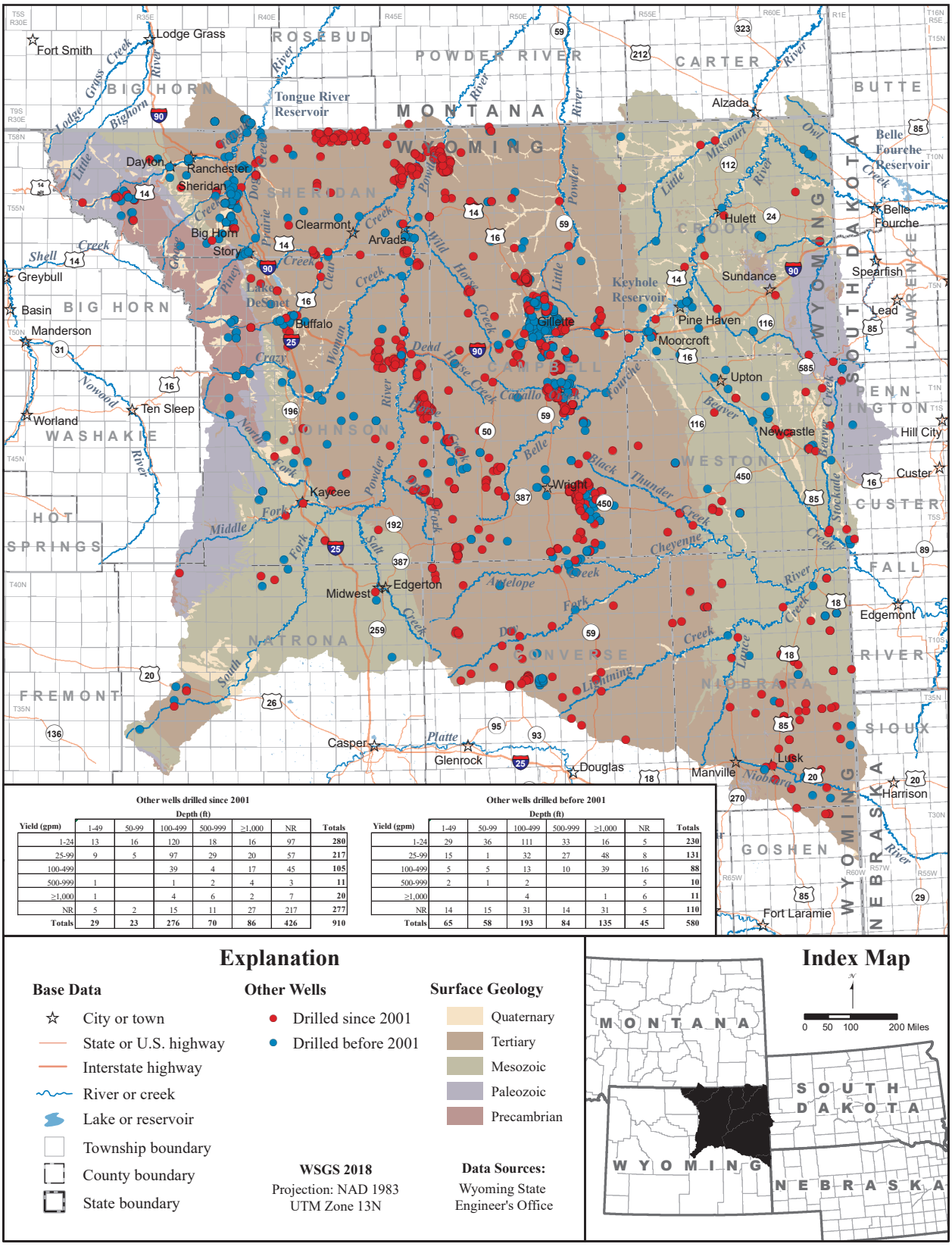


Figure 8-7. Wyoming SEO, Montana DNRC, South Dakota DENR, and Nebraska DNR permitted and drilled other wells, NERB.

8.6.3.5 Municipal-use permits

All 109 groundwater permits issued solely for municipal use (MUN) in the NERB are in Wyoming (tables 8-6 through 8-9). Figure 8-3 shows the spatial distribution of likely drilled municipal wells. Most municipal permits issued since 2002 do not contain depth data. No municipal-use permits are listed in neighboring states.

Tables 8-10 and 8-11 distinguish 109 municipal-use groundwater permits on file with the SEO by status. Table 8-10 summarizes selected information on 47 municipal-use permits that have been fully adjudicated. Table 8-10 includes available information on permitted yield, well depth, depth of the producing interval, and the producing hydrogeologic unit. Only one permit in table 8-8 is for multiple uses. Because the "fully adjudicated" permit status indicates that the well has been inspected, the information in table 8-10 is presumed to be accurate. The wells in table 8-10 produce water from alluvial and bedrock aquifers (pl. 2). Information on producing intervals was obtained from SWAP data, WWDC consultant reports, and SEO data.

Table 8-11 summarizes selected information on 78 SEO municipal well permits listed as incomplete or have no status listed. Table 8-11 includes available information on permitted yield and well depth. Eleven of the permits in table 8-11 are for multiple uses. The wells in table 8-11 produce water from alluvial and bedrock aquifers (pl. 2).

While cancelled permits may or may not be associated with a completed well, abandoned status generally refers to a previously existing well.

8.6.3.6 Domestic-use permits

Domestic water withdrawals include non-community public water systems and rural domestic users. Tables 8-6 through 8-9 show that groundwater permits for domestic use (DOM) outnumber permits for all other non-CBM uses except livestock and monitoring wells.

Figure 8-4 shows the distribution of likely drilled domestic-use permits. Most domestic wells are in rural areas outside of municipalities in Johnson, Sheridan, Campbell, Crook, Weston, and Niobrara counties. Most wells are completed in Tertiary, Cretaceous, and Paleozoic geologic units. The depth versus yield tables in figure 8-4 show that basin wide, the largest percentage of permits issued after 2002 allow well depths up to 499 ft and yields up to 25 gpm. Around 2 percent of domestic-use permits do not provide any recorded depth information.

8.6.3.7 Source Water Assessment Program (SWAP) wells and springs

The SWAP, a component of the federal Safe Drinking Water Act, is designed to help states protect public water systems (PWS) and applies to both municipal and non-community public systems. The voluntary program, administered by the WDEQ Water Quality Division (WQD), encourages the development of source-water assessments and Wellhead Protection Plans (WHP) for groundwater PWS. A source-water assessment entails determining the source-water contributing area, inventorying potential sources of contamination to the PWS, determining the susceptibility of the PWS to identified potential contaminants, and summarizing the information in a report. An important aspect of these reports relative to this study is that the producing hydrogeologic unit is commonly identified. As discussed in section 5.7.4, the individual PWS reports provide valuable information on recharge areas, resource vulnerability, and local sources of potential contaminants for specific groundwater sources. The development and implementation of SWAP and WHP assessments and plans are ongoing throughout Wyoming. Additional information is available on the WDEQ website, http://deq.wyoming.gov/wqd/source-water-wellhead/.

Table 8-12 provides SEO water right permit number, yield, producing unit, and depth data for 169 SWAP wells in the NERB. The SEO permit numbers shown can be correlated with the wells shown in tables 8-10 and 8-11. Most wells in the SWAP database produce groundwater from Tertiary, Cretaceous, and Paleozoic units (table 8-12).

Figure 5-11 shows the geospatial distribution of SWAP wells in the NERB and their relative susceptibility to potential contaminants.

8.6.3.8 Industrial use

Tables 8-6 and 8-8 list 629 Wyoming permits and 1 South Dakota permit for industrial (IND) use. Primary industrial uses in the NERB have included construction company usage, as well as aggregate and gravel mining. The SEO database does not identify specific industrial uses.

8.6.3.8.1 Energy production

Groundwater associated with oil, gas, and coal production includes "produced water" withdrawn as a byproduct of extraction from hydrocarbon reservoirs and water utilized in the production and refining of energy resources. In some cases, produced water is used in production and refining operations; in others, water for operations is obtained from surface or underground sources. Some water plans (e.g., the

Table 8-10. SEO fully adjudicated municipal well permits in the NERB.

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	Hydrogeologic unit	Multi-use	Depth of producing interval (ft)
Clearmont	CLEARMONT WATER WELL #3	P1666.0W	35	172	Fully Adjudicated			90–172
Clearmont	CLEARMONT #1	P37666.0W	30	522	Fully Adjudicated	Wasatch		492–515
Clearmont	CLEARMONT #2	P45802.0W	70	1,447	Fully Adjudicated	Ft. Union		1,286–1,320
Clearmont	ENL CLEARMONT WATER WELL #3	P71412.0W	120	172	Fully Adjudicated			143–172
Edgerton	EDGERTON #6	P44002.0W	40	0	Fully Adjudicated			2,000–2,087
Edgerton	EDGERTON WATER WELL #5	P6319.0W	35	0	Fully Adjudicated			Unknown
Hulett	HULETT ARTESIAN #2	P118.0G	150	690	Fully Adjudicated			590–690
Hulett	HULETT ARTESIAN WELL #1	P31.0C	150	620	Fully Adjudicated			600–620
Hulett	HULETT WELL #3	P56489.0W	150	772	Fully Adjudicated			696–740
Kaycee	KAYCEE WELL #1	P69394.0W	25	1,612	Fully Adjudicated			1,346–1,612
Kaycee	KAYCEE WELL #2	P72663.0W	175	2,000	Fully Adjudicated			710–1,000
Lusk	TOWN OF LUSK #1 WELL	P285.0G	350	132	Fully Adjudicated			70–130
Lusk	TOWN OF LUSK #3	P286.0G	280	151	Fully Adjudicated			70–150
Lusk	TOWN OF LUSK #4 WELL	P483.0C	285	140	Fully Adjudicated			70–140
Lusk	TOWN OF LUSK #7	P59002.0W	400	460	Fully Adjudicated			230–258
Lusk	TOWN LUSK #8	P59003.0W	800	484	Fully Adjudicated			230–270
Lusk	ENL TOWN OF LUSK #1	P76207.0W	550	132	Fully Adjudicated			70–130
Lusk	ENL TOWN OF LUSK #3	P76208.0W	220	151	Fully Adjudicated			70–150
Lusk	ENL TOWN OF LUSK #7	P76209.0W	350	460	Fully Adjudicated			230–258
Lusk	ENL TOWN OF LUSK #8	P78254.0W	100	484	Fully Adjudicated			230–270
Moorcroft	MOORCROFT #5	P33968.0W	30	485	Fully Adjudicated			310–470
Moorcroft	ENL MOORCROFT #5	P42845.0W	25	485	Fully Adjudicated			370–466
Moorcroft	MOORCROFT #6	P43549.0W	90	760	Fully Adjudicated			600–690
Moorcroft	MOORCROFT #1	P990.0W	25	500	Fully Adjudicated			200–Unknown
Moorcroft	MOORCROFT #2	P991.0W	20	400	Fully Adjudicated			200–Unknown
Moorcroft	MOORCROFT #3	P992.0W	20	385	Fully Adjudicated			175–Unknown
Moorcroft	MOORCROFT #4	P993.0W	30	485	Fully Adjudicated			135–Unknown

Table 8-10. continued

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	Hydrogeologic unit	Multi-use	Depth of producing interval (ft)
Newcastle	MUNICIPAL WELL #3	P1317.0W	200	2,872	Fully Adjudicated			2,211–Unknown
Newcastle	NEWCASTLE ARTESIAN WELL #1	P38.0G	1,400	2,638	Fully Adjudicated			2,612–2,638
Newcastle	NEWCASTLE #2 WELL	P389.0W	475	3,028	Fully Adjudicated			Unknown
Newcastle	NEWCASTLE #4	P39352.0W	500	3,245	Fully Adjudicated			2,743–2,120
Osage	OSAGE #3	P46982.0W	1,100	3,135	Fully Adjudicated		yes	2,716–3,135
Sundance	LOAFMAN WELL #1	P2520.0W	15	140	Fully Adjudicated			16–140
Sundance	LOAFMAN WELL #2	P2521.0W	15	115	Fully Adjudicated			6–115
Sundance	HARD WATER #5	P2523.0W	197	440	Fully Adjudicated			313–320
Upton	TOWN OF UPTON WELL #2	P28335.0W	205	3,162	Fully Adjudicated			2,900–3,162
Upton	TOWN OF UPTON WELL #3	P28336.0W	35	804	Fully Adjudicated			Unknown
Upton	TOWN OF UPTON WELL #4	P28337.0W	205	-1	Fully Adjudicated			Unknown
Upton	TOWN OF UPTON WELL #5	P28338.0W	35	545	Fully Adjudicated			Unknown
Upton	UPTON WELL #6	P62883.0W	200	3,310	Fully Adjudicated			2,820–3,310
Upton	ENL TOWN OF UPTON WELL #2	P63481.0W	120	3,162	Fully Adjudicated			2,900–3,162
Upton	ENL TOWN OF UPTON WELL #4	P63482.0W	170	3,193	Fully Adjudicated			2,724–3,193
Upton	UPTON WELL #7	P98208.0W	200	0	Fully Adjudicated			2,810–3,308
Wright	RJ 2	P46664.0W	250	2,660	Fully Adjudicated			Unknown
Wright	RJ 3	P46696.0W	225	2,730	Fully Adjudicated			Unknown
Wright	RJ 5	P48091.0W	400	2,700	Fully Adjudicated			1,232–2,679
Wright	RJ 4	P71834.0W	300	3,015	Fully Adjudicated			1,222–2,707
Totals			**10,802**					

Table 8-11. SEO municipal well permits listed with a status other than Fully Adjudicated in the NERB.

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	New since 2002	Multiple-use well
Buffalo	BUFFALO UNDERGROUND WATER SUPPLY #1	P1.0G	990	18	Incomplete		
Buffalo	CLEAR CREEK #2	P42.0W	790	25	Incomplete		
Buffalo	C. VANCE LUCAS WELL #1	P633.0W	25	239	Incomplete		Yes
Buffalo	FRANK E. LUCAS WELL #1	P634.0W	100	175	Incomplete		Yes
Dayton	DAYTON #1	P146036.0W	225	2,600	Incomplete		
Edgerton	EDGERTON PARSONS #1	P508.0C	10.9	130	Incomplete		
Gillette	ENL. S-17	P193939.0W	110	Unknown	Complete	Yes	
Gillette	ENL. S-27	P193941.0W	35	Unknown	Complete	Yes	
Gillette	SUNBURST #1 (DEEPENED)	P1015.0W	15	200	Incomplete		
Gillette	S-23	P101734.0W	150	2,252	Incomplete		
Gillette	S-24	P102212.0W	170	2,430	Incomplete		
Gillette	S-25	P102213.0W	125	2,469	Incomplete		
Gillette	FOX HILLS #5	P108708.0W	500	4,170	Incomplete		
Gillette	S-27	P109197.0W	150	Unknown	Incomplete		
Gillette	S-26	P109198.0W	150	2,515	Incomplete		
Gillette	GILLETTE #P-1	P1220.0W	90	500	Incomplete		
Gillette	GILLETTE # H 11	P1221.0W	80	500	Incomplete		
Gillette	M-10	P172432.0W	1,470	2,524	Incomplete		
Gillette	M-9	P172433.0W	1,470	2,523	Incomplete	Yes	
Gillette	ENL. S-20	P190124.0W	50	Unknown	Incomplete	Yes	
Gillette	ENL. S-19	P193940.0W	215	Unknown	Incomplete	Yes	
Gillette	MADISON 13	P204034.0W	1,600	Unknown	Incomplete	Yes	
Gillette	MADISON 14	P204035.0W	1,600	Unknown	Incomplete	Yes	
Gillette	MADISON 15	P204036.0W	1,600	Unknown	Incomplete	Yes	
Gillette	FOX HILLS #3	P30005.0W	340	4,436	Incomplete		Yes
Gillette	S-18	P41830.0W	250	1,522	Incomplete		

Table 8-11. continued

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	New since 2002	Multiple-use well
Gillette(cont.)							
Gillette	S-19	P41831.0W	130	Unknown	Incomplete		
Gillette	GILLETTE #H-26	P42002.0W	83	301	Incomplete		
Gillette	GILLETTE #H-27	P42003.0W	80	382	Incomplete		
Gillette	CITY OF GILLETTE S-9	P42004.0W	271	1,672	Incomplete		
Gillette	CITY OF GILLETTE S-10	P42005.0W	170	2,350	Incomplete		
Gillette	CITY OF GILLETTE S-11	P42006.0W	125	2,323	Incomplete		
Gillette	CITY OF GILLETTE S-12	P42007.0W	125	2,295	Incomplete		
Gillette	S-17	P42010.0W	220	Unknown	Incomplete		
Gillette	FOXHILLS #4	P60723.0W	550	4,350	Incomplete		
Gillette	ENL FOX HILLS #3	P66144.0W	210	4,436	Incomplete		
Gillette	ENL FOX HILLS #3	P85458.0W	950	4,436	Incomplete		Yes
Gillette	S-21	P99185.0W	150	2,250	Incomplete		
Gillette	S-22	P99186.0W	120	2,315	Incomplete		
Gillette	ENL. S-12	P190123.0W	100	Unknown	Unadjudicated	Yes	
Gillette	ENL. FOX HILLS NO. 5	P190131.0W	25	Unknown	Unadjudicated	Yes	
Gillette	S-20	P42985.0W	160	2,429	Unadjudicated		
Gillette/Moorcroft	M-1	P56867.0W	800	2,767	Incomplete		Yes
Gillette/Moorcroft	M-2	P56868.0W	800	2,614	Incomplete		Yes
Gillette/Moorcroft	M-3	P56869.0W	800	3,001	Incomplete		Yes
Gillette/Moorcroft	M-4	P56870.0W	900	2,525	Incomplete		Yes
Gillette/Moorcroft	M-5	P56871.0W	800	3,005	Incomplete		Yes
Gillette/Moorcroft	M-6	P56872.0W	800	3,005	Incomplete		Yes
Gillette/Moorcroft	M-7	P56873.0W	750	3,006	Incomplete		Yes
Gillette/Moorcroft	M-8	P56874.0W	750	3,008	Incomplete		Yes
Gillette/Moorcroft	ENL. M-3	P190132.0W	50	Unknown	Unadjudicated	Yes	

Table 8-11. continued

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	New since 2002	Multiple-use well
Hulett	HULETT #4	P104685.0W	300	1,923	Incomplete		
Lusk	LUSK WELL NO. 10	P191344.0W	400	579	Complete	Yes	
Lusk	LUSK WELL NO. 9	P191343.0W	450	Unknown	Unadjudicated		
Manville	MANVILLE #3	P104368.0W	65	Unknown	Incomplete		
Manville	MANVILLE WELL #1	P594.0C	150	Unknown	Incomplete		
Manville	MANVILLE WELL #2	P595.0C	100	Unknown	Incomplete		
Moorcroft	MOORCROFT MADISON WELL	P165471.0W	600	3,742	Complete	Yes	
Moorcroft	MOORCROFT #8	P104085.0W	55	1,204	Incomplete		
Moorcroft	MOORCROFT WELL NO. 9	P187371.0W	75	1,118	Incomplete		
Moorcroft	MOORCROFT WELL NO. 10	P187372.0W	75	1,097	Incomplete		
Moorcroft	MOORCROFT #7	P92166.0W	0	800	Incomplete		
Newcastle	CARLSON #1	P607.0W	650	2,738	Incomplete		Yes
Pine Haven	PINE HAVEN NO. 2	P147769.0W	250	Unknown	Incomplete		
Pine Haven	ENL. PINE HAVEN NO. 2	P185386.0W	100	Unknown	Incomplete		
Pine Haven	KEYHOLE #1	P78993.0W	150	4,110	Incomplete		
Sundance	COLE NO. 3 C WELL	P191655.0W	200	610	Complete	Yes	
Sundance	BEAGLE #1	P499.0G	100	33	Incomplete		Yes
Sundance	SUNDANCE #6	P72179.0W	400	1,184	Incomplete		Yes
Upton	UPTON NO. 8 WELL	P175186.0W	500	Unknown	Undefined	Yes	
Wright	RJ-6	P145417.0W	330	2,762	Complete		
Wright	ENL RJ-2	P189673.0W	0	Unknown	Complete	Yes	
Wright	2ND ENL RJ-3	P189674.0W	0	Unknown	Complete	Yes	
Wright	ENL RJ-4	P189675.0W	0	Unknown	Complete	Yes	

Table 8-11. continued

Municipality or community	Well name	WSEO permit number	Permit yield (gpm)	Well depth (ft)	Permit status	New since 2002	Multiple-use well
Wright (cont.)							
Wright	ENL RJ-5	P189676.0W	0	Unknown	Complete	Yes	
Wright	ENL RJ-6	P189677.0W	0	Unknown	Complete	Yes	
Wright	ENL RJ-2 WELL	P101356.0W	75	2,660	Incomplete		
Wright	RJ-7	P186050.0W	500	Unknown	Incomplete		
Totals			**27,755**				

Table 8-12. WDEQ Source Water Assessment Program (SWAP) wells and springs used for municipal and non-community public water supply in the NERB.

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Buffalo							
	BUFFALO, CITY OF	5600005-103	P9110W			Well	
Clearmont							
	CLEARMONT, TOWN OF	5600013-101	P37666W	30		Well	
	CLEARMONT, TOWN OF	5600013-102	P45802W	70		Well	
Edgerton							
	EDGERTON, TOWN OF	5600017-101	P44002W	40		Well	
	EDGERTON, TOWN OF	5600017-102	P6319W	35		Well	
Gillette							
	GILLETTE, CITY OF	5600019-101	P24347W		3,479	Well	Fox Hills Fm
	GILLETTE, CITY OF	5600019-102	P25111W		8,509	Well	Fox Hills/Fort Union Fm
	GILLETTE, CITY OF	5600019-103	P30005W		4,437	Well	Lance Fm/Fox Hills Fm
	GILLETTE, CITY OF	5600019-104	P60723W		4,350	Well	Lance Fm/Fox Hills Fm
	GILLETTE, CITY OF	5600019-105	P42004W		1,208	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-106	P42005W		2,350	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-107	P42007W		2,350	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-108	P42010W		2,334	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-109	P41830W		1,850	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-110	P41831W		1,750	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-111	P42985W	160	2,429	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-112	P42006W		2,323	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-113	P69300W		2,767	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-114	P69301W		2,614	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-115	P69302W		3,001	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-116	P69303W		2,525	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-117	P69304W		3,005	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-118	P69305W		3,005	Well	Madison Limestone

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Gillette (cont.)							
	GILLETTE, CITY OF	5600019-119	P69306W		3,006	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-120	P69307W		3,008	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-121	P69308W		2,511	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-122	P69309W		2,514	Well	Madison Limestone
	GILLETTE, CITY OF	5600019-123	P99185W		2,250	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-124	P99186W		2,315	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-125	P101734W		2,252	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-126	P102212W		2,430	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-127	P102213W		2,469	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-128	P109198W		2,515	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-129	P109197W		25,35	Well	Fort Union Fm
	GILLETTE, CITY OF	5600019-130	P108708W		4,170	Well	Lance Fm/Fox Hills Fm
Hulett							
	HULETT, TOWN OF	5600026-101	P83422W		1,923	Well	Pahasapa Limestone
Kaycee							
	KAYCEE, TOWN OF	5600196-101	P72663W	175	1,200	Well	Madison Limestone and Tensleep Fm
	KAYCEE, TOWN OF	5600196-102	P69394W	25	1,700	Well	Madison Limestone and Tensleep Fm
Moorcroft							
	MOORCROFT, TOWN OF	5600037-102	P33968W	30	486	Well	Lance Fm
	MOORCROFT, TOWN OF	5600037-103	P990W	25	500	Well	Lance Fm
	MOORCROFT, TOWN OF	5600037-104	P43549W	90	760	Well	Lance Fm
	MOORCROFT, TOWN OF	5600037-105	P104085W		1,204	Well	Lance Fm
Newcastle							
	NEWCASTLE, CITY OF	5600256-101	P38G	1,400	2,638	Well	Madison Limestone
	NEWCASTLE, CITY OF	5600256-102	P389W	475	3,022	Well	Madison Limestone

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Newcastle (cont.)							
	NEWCASTLE, CITY OF	5600256-103	P1317W	200		Well	Madison Limestone
	NEWCASTLE, CITY OF	5600256-104	P39352W	500	3,121	Well	Madison Limestone
Pine Haven							
	PINE HAVEN, TOWN OF	5600191-101	P9493W	0.42	717	Well	Newcastle Fm
	PINEY CREEK GROCERY	5601145-101	P15801W		58	Well	
Sundance							
	SUNDANCE, CITY OF	5600055-101	P1544W		517	Well	Minnelusa Fm and Pahasapa Limestone
	SUNDANCE, CITY OF	5600055-102	P8377W		1,123	Well	Minnelusa Fm and Pahasapa Limestone
	SUNDANCE, CITY OF	5600055-103	P50484W		1,236	Well	Minnelusa Fm and Pahasapa Limestone
	SUNDANCE, CITY OF	5600055-104	P72179W		1,184	Well	Minnelusa Fm and Pahasapa Limestone
Upton							
	UPTON, TOWN OF	5600140-101	P28335W	205	3,161	Well	Madison Limestone
	UPTON, TOWN OF	5600140-102	P28337W	205	3,193	Well	Madison Limestone
	UPTON, TOWN OF	5600140-103	P28338W	35	545	Well	Newcastle Fm
	UPTON, TOWN OF	5600140-104	P98208W	200	3,308	Well	Madison Limestone
	UPTON, TOWN OF	5600140-105			3,300		Madison Limestone
Wright							
	WRIGHT WATER & SEWER DISTRICT	5600136-101	P46664W	250	2,660	Well	Fort Union Fm
	WRIGHT WATER & SEWER DISTRICT	5600136-102	P46696W	225	2,730	Well	Fort Union Fm
	WRIGHT WATER & SEWER DISTRICT	5600136-103	P71834W	300	3,015	Well	Fort Union Fm
	WRIGHT WATER & SEWER DISTRICT	5600136-104	P48091W	400	2,700	Well	Fort Union Fm
Unknown							
	AMERICAN COLLOID-COLONY EAST	5601235-101	P130433W		820	Well	Falls River Sandstone

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Unknown (cont.)							
	AMERICAN COLLOID-COLONY WEST	5601236-101	P129078W		880	Well	Falls River Sandstone
	AMERICAN COLLOID-COLONY WEST	5601236-102	P145936W	50	775	Well	Falls River Sandstone
	ANTELOPE COAL COMPANY	5601374-101	P56958W		2,620	Well	Ft. Union Fm
	ANTELOPE MOBILE HOME PARK	5600131-101			1,000	Well	Wasatch Fm
	ANTELOPE MOBILE HOME PARK	5600131-102			750	Well	Wasatch Fm
	ANTELOPE VALLEY	5600251-101	P37361W	90	1,305	Well	Wasatch Fm
	ANTELOPE VALLEY	5600251-102	P64374W	125	1,672	Well	Wasatch Fm
	ANTELOPE VALLEY	5600251-103	P64375W	120	2,130	Well	Wasatch Fm
	ANTELOPE VALLEY	5600251-104	P102153W		10,614	Well	Wasatch Fm
	ARROWHEAD LODGE	5600480-101	P819AW		26	Well	
	ARROWHEAD LODGE	5600480-102	P819BW		26	Well	
	BALD MOUNTAIN TRAILER COURT	5600258-101	P23207W		200	Well	Wasatch Fm
	BALD MOUNTAIN TRAILER COURT	5600258-102	P99232W	18	240	Well	Wasatch Fm
	BALD MOUNTAIN TRAILER COURT	5600258-103	P33490W		200	Well	Wasatch Fm
	BALD MOUNTAIN TRAILER COURT	5600258-104	P64950W	7	180	Well	Wasatch Fm
	BEAR LODGE	5600479-101	P525W	25	74	Well	Plutonic Rock
	BEAR LODGE	5600479-102	P111458W	10	80	Well	Plutonic Rock
	BELLE FOURCHE P.L. DONKEY CRK	5601156-101			439	Well	Fort Union Fm
	BELLE FOURCHE P.L. DONKEY CRK	5601156-102			439	Well	Fort Union Fm
	BIGHORN MOUNTAIN CAMPGROUND	5600229-101			136	Well	Wasatch Fm
	BIGHORN NF - SIBLEY LAKE CG	5680231-101	P61644		125	Well	Plutonic Rocks
	BIGHORN NF BURGESS JCT VISITOR CNTR	5680232-101	P86363W	0	285	Well	Plutonic Rocks
	BIGHORN NF TIE HACK CG	5680184-101	P107962W		90	Well	Oldest Gneiss Complex
	BIGHORN NF-BURGESS RANGER STATION	5680244-101	P105302W		98	Well	Plutonic Rock
	BIRD DRIVE WATER SYSTEM	5600122-101	P2599W		1,210	Well	Fort Union
	BLACK HILLS NF-COOK LAKE CG	5680010-101	P74466W	10	65	Well	Sundance Fm

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Unknown (cont.)							
	BLACK HILLS NF-COOK LAKE CG	5680010-103	P74468W	5	260	Well	Sundance Fm
	BLM-MIDDLE FORK POWDER RIV CG	5680241-101	P100937W		45	Well	Alluvium
	BLM-MOSIER GULCH PICNIC AREA	5680234-101	P105982W		93	Well	Wasatch Fm, Moncrief member
	CAMPBELL COUNTY AIRPORT	5601023-101	P63913W	125	1,130	Well	
	CEDAR HILLS WATER ASSOCIATION	5600780-101	P45140W		640	Well	Ft. Union Fm. Tongue river and Lebo members
	CEDAR HILLS WATER ASSOCIATION	5600780-102	P45318W		1,365	Well	Ft. Union Fm. Tongue river and Lebo members
	CRESTVIEW ESTATES SUBDIVISION	5600853-101	P56901W		1,550	Well	Wasatch Fm
	DEVIL'S TOWER KOA-CAMPSTOOL ET	5600370-101	P82103W	50	1,375	Well	Madison Limestone
	DEVIL'S TOWER NAT'L MONUMENT	5680114-101	P1923W		1,341	Well	
	EATON'S DUDE RANCH	5600929-101	P134657W		1,740	Well	Madison Limestone
	EIGHT MILE SUBDIVISION	5600829-101	P88702W		1,466	Well	Wasatch Fm
	FORCE ROAD JOINT POWERS BOARD	5600148-101	P29916W		1,150	Well	Wasatch Fm
	FORCE ROAD JOINT POWERS BOARD	5600148-102	P56602W		1,520	Well	Wasatch Fm
	FORT PHIL KEARNEY ST HIST SITE	5600672-101	P14634W	5	88	Well	Wasatch
	FOUR J SCHOOL CAMPBELL SCH DIS	5601056-101	P70087W		750	Well	
	FREEDOM HILLS SUBDIVISION	5600789-101	P85154W		1,600	Well	Ft. Union Fm
	FREEDOM HILLS SUBDIVISION	5600789-102	P85155W		1,500	Well	Ft. Union Fm
	INDIAN CAMPGROUND	5601360-101	P1298W		15	Well	terrace deposits
	INTERSTATE INDUSTRIAL PARK	5600909-101	P33465W	50		Well	
	JACOBS RANCH MINE	5600924-101				Well	
	KEYHOLE RESORT/MARINA	5600373-101	P27054W	20	120	Well	
	KEYHOLE RESORT/MOTEL	5601249-101	P15574W		150	Well	
	KEYHOLE ST PARK COTTONWOOD	5600652-101	P144710W	20	284	Well	Ft. Union
	KEYHOLE ST PARK PAT'S POINT	5680180-101	P84789W		140	Well	Falls River SS
	KEYHOLE ST PARK PRONGHORN	5600651-101	P28556W	25	150	Well	Falls River Sandstone

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Unknown (cont.)							
	KOA BIGHORN MOUNTAIN	5600242-101	P69061W		380	Well	Fort Union Fm
	KOA BIGHORN MOUNTAIN	5600242-102			165	Well	Fort Union Fm
	KOA BIGHORN MOUNTAIN	5600242-103			165	Well	Fort Union Fm
	LAK RANCH	5601447-101	P75560W	100	4,190	Well	Madison Limestone
	LANCE CREEK WATER DISTRICT	5600109-101	P273W			Well	
	LANCE CREEK WATER DISTRICT	5600109-102	P272W			Well	
	MC GEE MOBILE HOME PARK	5601449-101	P27239W		275	Well	Wasatch Fm
	MEANS IMP. & SERVICE DIST.	5600760-101	P131367W		1,075	Well	Wasatch Fm
	MEANS IMP. & SERVICE DIST.	5600760-102	P131366W		1,456	Well	Wasatch Fm
	NICKELSON FARMS WATER COMPANY	5600619-101	P37957W	100	1,300	Well	Fort Union Fm
	NICKELSON FARMS WATER COMPANY	5600619-102	P52304W	100	1,488	Well	Fort Union Fm
	NORTH VIEW MOBILE HOME COURT	5600121-101	P45223W	25	491	Well	Wasatch Fm
	NORTHERN WY COMMUNITY COLLEGE	5601159-101	P84857W		1,166	Well	
	OSAGE WATER DISTRICT	5600038-101	P143G	200	3,000	Well	Madison Limestone
	OSAGE WATER DISTRICT	5600038-102	P50143W	25	3,101	Well	Madison Limestone
	POWDER RIVER CO-RAWHIDE MINE	5600815-101	P28705W	160	1,420	Well	
	POWDER RVR COAL-CABALLO MINE	5600328-101	P30008W	120	1,605	Well	Ft. Union Fm
	POWDER RVR COAL-CABALLO MINE	5600328-102	P84539W		1,400	Well	Ft. Union Fm
	PRAIRIE VIEW CAMPGROUND	5601070-101	P43048W		100	Well	Arikaree Fm
	RAG COAL WEST INC/RAWHIDE SCHOOL	5600123-101	P34920W	100		Well	
	RECLUSE SCHOOL CAMPBELL SCH DS	5601057-101	P40511W	15	1,230	Well	
	SAND CREEK TRADING POST	5600300-101	P59654W	4	39	Well	Alluvium
	SLEEPY HOLLOW SUBDIVISION	5600764-101	P98210W		2,410	Well	Wasatch Fm
	SLEEPY HOLLOW SUBDIVISION	5600764-102	P69561W		1,164	Well	Wasatch Fm
	SLEEPY HOLLOW SUBDIVISION	5600764-103	P69562W		1,479	Well	Wasatch Fm
	SLEEPY HOLLOW SUBDIVISION	5600764-104	P81859W		1,967	Well	Wasatch Fm

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Unknown (cont.)							
	SOUTHFORK ESTATES	5600832-101	P57603W		1,600	Well	Wasatch Fm
	STONE GATE ESTATES	5601329-101	P87209W	25	1,706	Well	Wasatch Fm
	STONE GATE ESTATES	5601329-102	P95375W	80	1,620	Well	Wasatch Fm
	STORY ELEMENTARY SCHOOL	5600578-101	P54850W		90	Well	
	TRITON COAL CO-BUCKSKIN MINE	5600818-101	P46018W		1,362	Well	Ft. Union Fm
	TRITON COAL CO-BUCKSKIN MINE	5600818-102	P110771W		1,510	Well	Ft. Union Fm
	U.S. AIR FORCE DET 21, ECRG	5601117-101			647	Well	Greenhorn Fm
	UCROSS GUEST RANCH	5601149-101	P102121W		795	Well	
	UNION PACIFIC RAILROAD	5600978-101	P79678W	110	1,471	Well	
	UNION PACIFIC RAILROAD	5600978-102	P70871W	40	1,473	Well	
	VISTA WEST SUBDIVISION	5600246-101	P91988W		400	Well	Intrusive/Extrusive igneous rocks w/ Mississippian through Cambrian masses
	VISTA WEST SUBDIVISION	5600246-102	P91989W		1,140	Well	Intrusive/Extrusive igneous rocks w/ Mississippian through Cambrian masses
	WAGON BOX INN	5601103-101	P62530W	25	60	Well	Alluvium/Colluvium
	WAGON BOX INN	5601103-102	P80128W			Well	Alluvium/Colluvium
	WESTERN FUELS-WYOMING INC.	5601214-101	P69886W		1,814	Well	Ft. Union Fm
	WESTON COUNTY MALLO CAMP	5600515-101	P1516W		18	Well	Alluvium
	WESTRIDGE WATER USERS ASSOC.	5600146-101	P24603W	80	1,360	Well	Wasatch Fm
	WESTRIDGE WATER USERS ASSOC.	5600146-102	P14224W	25	1,186	Well	Wasatch Fm
	WINLAND INDUSTRIAL PARK	5601410-101	P61523W		1,090	Well	Wasatch Fm
	WRANGLER ESTATES	5601474-101	P132906W		1,620	Well	Fort Union Fm
	WY TRANS DEPT - WALTMAN RA	5600964-101	P70877W	15	142	Well	Wind River Fm
	WY TRANS DEPT MOORCROFT RA	5600730-101	P19065W	25	300	Well	
	WY TRANS DEPT POWDER RIVER RA	5600949-101	P76205W	25	1,002	Well	
		5600487-101	P50731W	25	21	Well	

Table 8-12. continued

Municipality	Well name	Public water system ID	WSEO permit no.	Yield (gpm)	Well depth (ft)	Source type	Producing unit
Unknown (cont.)							
		5600487-102	P50730W	17	25	Well	
		5600487-103	P5495W	20	32	Well	
		5600545-101	P15230W	15	100	Well	
		5601050-101	P71452W	60	1,494	Well	
		5601192-101	P60219W	20	921	Well	Ft. Union Fm
		5680179-101	P28560W	25	180	Well	Falls River SS

2012 Wind/Bighorn River Basin Water Plan) have treated produced water withdrawals as industrial groundwater use, while others (e.g., the 2006 Platte River Basin Water Plan) have included only water used for production and refining operations in estimates of industrial use. The information in chapter 10 on currently produced water associated with energy operations was obtained from the WOGCC (2017), the U.S. Geological Survey USGS (Maupin and others; Lovelace, 2009), and the U.S. Energy Information Administration (2018).

Figures 5-4 through 5-6 show the extent of energy development as it relates to water resources in the NERB. Figure 5-4 shows conventional oil and gas infrastructure, figure 5-5 provides the locations of Class II (petroleum-produced water) and Class V (CBM-produced water) injection wells, and fig. 5-6 maps Wyoming Pollutant Discharge Elimination System (WYPDES) outfalls and WDEQ groundwater pollution control facilities.

Chapter 10 examines energy production and groundwater. Table 10-1 lists annual production levels of oil, gas, coal, and produced-water during 2003–2016.

Effluent waters from various facilities of suitable quality can be put to beneficial use (e.g., stock watering, agriculture, drilling, and industrial dust suppression). Otherwise, effluent water is primarily discharged to the surface under the regulation of WDEQ Wyoming Pollutant Discharge Elimination System (WYPDES) permits. WDEQ data indicate that most WYPDES permits shown in figure 5-6, particularly in the Powder River, Belle Fourche, Tongue, and Cheyenne River basins, were issued in association with coalbed methane production. Estimates of historical volumes of CBM co-produced water discharged in the NERB can be obtained from the WOGCC website, http://pipeline.wyo.gov/crms.cfm.

Produced water volumes that are discharged to the surface or put to other uses are generally considered to be partially consumptive and, in a few cases, wholly consumptive. Produced (effluent) water management typically involves some consumptive losses to evapotranspiration. On the other hand, injecting produced water into hydrogeologic units at depths where there is minimal chance of future withdrawal effectively removes it from the water budget of the basin and is wholly consumptive. The water balance developed within this study adds discharged effluent water volumes to precipitation. Once discharged, effluent waters are consumed by evapotranspiration, add to surface water outflows, and recharge shallow aquifers.

8.6.3.8.2 Groundwater use for non-energy minerals development

Groundwater withdrawn for non-energy mineral development in the NERB is primarily used for the production of sand, gravel, limestone, bentonite, and scoria. Figure 5-8 shows the locations of groundwater permits for non-energy minerals, coal, and uranium mines in the NERB.

Mining permits are shown on the WDEQ Land Quality Division website: http://deq.wyoming.gov/lqd/.

8.6.3.9 Monitoring wells

Tables 8-6 through 8-8 list 7,930 SEO monitoring well permits in Wyoming, 109 monitoring wells in Montana, and 13 in South Dakota. Monitoring wells are typically used to track the levels and quality of groundwater associated with a contaminated site or a potentially contaminated site (e.g., an underground fuel storage tank) or to monitor for groundwater impacts from various activities (e.g., mining or waste management). When used for monitoring alone, these wells have no permitted yield; however, there may be a permitted yield for other, secondary uses. The SEO stopped requiring permits for monitoring wells of 4 in or less in diameter in 2004; therefore, the data for these permits are incomplete.

Figure 8-6 shows the distribution of likely drilled SEO monitoring well permits in the NERB. Most monitoring wells are located along Wyoming State Highway 59 in association with operating coalmines. The depth versus yield tables on figure 8-6 show that most permits are issued for depths less than 500 ft. This suggests that shallow water table aquifers susceptible to contamination are the most frequent target of groundwater monitoring programs in the NERB. Although recorded depths are available for most monitoring wells in the database, only 66 well permits include recorded yield data. More than 800 monitoring wells were permitted after 2002; however, even this high number is understated because of the 2004 SEO policy change that removed the permit requirement for monitoring wells under 4 in in diameter.

8.6.3.10 Permits for other and miscellaneous uses

Table 8-6 indicates that the SEO has issued 3,387 permits for “other” uses and 4,813 permits for “multi-use” wells. Multi-use permits list more than one use; for example, a permit that shows both “domestic” and “stock” use is a multi-use permit. Tables 8-7 and 8-8 list permits for “other” wells and “multi-use” permits issued by Montana and South Dakota, respectively. There are

no permits recorded for either type in Nebraska (table 8-9).

Some "multi-use" permits are for test wells used to determine aquifer hydraulic characteristics. Information on specific miscellaneous-use and test wells may be found in some permit SEO applications available online and in the WWDC water projects listed in appendix B.

Figure 8-7 shows that miscellaneous-use and other-use wells are located throughout the NERB. The depth versus yield tables in figure 8-7 show that most groundwater permits have been issued for depths up to 99 ft and for yields of 1 to 499 gpm for both total permits and permits issued since 2002. About 30 percent of these permits do not list a recorded depth.

8.6.3.11 Hydrothermal use

The NERB has no potential for high-grade geothermal energy development. However, Buelow and others (1986) identified three areas in the NERB with limited potential for hydrothermal development: the Salt Creek-Meadow Creek area north of Casper, along Lightning and Lance creeks in the Cheyenne River Basin, and on the southwestern flanks of the Black Hills near Newcastle. A WSGS inventory of thermal springs in Wyoming (Breckenridge and Hinckley, 1978) did not identify any hydrothermal springs in the NERB.

The SEO database lists hydrothermal development as a sub-category in individual permit applications for some miscellaneous-use wells. Determination of the number of wells and springs permitted for hydrothermal use was beyond the scope of this study.

8.7 GROUNDWATER INTERFERENCE/ INTERCONNECTION WITH SURFACE WATER

The potential for interference between wells and well fields located within areas of interconnected surface and groundwater that exhibit historically high levels of drawdown must be considered when assessing the historic, current, and future use of groundwater in the NERB. The use of groundwater resources is not addressed in the Belle Fourche and Yellowstone compacts but is mentioned in the Upper Niobrara Compact (app. D).

8.7.1 Interference between wells

As a well withdraws water from an unconfined aquifer, it depresses the groundwater level around the well casing in a generally radial configuration, called a "cone of depression." In areas where several actively pumping wells are sited in close proximity to each other, their respective cones of depression may overlap and "well interference" may result. If well interference becomes excessive, aquifer water levels may drop below the depth of some wells, causing conflicts between users. In Wyoming, the SEO may address cases of excessive well interference by recommending the formation of a groundwater control area wherein groundwater uses are actively managed by a groundwater control area advisory board. According to Wyoming State Statute WSS 41-3-912, a "control area" can be designated by the Board of Control on the recommendation of the State Engineer for any of the following reasons:

- The use of underground water is approaching a use equal to the current recharge rate
- Groundwater levels are declining or have declined extensively.
- Conflicts between users are occurring or foreseeable.
- The waste of water is occurring or may occur.
- Other conditions exist or may arise that require regulation for the protection of the public interest.

Currently, there are no designated control areas in the NERB. Additional information about groundwater control areas can be found online: https://sites.google.com/a/wyo.gov/seo/ground-water/groundwater-control-areas-advisory-boards.

8.7.2 Interconnection between groundwater and surface water

Surface flows are subject to strict water rights, and conflicts occur where groundwater extraction affects surface flow. Although the Wyoming Constitution establishes that all surface water and groundwater within Wyoming's borders is owned by the state, the right to put surface water and groundwater to beneficial use is permitted as water rights by the Wyoming SEO and adjudicated by the Wyoming Board of Control. Surface water resources are subject to interstate agreements that limit how much streamflow can be depleted before leaving the state. Furthermore, conflicts among users within the state or across state lines can occur where groundwater extraction may affect surface flows. Although interconnection between groundwater and surface water is not currently a significant water rights issue in the NERB, it could

become a point of contention in the future as the basin's population grows.

Appendix D contains copies of the Belle Fourche, Yellowstone, and Upper Niobrara compacts (SEO, 2017). The Interstate Streams Division of the SEO administers the provisions of compacts that fall under the authority of the State of Wyoming.