



Hydrogeologic Parameters for the Tensleep Aquifer in Wyoming

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ABSTRACT

This report presents and summarizes available hydrogeologic parameter data for the Tensleep aquifer in Wyoming, including porosity, permeability, areas of high and low long-term average recharge estimates, oil-field water drive, water quality, and temperature. The term “Tensleep” refers broadly to equivalent rock units and aquifers, such as the Minnelusa and Casper formations.

Porosity and permeability values obtained from the Wyoming Geological Association’s oil and gas field symposium volumes generally exhibit a trend of higher values along basin edges and lower values toward the deeper parts of sedimentary basins. Graphical analysis illustrates a decrease in both porosity and permeability with increasing depth. Long-term average recharge estimates, expressed in terms of baseflow, were determined for Tensleep outcrops across the state and are based on a published baseflow study. The areas with the highest long-term average recharge estimates are the central-western Bighorn Mountains, the central Wyoming Range, the northwestern Gros Ventre Range, and the southeastern Bighorn Mountains.

The Wyoming Geological Association’s oil and gas field symposium volumes identified oil fields with water drive at the time of publication. Although the drive mechanisms may have changed since publication, several oil fields in the Bighorn, Wind River, Laramie, and Powder River Basins displayed Tensleep water drive. These water-driven fields are located basinward of Tensleep outcrops where recharge may have occurred. They are also beyond zones of suspected rejected recharge as indicated by springs that may originate from the Tensleep.

Water-quality maps show data from the U.S. Geological Survey (USGS) environmental sample database (National Water Information System water-quality samples) and from the Wyoming Oil and Gas Conservation Commission (WOGCC) database of produced water from oil and gas fields. Salinity maps indicate increasing salinity from mountain flanks to deeper basin areas, with a notable exception in the northeastern Powder River Basin. This region, characterized by exceptionally high salinity levels, exhibits peak concentrations of chloride and sodium. Conversely, calcium and sulfate concentrations remain relatively moderate. The sodium-adsorption ratio (SAR) also increases with distance from the mountain fronts, rendering the Tensleep aquifer less suitable for irrigation in many parts of the state. Lithium concentrations are generally low and exhibit no exceptional trends, with limited data available for deeper basin regions.

Temperatures derived from borehole and sample-water measurements generally increase with depth within the sedimentary basins. However, an anomalous zone of cooler water temperature exists in the northeastern Powder River Basin. This area coincides with a region of exceptionally high salinity levels. The cause of this anomaly remains unknown.

INTRODUCTION

Previous Wyoming State Geological Survey (WSGS) reports have primarily examined how individual parameters (e.g., salinity or geothermal resources) vary with depth within a single basin. This report addresses the complexities of hydrogeologic systems by examining the Tensleep Sandstone and its equivalents statewide. The Tensleep is a major aquifer in Wyoming, and understanding its hydrogeologic characteristics is crucial for effective water resource management.

One of the key questions in Wyoming hydrogeology is the effectiveness of confining units between aquifers. Examining water quality within individual aquifers provides a means to address this question. This report represents the first in a series of studies aimed at characterizing individual aquifers. By comparing water

chemistry between aquifers in future studies, we can gain insights into the integrity of confining units. Key areas of investigation include (1) the relationship between porosity and permeability within the aquifer; (2) the relationship between water drive in oil fields, spring locations, and recharge areas; (3) changes in water quality as groundwater flows through the aquifer from mountain flanks to sedimentary basins; and (4) variations in recharge along mountain fronts.

The objective of this report is to provide a comprehensive compilation of hydrogeologic parameters for the Tensleep aquifer in Wyoming, including porosity, permeability, estimated recharge, oil field water drive, water quality, and temperature. This report does not include structural, thickness, or potentiometric maps of the Tensleep aquifer. The introductory section includes tables referencing publications with these maps. The scope of this work involved compiling existing data from various state and federal agencies, as well as data from geological publications. The primary focus of this report is data synthesis.

The methodology employed in this report was multifaceted, focused on rapid data compilation without new data generation. One aspect involved synthesizing existing datasets into easily interpretable maps. Two datasets, water-quality data from oil and gas fields and environmental sampling efforts, were combined. Additionally, for this project, only water-quality data from the Tensleep aquifer are presented. Another aspect involved a literature review to compile published porosity and permeability values, including the identification of oil fields with water drive. While some parameters exhibit spatial variation, contouring the data implies a complete understanding of flow paths, which necessitates potentiometric maps and was beyond the scope of this project. Consequently, data on maps show general trends. Finally, long-term average recharge areas were estimated for Tensleep outcrops using the methods of Taboga and Stafford (2020).

DESCRIPTION OF THE TENSLEEP SANDSTONE

The Tensleep Sandstone is a Pennsylvanian–Permian rock unit found across much of Wyoming. It consists of several equivalent formations, including the Wells Formation, Weber Sandstone, Minnelusa Formation, Casper Formation, Fountain Formation, Lyons Sandstone, and the Hartville Formation. In this report, “Tensleep Sandstone” refers to all these equivalent rock units.

Previous Work Describing the Tensleep Sandstone and its Equivalents

Numerous publications describe the Tensleep Sandstone and its equivalents in Wyoming, including Mallory (1975), Maughan (1975), and Love and others (1993). Bartos and others (2010, 2012, 2013, 2014a and b, 2019) in the River Basin Available Groundwater Determination Technical Memoranda (hereafter referred to as “River Basin Plans”), provide valuable insights into the hydrogeology of the Tensleep Sandstone and its correlative units throughout the state.

In the River Basin Plans, the geologic maps differ from the hydrostratigraphic maps because different geologic units are combined to form the hydrostratigraphic units. For example, the geologic map in the Powder/Tongue/Northeast River Plan distinguishes the Hartville and Minnelusa formations but combines the Tensleep Sandstone with the Amsden Formation (Taboga and others, 2019). The hydrogeologic map in the same plan uses undifferentiated hydrostratigraphic units by grouping the Minnelusa, Minnekahta, Madison, and Pahasapa aquifers with the Opeche confining unit, along with the undefined Englewood and Darby formations. While the Hartville aquifer, the Minnelusa aquifer, and a combined Tensleep and undefined Amsden Formation are present in portions of the map, the text treats the Tensleep, Amsden, Hartville, and Minnelusa as distinct units.

Another example is the Wind/Bighorn River Basin Plan, which equates the lithostratigraphic Tensleep Sandstone to the hydrogeologic Tensleep aquifer in its Wind River Basin section. However, in the Bighorn Basin sections, it includes the Ranchester Limestone Member of the Amsden Formation within the Tensleep aquifer (plate III of Taucher and others, 2012). The Tensleep and Amsden are shown together on the surficial geologic map (plate I of Taucher and others, 2012). The Tensleep and Amsden aquifers are jointly mapped as part of the Paleozoic aquifer system on the surficial hydrogeologic map (plate IV of Taucher and others, 2012). The isopach map presents the Tensleep aquifer and Amsden aquifer as a single unit in the Wind River Basin (plate VI of Taucher and others, 2012), and in the Bighorn Basin, the Tensleep and Amsden extend across about half of Park County (plate VIII of Taucher and others, 2012).

The Platte River Basin Plan offers a detailed discussion of the relationships among the Tensleep Sandstone, Casper Formation, and Hartville Formation (Bartos and others, Chapter 7 in Taucher and others, 2013).

The USGS Regional Aquifer-System Analysis (RASA) of the Upper Colorado River Basin, which included the Greater Green River Basin (Geldon, 2003a, 2003b) spanned Wyoming, Colorado, Utah, Arizona, and New Mexico. Geldon's classification scheme groups the Tensleep with the Weber-De Chelly, Coconino, and White Rim Sandstones, the Wells Formation, and the Frying Pan and Schoolhouse members of the Maroon Formation. These units are termed the Weber-De Chelly Zone of the Canyonlands aquifer (table 1 of Geldon, 2003b). In this RASA, one plate shows the unit-averaged porosity and hydraulic conductivity of the Weber-De Chelly Zone, while a second plate shows composite transmissivity and maximum yields. In the geology report (Geldon, 2003a), the thickness of this zone is presented in plate 16, which also includes the lithofacies. The Tensleep is the dominant lithofacies in the Greater Green River Basin, the Weber Sandstone dominates near the Uinta Mountains, and the Wells Formation occurs in the Overthrust Belt.

Lee (1927) and Condra and Reed (1950) describe the Lyons Sandstone extending to southeastern Wyoming and note its equivalence to the upper Tensleep. A commercial oilfield waste disposal facility proposed by Tallgrass Water Great Plains, LLC, plans to inject material into the Lyons Formation in southeastern Wyoming (Tallgrass High Plains Storage, LCC, 2023).

Tensleep Sandstone and its Equivalents

The Tensleep Sandstone, a Pennsylvanian–Permian rock unit, is present in the Bighorn Basin, the Wind River Basin, and along the eastern flank of the Bighorn Mountains. In this report, the term “Tensleep” encompasses equivalent formations across Wyoming. These include the Minnelusa Formation in the eastern Powder River Basin (including its Leo, Converse, and Bell sandstone members), the Casper Formation in the Laramie Basin, the Weber and Morgan formations in the Bridger Basin, the Hartville Formation in eastern Wyoming, the Lyons Sandstone in southeastern Wyoming, and the Wells Formation in the Overthrust Belt. For simplicity, the unmodified term “Tensleep” refers broadly to the geologic formation and its equivalents, unless otherwise specified.

Structural Geology

While the primary focus of this report is on the hydrogeologic parameters, a review of relevant literature has revealed several existing structural geology maps of the Tensleep Sandstone. Table 1 provides a list of these publications. This list is not exhaustive, as the compilation of structural maps was not central to this study.

A common limitation of these maps is the scarcity of data in the deeper portions of Wyoming’s basins. The economic incentives for drilling deep wells in these areas have historically been insufficient. Consequently, some structural maps exhibit contours that extend across entire basins without clear supporting data, particularly in areas with thicker sedimentary fill.

Thickness Overview

Several maps illustrating the thickness of the Tensleep and its equivalents are available. These maps are listed in table 2; however, a comprehensive review of Tensleep thickness is beyond the scope of this report.

Table 1. Sources of structural maps of the Tensleep Sandstone and its equivalents in Wyoming.

Author(s)	Coverage	Location in Document; Comments
Bartos and others, 2002	Eastern Powder River Basin and western Black Hills	Both sheets show the elevation of the top of the Minnelusa. Sheet 3 covers the northern part of the study area, while Sheet 4 covers the southern part of the study area.
Biggs and Espach, 1960	Statewide	The book is a compilation of data on oil and gas fields with a separate section for each field. Most sections include a structural geology map of the field, and it is common for this map to be a Tensleep structure map.
Cardinal and others, 1989	Bighorn Basin and Wind River Basin	This volume is a compilation of data on oil and gas fields with a separate section for each field. Many of the sections include a map of the Tensleep structure.
Cardinal and Holmes, 1984	Southeastern Wyoming (including the southeastern Powder River Basin, Hartville Uplift, to Wyoming’s southern boundary; also includes southwest South Dakota and western Nebraska)	The structural map shows the top of the Pennsylvanian, which corresponds to the base of the Red Shale Marker. This structural map is included on the isopachs maps (figures 1, 2, 3, and 4).
Cardinal and Steward, 1979	Greater Green River Basin	This volume is a compilation of data on oil and gas fields with a separate section for each field. Some sections include a map of the Tensleep structure.
Crysdale, 1990	Powder River Basin	The map presents computer-generated contours; however, the software used to create the contours could not account for the effects of reverse faults on the structure of the Minnelusa.

Table 1. Continued

Author(s)	Coverage	Location in Document; Comments
Doremus, 1986	Northeastern Bighorn Basin	Figure 7 is a map of the top of the Tensleep.
Foster, 1958	Powder River Basin	The structure map depicts the top of the Minnelusa and serves as part of the base map for figures 2, 3, and 4, which are isopach maps of the upper, middle, and lower Minnelusa, respectively. This map dates back to the 1950s, and many wells were drilled since then. Additionally, the map predates Huntoon's (1985a) introduction of the concept of severed aquifers along basin margins; therefore, these maps do not incorporate that concept.
Fox and Higley, 1987	Powder River Basin	Publication is a map that presents computer-generated contours. The authors noted that not all data points were as closely honored as they would be on a hand-drawn map due to mathematical constraints of the computer program.
Garland, 1996	Southern Powder River Basin and northern Laramie Range	Plate II is a structural map of the top of the Casper Formation.
Geomap Company, 1989	Bighorn Basin and Wind River Basin	The map is one of the plates in a back folder. Structural contours are shown on the Phosphoria and Minnelusa formations. In the Bighorn and the Wind River basins, most authors use the term "Tensleep" instead of "Minnelusa." The map does not provide control points. It is copyrighted, and those wishing to use it should seek permission.
Head and others, 1979	Powder River Basin	Figure 2 on the map plate shows the top of the Minnelusa Formation and equivalent rocks.
Head and Merkel, 1977	Powder River Basin	Figure 1 is a machine-contoured structural map of the top of the Minnelusa Formation. The Petroleum Information Corporation compiled the data used for contouring.
Jarvis, 1986	Southeastern Bighorn Basin	Plate II is "Elevation of the Top of the Tensleep Sandstone." The map does not show well control.
Johnson, 1994	Hanna Basin	Plate II shows the elevation of the top of the Tensleep Sandstone in the Troublesome–Difficulty Creek area, Carbon County, Wyoming. No well control is shown.

Table 1. Continued

Author(s)	Coverage	Location in Document; Comments
Kyllonen and Peter, 1986	Northern Black Hills and Bear Lodge Mountains	Figures 4 and 6 are structural maps of the top of the Minnelusa Formation. Figure 4 does not show well control, whereas figure 6 does.
Lawyer and others, 1981	Powder River Basin	The volume is a compilation of data on oil and gas fields with a separate section on each field. Typically, each section includes a map, some of which are Tensleep or Minnelusa structure maps.
Libra and others, 1981	Bighorn Basin	Plate I is a structural contour map of the Tensleep in the Bighorn Basin. The map is copyrighted by the Petroleum Ownership Map Company, Casper, WY, in 1974.
Lowry and others, 1976	Bighorn Basin	Sheet 1 is a Tensleep structural map.
Miller and others, 1992	Greater Green River Basin	The volume is a compilation of data on oil and gas fields with a separate section on each field. Typically, each field has a structural map, and a few fields include a structure map of the Tensleep or one of its equivalents.
Spencer, 1986	Southern Bighorn Basin	Plate II is a structural map of the Tensleep Sandstone. The map does not show well control.
Stacy, 1994	Casper Mountain	Figure 2 shows the elevation of the top of Casper Formation in the Casper Mountain area, extending from Casper to the south of Casper Mountain. This map includes well control.
Zapp, 1956	Bighorn Basin	This publication is a map that covers the perimeter of the basin, with no data available for the deep part of the basin. The map presents structural contours mapped on the top of the Tensleep. It also indicates the approximate direction and magnitude, in feet per mile, of the probable inclination of oil-water contact at the time of the oil pool's discovery.
Zhang, 2018	Western flank of Denver Basin, west of Cheyenne	Figure 1 is a structural map of the Casper Formation for a small study area on the eastern flank of the Laramie Mountains, west of Cheyenne, Wyoming.

Table 2. Sources of thickness maps for the Tensleep Sandstone and its equivalents in Wyoming.

Author(s)	Coverage	Location in Document; Comments
Cardinal and Holmes, 1984	Southeastern Wyoming (including the southeastern Powder River Basin, Hartville Uplift, to Wyoming's southern boundary; also includes southwest South Dakota and western Nebraska)	Figure 1 is an isopach map of the Upper Minnelusa, Lower Wolfcampian age. Figure 2 is an isopach map of the Pennsylvanian excluding the basal sands. Figure 3 is an isopach map of the Middle Minnelusa, Virgilian–Missourian age. Figure 4 is an isopach map of the Middle Minnelusa, Desmoinesian age.
Foster, 1958	Powder River Basin	Figures 2, 3, and 4 are isopach maps of the upper, middle, and lower Minnelusa, respectively.
Geldon, 2003a	Greater Green River Basin	Plate 16 is a thickness map that is part of a regional compilation covering Arizona, Colorado, New Mexico, Utah, and Wyoming.
Keefer and Van Lieu, 1966	Wind River Basin	Figure 17 shows the thickness of the Tensleep and Amsden formations.
Kyllonen and Peter, 1986	Northern Black Hills and Bear Lodge Mountains	Figure 9 is a thickness map of the Minnelusa Formation.
Mallory, 1972	Rocky Mountain Region (from Arizona and New Mexico north to Canada)	Figure 4 is a map of the Pennsylvanian system thickness. Figures 5–9 show thicknesses of specific ages within the Pennsylvanian.
Maughan, 1975	Eastern Wyoming and Black Hills	Figure 49 shows the thicknesses for the upper parts of the Casper, Hartville, and Minnelusa formations.
McKee and others, 1975	Lower 48 states	The following plates show thicknesses of Pennsylvanian sediments in Wyoming: 3-A, 6-A, 7-A, 8-A, 9-A, and 11. In western Wyoming, this includes the Tensleep, but in eastern Wyoming, its equivalents extend into the Permian (Maughan, 1975). Plate 13 presents stratigraphic columns that show the equivalent formations.
Taucher and others, 2012	Wind River Basin and Bighorn Basin	Plate VII: Isopach Maps of Selected Aquifers—Wind River Basin. Plate VIII: Isopach Maps of Selected Aquifers—Bighorn Basin. Isopach maps (Plate III, Map E, and Plate VIII, map E) are from Keefer and Van Lieu (1966) and Thomas (1965). The report also includes GIS files.
Thomas, 1965	Bighorn Basin	Figure 10 is a generalized map from a figure in an original page-sized journal.

Table 2. Continued

Author(s)	Coverage	Location in Document; Comments
Trotter, 1984	Powder River Basin	Figure 9 is a thickness map of the upper Minnelusa. Figure 10 is a thickness map of the middle Minnelusa. Figure 11 is a thickness map of the lower Minnelusa. Figure 12 is a total thickness map of the Minnelusa. Figure 13 is a total thickness map of the upper and middle Minnelusa.
Zapp, 1956	Bighorn Basin	In this map product, a thickness map of the Tensleep appears as a smaller figure adjacent to the main structural map.

BACKGROUND ON THE TENSLEEP AQUIFER

Use of the Term “Tensleep Aquifer”

The Tensleep aquifer specifically refers to water-bearing sedimentary rocks interpreted to be deposits from eolian sand dunes or nearshore marine sand bodies (such as the Tensleep Sandstone), sediments related to basement uplifts (such as the Fountain Formation), or shallow seas that preserved interbedded carbonate layers between the sandier sequences (such as the Casper and Minnelusa formations). While future research may reveal that these units are not hydrologically connected, they are assumed to be in communication for the purposes of this study. As previously discussed, the term Tensleep aquifer is used broadly throughout this report to encompass aquifers within these equivalent formations. For brevity, the term Tensleep may occasionally refer to both the Tensleep Sandstone and the Tensleep aquifer, unless otherwise specified.

Tensleep Potentiometric Maps

Available potentiometric maps are summarized in table 3. Earlier maps are generalized and do not account for basin-margin structures. More recent maps incorporate faulting at basin margins. Similar to the structural maps, data availability is limited for the central basin areas.

The concept of an unconfined aquifer transitioning to a confined aquifer beneath confining units, sometimes becoming artesian, has appeared in geological literature for over 135 years (Chamberlin, 1885; Darton, 1897). This concept is well documented in many textbooks (e.g., Hiscock and Bense, 2014; Fetter, 2018) and websites (e.g., Indiana Department of Natural Resources, 2023; National Groundwater Association, 2023a, 2023b). The Tensleep aquifer exhibits similar behavior, transitioning from an unconfined, water-table aquifer where exposed at the surface to a confined aquifer where it dips beneath other units.

Some studies have classified the Tensleep–Minnelusa as part of larger aquifer systems. For example, Feathers and others (1981) included it within the Madison aquifer system in the Powder River Basin, and Spencer (1986) grouped it with other Paleozoic aquifers in the Bighorn Basin.

Table 3. Sources of potentiometric maps for the Tensleep aquifer and its equivalents in Wyoming.

Author(s)	Coverage	Location in Document; Comments
Bartos and others, 2002	Eastern Powder River Basin and western Black Hills	The potentiometric surface of the Minnelusa is shown, with sheet 1 covering the northern part of the study area and sheet 2 covering the southern part of the study area.
Bredehoeft and others, 1992	Bighorn Basin	Figure 7 is a smaller version of Bredehoeft and Bennett's (1972) map, and Haun's (1984) map is figure 8.
Bredehoeft and Bennett, 1972	Bighorn Basin	A map showing the predevelopment conditions of the Tensleep potentiometric surface. The map does not account for the basin's structure, including oil and gas field anticlines and other asymmetric anticlines, which have been considered in other publications (such as Haun's 1984 map, Huntton (1985b), Jarvis (1986), and Spencer (1986)). However, the map does depict Zapp's (1956) approximate direction and magnitude, in feet per mile, of the probable inclination of oil-water contact at time of the pool's discovery.
Cooley, 1986	Eastern margin of Bighorn Basin near Ten Sleep, Wyoming	Plate 3 is a map of the 1978 potentiometric surface of the Tensleep Sandstone. It includes some contours along the southwestern flank of the Bighorn Mountains.
Davis, 1984	Laramie Basin	Figure 3 is a present-day (at the time of publication) potentiometric map of the Casper aquifer. Figure 6 is a reconstructed potentiometric map of the Casper aquifer prior to oil field development.
Garland, 1996	Southern Powder River Basin; northern Laramie Mountains	Plate III highlights groundwater flow "compartments" formed by structures along the northern Laramie Mountains and the southern Powder River Basin.
Geldon, 2003b	Arizona, New Mexico, Colorado, Utah, and southwest Wyoming	The report emphasizes the Four Corners region, but the map includes contours in the Greater Green River Basin. The map (plate 11, right map) depicts the Weber–De Chelly and Cutler–Maroon Zones of the Canyonlands aquifer in the Upper Colorado River Basin. It features arrows indicating the direction of flow, assuming the aquifer is isotropic. However, arrows only show flow into the Greater Green River Basin and do not indicate an escape path for water out of the basin.
Johnson, 1994	Northern Hanna Basin	Plate III shows the potentiometric surface of the Tensleep aquifer in the Troublesome–Difficulty area, Carbon County, Wyoming.
Kyllonen and Peter, 1986	Northern Black Hills and Bear Lodge Mountains	Figure 10 is a potentiometric surface map of the Minnelusa aquifer in 1960.

Table 3. Continued

Author(s)	Coverage	Location in Document; Comments
Lindner-Lunsford and others, 1989	Arizona, New Mexico, Colorado, Utah, and southwest Wyoming	Figure 12 on plate 2 is a generalized potentiometric map of upper Paleozoic aquifers, including the Weber and Tensleep.
Lundy, 1978	Laramie Basin	Figure 8 is a generalized potentiometric surface map for the top of the Casper Formation.
Strobel and others, 2000	Black Hills	Two sheets present the potentiometric surface of the Minnelusa Formation in the Black Hills area, which is primarily in South Dakota. Sheet 1 covers the northern area and sheet 2 covers the southern area.
Taucher and others, 2012	Bighorn Basin	Plate XII is a potentiometric surface map of the Tensleep aquifer. It is from Bredehoeft and Bennett (1972), which did not account for the structure of the basin and represents predevelopment conditions.
Taucher and others, 2012	Southern Bighorn Basin	Plate XIII is a potentiometric surface map for the Tensleep and other upper Paleozoic aquifers. The original map was created by Spencer (1986) and Jarvis (1986). It provides well locations and head values.
Taucher and others, 2013.	Hartville Uplift and the northwest edge of the Denver-Julesburg Basin.	Plate 5 is a generalized potentiometric surface map in the Paleozoic aquifer system of the Denver–Julesburg Basin, which includes the Casper, Fountain, and Hartville Formations.
Thompson, 1979	Laramie Basin	Figure 10 is a potentiometric map associated with the Casper aquifer near Laramie, Wyoming.

Variability of Tensleep Water Levels

Hydrographs of the Tensleep are available from the Wyoming State Engineer’s office (2023) and the U.S. Geological Survey (2023). Figures 1 and 2 show hydrographs with associated location maps. Individual hydrographs illustrate the variability of water levels over time in specific areas. The composite hydrograph displays water-level depths at a consistent scale, offering a statewide perspective (figure 3). While individual hydrograph variability may be of local interest, it appears less pronounced at the statewide scale (figure 3). The compilation graph also indicates the timeframes of the hydrographs relative to one another (figure 3).

Individual hydrographs reveal that water levels can rise in one part of the state while declining in another. Around 2001, wells Cole 41A, CCMOW 6A, and CCMOW 5A in the northeastern Powder River Basin exhibited high water levels (figure 2). Well ETSI T-1 in the Powder River Basin also showed rising water levels during this period (figure 2). At Natural Bridge in the southern Powder River Basin (NB in figure 1), this period was part of an extended high water-level phase. In the Laramie Basin, wells Htn 1 and Htn 2 showed low water levels during this time (figure 1). These wells are in close proximity and plot together on the composite hydrograph

(figure 3). Water levels in Htn 2 were slightly over 9 feet higher than water levels in Htn 1. In the southern Bighorn Basin, GTW 1 experienced declining water levels in 2001 (figure 1). Future analysis of hydrographs may help differentiate between local and regional recharge events, as well as the potential effects of varying pumping rates across the state. It is also important to note that some of the water levels are for wells that would flow if left uncapped, such as CCMOW 2A (figure 2).

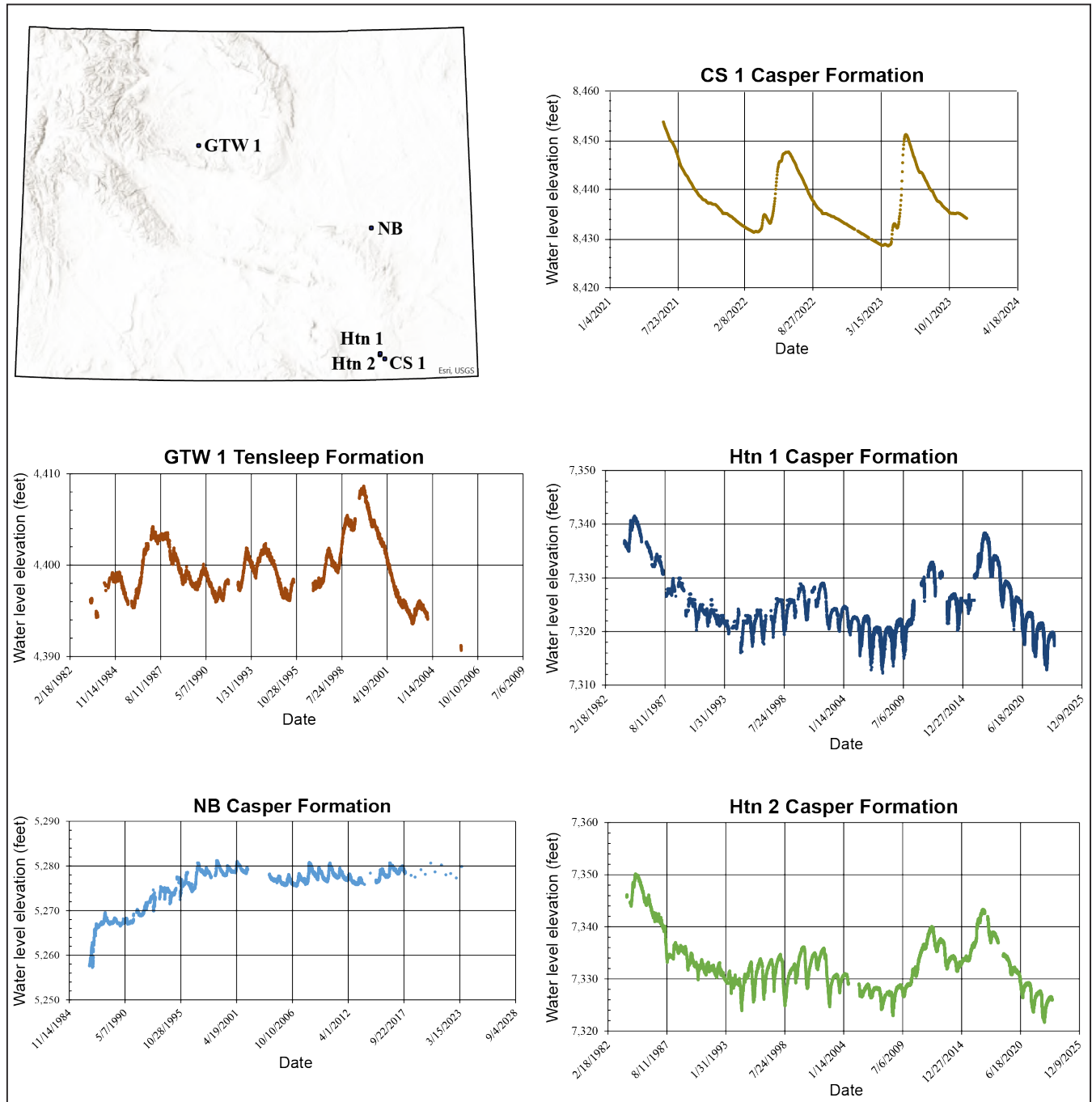


Figure 1. Location map highlighting wells in central and southeastern Wyoming, with corresponding Tensleep hydrograph shown for each well.

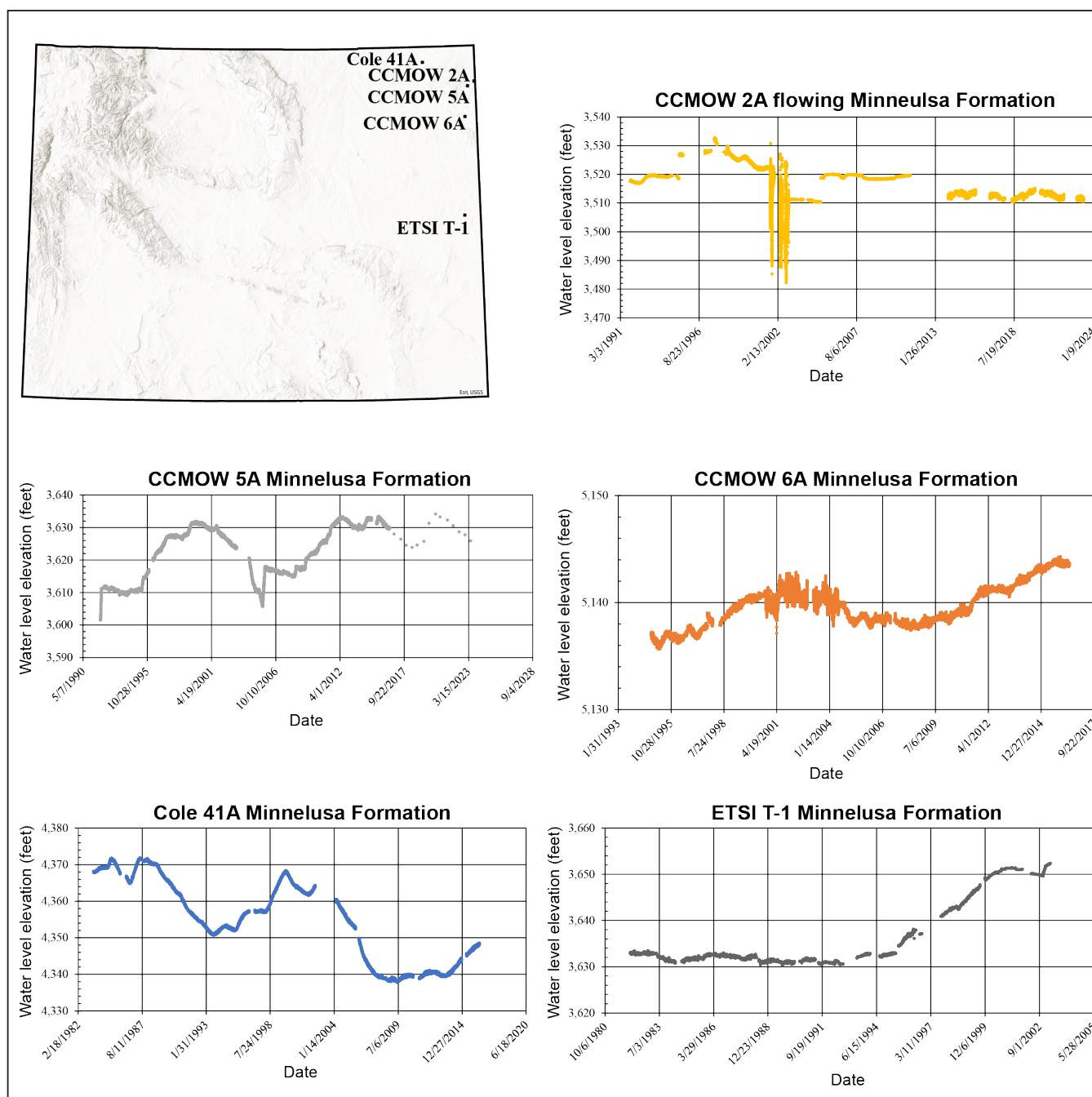


Figure 2. Location map highlighting wells in northeastern Wyoming, with corresponding Tensleep hydrograph shown for each well.

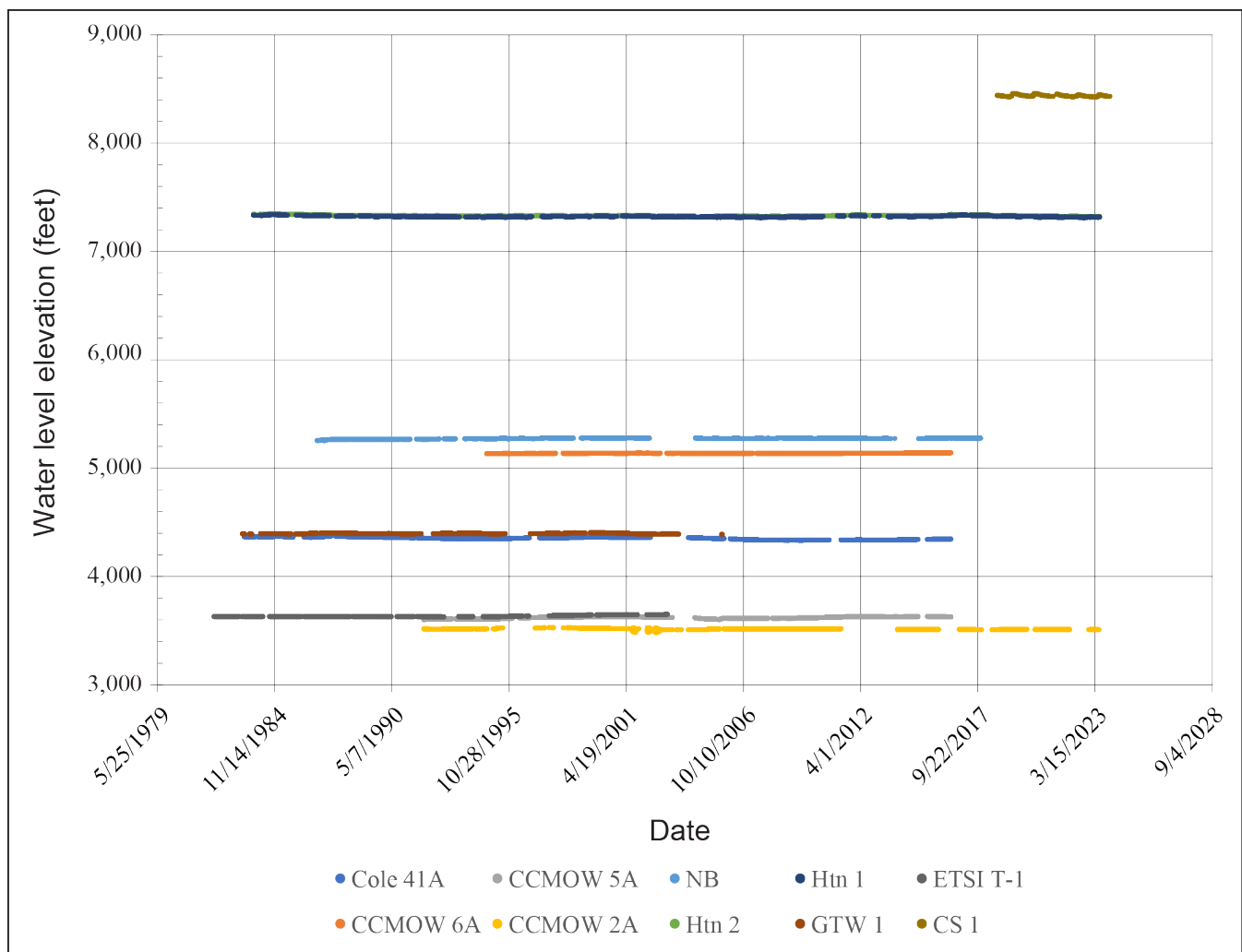


Figure 3. Tensleep hydrographs shown on a statewide scale. The variations shown in this composite hydrograph are subordinate to the well’s water-level elevation. On a statewide scale, this composite hydrograph shows that the variations seen in each hydrograph (figure 1 and figure 2) are secondary when comparing the well’s range of water levels to other wells’ ranges of water levels. The highest water-level elevation occurs in southeastern Wyoming (CS 1). Directly below it are two nearly overlapping hydrographs—Htn 1 and Htn 2. In the 5,000-foot to 6,000-foot bin, NB has the highest elevation, while CCMOW 6A has the lowest. In the 4,000-foot to 5,000-foot bin, Cole 41A is in northeastern Wyoming, and GTW 1 (from west-central Wyoming) plots above it. In the 3,000-foot to 4,000-foot bin lie three wells in eastern Wyoming. ETSI T-1 has the earliest record of water levels, beginning in the early 1980s. These data overlap the initial record of CCMOW 5A. The shallowest hydrograph is CCMOW 2A, a flowing well in northeastern Wyoming, near the state’s border with South Dakota.

The USGS previously maintained water levels collected by the State Engineer’s Office (SEO). Although this practice has lapsed, the USGS still provides a subset of SEO data to users. Table 4 details the data available from each source and provides identifiers for users wishing to obtain the data. The table also lists the codes used for hydrograph locations in figures 1, 2, and 3.

Table 4. Sources of Tensleep hydrograph data, time limitations on the data, and identifiers of the data.

Figure 1 Identification	SEO Name	USGS Name	Formation	SEO Permit Number	USGS Date Range ^a	SEO Date Range ^b	USGS Site Number
CS 1	---	CS1	Casper	---	Daily Data: 08/16/2018 to 10/04/2023; Field Measurements: 02/28/2018 to 09/14/2023	---	411412105272001
Htn 2	Huntoon No. 2	Htn-2	Casper	44232	Daily Data: 11/16/1983 to 09/29/2011; Field Measurements: 9/1/1978 to 10/17/2011	1983 to 2025	411703105314001
Htn 1	Huntoon No. 1	Htn-1	Casper	35758	Daily Data: 11/15/1983 to 06/14/2011; Field Measurements: 4/1/1977 to 10/17/2011	1983 to 2025	411751105312701
NB	Natural Bridge	Natural	Casper	73137	Daily Data: 11/06/1986 to 09/29/2010 Field Measurements: 12/18/1986 to 12/12/2011	1986 to 2025	424420105364201
ETSI T-1	---	ETSI T-1	Minnelusa	24279	Daily Data: 01/12/1982 to 03/20/2003 Field Measurement: 09/04/1974	---	430421104200701
GTW 1	---	GTW-1	Tensleep	60622	Daily Data: 5/10/1983 to 10/11/2005; Field Measurements: 5/26/1982 to 9/22/2008	---	434136108183301
CCMOW 6A	CCMOW-6A	---	Minnelusa	96807	Daily Data: 09/30/1997 to 09/29/2011; Field Measurements: 07/22/1994 to 10/11/2011	1994 to 2025	441113104151002
Cole 41A	Cole No. 41A Minnelusa	---	Minnelusa	63295	Daily Data: 06/08/1983 to 09/29/2009; Field Measurements: 11/13/2003 to 04/25/2012	1983 to 2016	444854104534502
CCMOW 5A	CCMOW-5A	---	Minnelusa	85806	Field Measurement: 08/25/1991	1992 to 2025	443158104114202
CCMOW 2A	CCMOW-2A	---	Minnelusa	85421	---	1992 to 2025	---

^a Hydrographs are from downloads of Daily Data. Field Measurements are groundwater levels not in the hydrographs.^b SEO date ranges estimated from the graphs.

COMPILATION OF SELECTED HYDROGEOLOGIC PARAMETERS

Porosity and Permeability

Previous Studies

Many authors have studied the porosity and permeability of the Tensleep. Fox and others (1975) compiled porosity values for the Tensleep and Weber formations in Wyoming, presenting maps that delineate porosity values surrounding basins west of the Laramie Mountains, Casper Arch, and Bighorn Mountains. They also provided charts illustrating porosity versus permeability derived from core analyses, with separate charts for the Bighorn Basin, the Wind River Basin, and the Greater Green River Basin.

Feathers and others (1981) tabulated porosity, permeability, thickness, and calculated transmissivity for the upper Minnelusa Formation (“Converse sands”) and the middle Minnelusa Formation (“Leo sands”).

Early research on Tensleep porosity and permeability showed a general trend of decreasing permeability with decreasing porosity, despite considerable scatter (Bredehoeft, 1964; Mou and Brenner, 1982). Morgan and others (1978) illustrated how porosity variations in the Oregon Basin Tensleep reservoir correlate with the amounts of dolomite, anhydrite, and dolomite cement. Although the study does not provide extensive individual porosity values directly applicable to this research, it offers a detailed summary of years of investigation into the Oregon Basin field. Shebl (1995) examined cores from 15 oil and gas fields in the Bighorn Basin, summarizing porosity and permeability characteristics of the different deposit types within the Tensleep Sandstone, and summarizing the effects of diagenesis and clays on porosity and permeability. While few specific porosity and permeability values were presented, the study concluded that bounding surfaces inhibit vertical flow, whereas horizontal permeability facilitates lateral flow. Subsequent research highlighted the significance of specific facies within the Tensleep. Wang and others (2022) demonstrated the importance of bedding type in Minnelusa eolian sandstones, differentiating between massive bedding and cross-bedding in a well drilled in the northeastern Powder River Basin. Analysis of core plugs from 9,282 feet and 9,538 feet revealed that massive sandstone exhibited lower porosities and permeabilities. For permeability of approximately one millidarcy (md), porosities ranged from about 3 to 10 percent. Below one md, most permeability values were associated with massive bedding, while above one md, most samples exhibited cross-bedding.

Geldon (2003b) compiled porosity and hydraulic conductivities for the Weber Sandstone, a Tensleep equivalent. However, the focus of that report was the Four Corners area, and the maps only extend to the Greater Green River Basin.

This Study

Porosity and permeability values for oil and gas fields are available in the Wyoming Geological Association’s publications on these fields (Wyoming Geological Association, 1957; Cardinal and Steward, 1979; Lawyer and others, 1981; Hollis and Potter, 1984; Cardinal and others, 1989; Miller and others, 1992; Finley and Miller, 2000; Oil and Gas Field Symposium Committee, 2011). This report incorporates these values to provide a statewide map of average porosity in the Tensleep Sandstone (figure 4). While this report does not present porosity and permeability data from outside oil and gas fields, the compiled data provide valuable insights into the hydrogeologic characteristics of the Tensleep Sandstone within these fields.

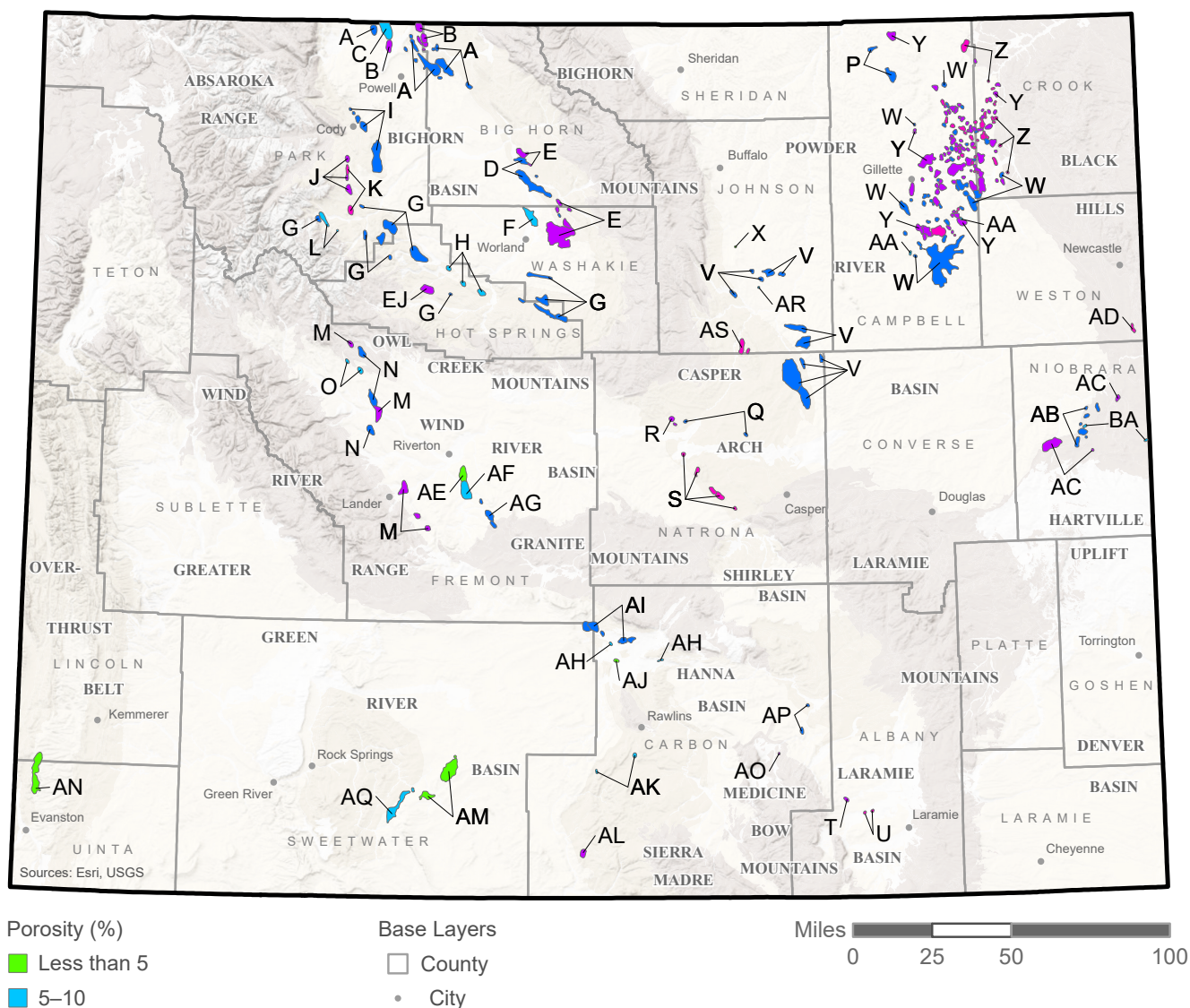


Figure 4. Map illustrating average porosities in the Tensleep reservoirs in oil and gas fields across Wyoming. Letters refer to group porosity (appendix 1). In some areas, including the northeastern Powder River Basin, only a few representative fields have group porosity labels.

Porosity

Porosity, expressed as the percentage of void space in a rock, is a key factor influencing aquifer productivity. Higher porosity results in greater storage of fluids or gases. Porosity data for the Tensleep Sandstone and its equivalents are from the Wyoming Geological Association’s symposium oil and gas fields volumes and are in appendix 1, sorted by basin, group porosity, and field name. Group porosity represents a porosity range or bin used for mapping and analysis.

To create accurate porosity maps, the technique used sets the upper value for each bin slightly below the maximum. For example, a range of 10 to 15 percent is defined as 10 to <15 percent. This technique was consistently applied to other mapped parameters throughout the report.

Bighorn Basin

Porosity values in the Bighorn Basin exhibit spatial variability. In the northern part of the basin is a cluster of fields with 10 to 15 percent porosity (A in figure 4) and a few fields farther north exhibiting 15 to 20 percent porosity (B in figure 4). A single field with 5 to 10 percent porosity (C in figure 4) lies northwest of these clusters. On the eastern side, several fields with 10 to 15 percent porosity (D in figure 4) are surrounded by fields with 15 to 20 percent porosity (E in figure 4), and a single 5 to 10 percent porosity field (F in figure 4) is located to the west. The southern and southwestern Bighorn Basin contains numerous fields with 10 to 15 percent porosity (G in figure 4) interspersed with three smaller fields exhibiting 5 to 10 percent porosity (H in figure 4). Southwest of these fields lies field EJ, with 15 to 20 percent porosity. The western Bighorn Basin features a series of fields with 10 to 15 percent porosity (G in figure 4), fields with 15 to 20 percent porosity (J in figure 4), and two smaller fields with 20 to 25 percent porosity (K in figure 4). Two small fields with lower porosities of 5 to 10 percent (L in figure 4) are west of this assemblage. Lastly, a string of fields with 10 to 15 percent porosity (I in figure 4) is near Cody.

Wind River Basin

Several fields in the western Wind River Basin have 15 to 20 percent porosity (M in figure 4). Two smaller fields with 5 to 10 percent porosity (O in figure 4) and three with 10 to 15 percent porosity (N in figure 4) are interspersed among this group. Three additional small fields with 15 to 20 percent porosity, also labeled M, are located at the southern end of this series. Southeast of Riverton is a field with 1 to 5 percent porosity (AE in figure 4). Another field with 5 to 10 percent porosity (AF in figure 4) is directly to the south. Farther southeast are three fields with 10 to 15 percent porosity (AG in figure 4).

Casper Arch

A series of small fields having varying porosities extends eastward along the Casper Arch. These fields have porosities ranging from 10 to 15 percent (Q in figure 4), 15 to 20 percent (R in figure 4), and 20 to 30 percent (S in figure 4).

Powder River Basin

The Powder River Basin contains numerous fields. The western edge of the Powder River Basin has many fields with 10 to 15 percent porosity (V in figure 4). South of these fields is one small field with 5 to 10 percent porosity (AR in figure 4). Northwest of the V fields lies a single field exhibiting 1 to 5 percent porosity (X in figure 4). Two small fields with 20 to 30 percent porosity (AS in figure 4) are south and west of these V fields, on the Casper Arch.

The northeastern Powder River Basin contains large clusters of small Minnelusa Formation fields. Many of these fields are unlabeled on the map due to their small size and high density. In the southern part of this cluster is a large field with 10 to 15 percent porosity (W in figure 4). West of these fields lies a small field with 1 to 5 percent porosity (AA in figure 4). Farther north, numerous fields have 15 to 20 percent porosity (W in figure 4), along with a single field with 5 to 10 percent porosity (AA in figure 4). Farther north are fields with 20 to 30 percent porosity (Z in figure 4). Near the northern border of Wyoming, a general trend of increasing porosity from west to east (deeper to shallower) is evident, with fields exhibiting porosities of 10 to 15 percent (P in figure 4), 15 to 20 percent (Y in figure 4), and 20 to 30 percent (Z in figure 4). This general trend aligns with the overall observation that porosity tends to increase towards shallower depths and basin margins. However,

exceptions to this trend are common, reflecting the complex and heterogeneous porosity distribution within the basin. These trends were not statistically analyzed in this study.

In the southeastern Powder River Basin and extending onto the Hartville Uplift, several fields exhibit 10 to 15 percent porosity (AB in figure 4). A few fields have 15 to 20 percent porosity (AC in figure 4). Northeast of these fields is a single field with 20 to 30 percent porosity (AD in figure 4). East are two small fields with 5 to 10 percent porosity (BA in figure 4).

Laramie Basin, Hanna Basin, North of Medicine Bow Mountains

Within the Laramie Basin, porosity data are available for only three fields. These include one small field with 15 to 20 percent porosity (T in figure 4) and two small fields with 20 to 30 percent porosity (U in figure 4). Northwest of the Laramie Basin, on the southeastern flank of the Hanna Basin, two fields have 10 to 15 percent porosity (AP in figure 4). Southwest of these fields lies one small field on the northern flank of the Medicine Bow Mountains with 15 to 20 percent porosity (AO in figure 4).

Greater Green River Basin

The eastern Greater Green River Basin has a scattered distribution of fields with varying porosities. A cluster of fields with 10 to 15 percent porosity (AI in figure 4) is in the northern part of this area. Two small fields with 5 to 10 percent porosity (AH in figure 4) are located south and southeast of this cluster. A field with 1 to 5 percent porosity (AJ in figure 4) lies south of the western AH field. Southwest of Rawlins, two additional fields exhibit 5 to 10 percent porosity (AK in figure 4). South of these fields, on the extreme western flank of the Sierra Madre Mountains, lies a field with 10 to 15 percent porosity (AL in figure 4). Moving westward, a field east of Rock Springs has two parts with porosities of 5 to 10 percent (AQ in figure 4). Northeast of these fields are two more fields with lower porosity values of 1 to 5 percent (AM in figure 4). Finally, a large field with 1 to 5 percent porosity (AN in figure 4) lies west of the Greater Green River Basin, in the Overthrust Belt of southwestern Wyoming.

Permeability

Permeability is a measure of a rock's ability to transmit fluids. Permeability data for the Tensleep Sandstone and its equivalents are from the Wyoming Geological Association's oil and gas field symposium volumes and are listed in appendix 2, categorized by basin, group permeability, and field name. Group permeability represents a range or bin used for mapping and analysis. Figure 5 shows the wide range of permeability values within the Tensleep Sandstone.

Bighorn Basin

Permeability values in the Bighorn Basin exhibit significant variation. In the northern region, most fields exhibit permeability ranging from 10 md to 100 md (A in figure 5), with some greater than 100 md (B in figure 5). One field has notably lower permeability, ranging from 0.1 md to 1 md (C in figure 5). Along the eastern flank, the largest field and several smaller ones have permeabilities of 10 md to 100 md (D in figure 5), while three others exceed 100 md (E in figure 5). A single field has permeabilities of 1 md to 10 md (F in figure 5). Fields in the southern and southwestern areas predominantly range from 10 md to 100 md (G in figure 5), with a few exhibiting 1 md to 10 md (H in figure 5). In the western Bighorn Basin, the largest field demonstrates 10 md to 100 md permeability (Gm in figure 5), while surrounding fields span various classes, 0.1 md to 1 md (Hi in figure 5), 1 md to 10 md (H in figure 5), 10 md to 100 md (G in figure 5), and greater than 100 md (I in figure 5).

Wind River Basin

Fewer fields in the Wind River Basin have permeability data. Along the western anticline trend, permeabilities are categorized as 10 md to 100 md (M in figure 5), 1 md to 10 md (N in figure 5), and 0.1 md to 1 md (O in figure 5). Two fields near the Wind River Range have permeabilities greater than 100 md (P in figure 5).

Casper Arch

Several fields on the southwestern Casper Arch have high permeabilities exceeding 100 md (S in figure 5). A few fields in the northern arch have permeabilities of 10 md to 100 md (R in figure 5). Fields at the border between the Casper Arch and the Powder River Basin have permeabilities of 1 md to 10 md (V in figure 5), 10 md to 100 md (W in figure 5), and greater than 100 md (U in figure 5).

Powder River Basin

In the extreme western Powder River Basin, adjacent to the eastern flank of the Bighorn Mountains, small fields have permeabilities ranging from 10 md to 100 md (W in figure 5) and 1 md to 10 md (V in figure 5). A large cluster of fields in the northeastern basin displays a wide range of permeabilities. In the southern part of this cluster, a large field exhibits low permeability of 0.1 md to 1 md (BA in figure 5), while fields to the northeast show much higher permeabilities of 10 md to 100 md (AA in figure 5). Farther north, many fields have permeabilities greater than 100 md (CA in figure 5). A few fields have permeabilities of 1 md to 10 md (Z in figure 5).

Hartville Uplift

Small fields in the northeastern Hartville Uplift exhibit permeabilities spanning three orders of magnitude: 1 md to 10 md (Z in figure 5), 10 md to 100 md (X in figure 5), and greater than 100 md (Y in figure 5).

Laramie Basin

In the western Laramie Basin, two small fields have permeability measurements, both within the 10 md to 100 md range (YA in figure 5). On the northwestern flank of the Laramie Basin, two small fields exhibit high permeabilities, one greater than 100 md (EA in figure 5) and the other with a permeability of 10 md to 100 md (GA in figure 5).

Greater Green River Basin

Finally, in the eastern Greater Green River Basin, two small fields have relatively low permeabilities of 1 md to 10 md (FA in figure 5). One of these fields is north of Rawlins, and one is located southwest of Rawlins. Between these two fields are two other small fields with permeabilities of 0.1 md to 1 md (FAL in figure 5). North of these fields, on the southern flank of the Granite Mountains, some fields display moderately high permeabilities of 10 md to 100 md (HA in figure 5). A field west of the Sierra Madre, near the southern Wyoming border, shows permeability greater than 100 md (EE in figure 5). Fields east of Rock Springs have the lowest permeabilities of 0 md to 0.1 md (DA in figure 5), while two fields farther west display moderately high permeabilities of 10 md to 100 md (IA in figure 5).

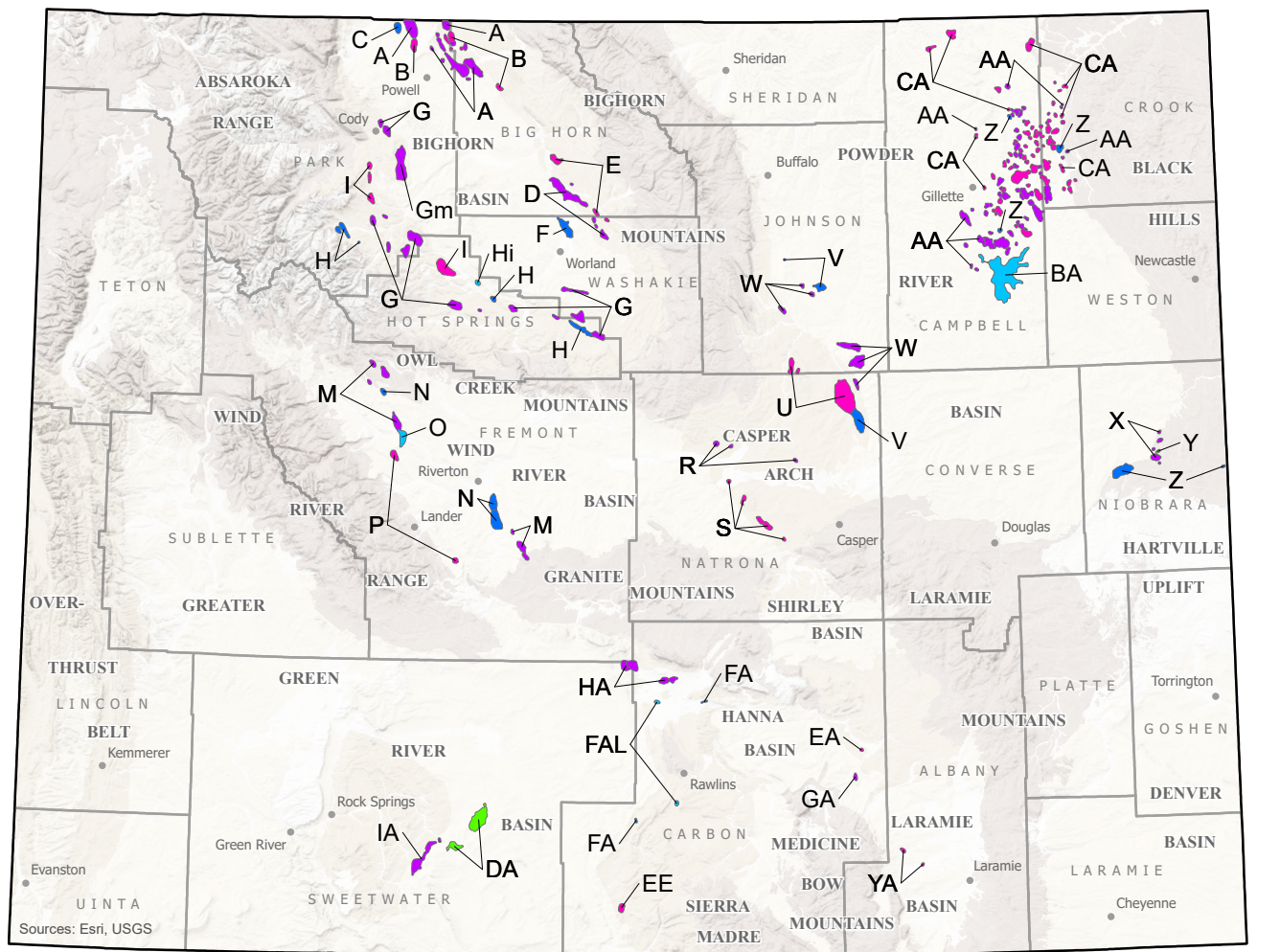


Figure 5. Map illustrating average permeabilities in the Tensleep reservoirs in oil and gas fields across Wyoming. Letters refer to group permeability (appendix 2). In some areas, including the northeastern Powder River Basin, only a few representative fields have group permeability labels.

Figure 6 illustrates average porosity plotted against depth using data compiled from the Wyoming Geological Association’s oil and gas field symposium volumes. Porosity data points exhibit significant scatter but suggest a general decreasing trend with depth. The color scale in figure 6 matches that in figure 4.

Figure 7 presents average permeability versus depth for the compiled data. Permeabilities below 1 md first appear at a depth of approximately 5,000 feet, but permeabilities at similar depths can be orders of magnitude higher. Below 6,000 feet, one permeability value falls below 0.1 md, and two more values below 0.1 md occur at depths greater than 16,000 feet. The limited data set makes it difficult to determine whether these low permeability values at depth indicate a true trend or are artifacts of insufficient sampling.

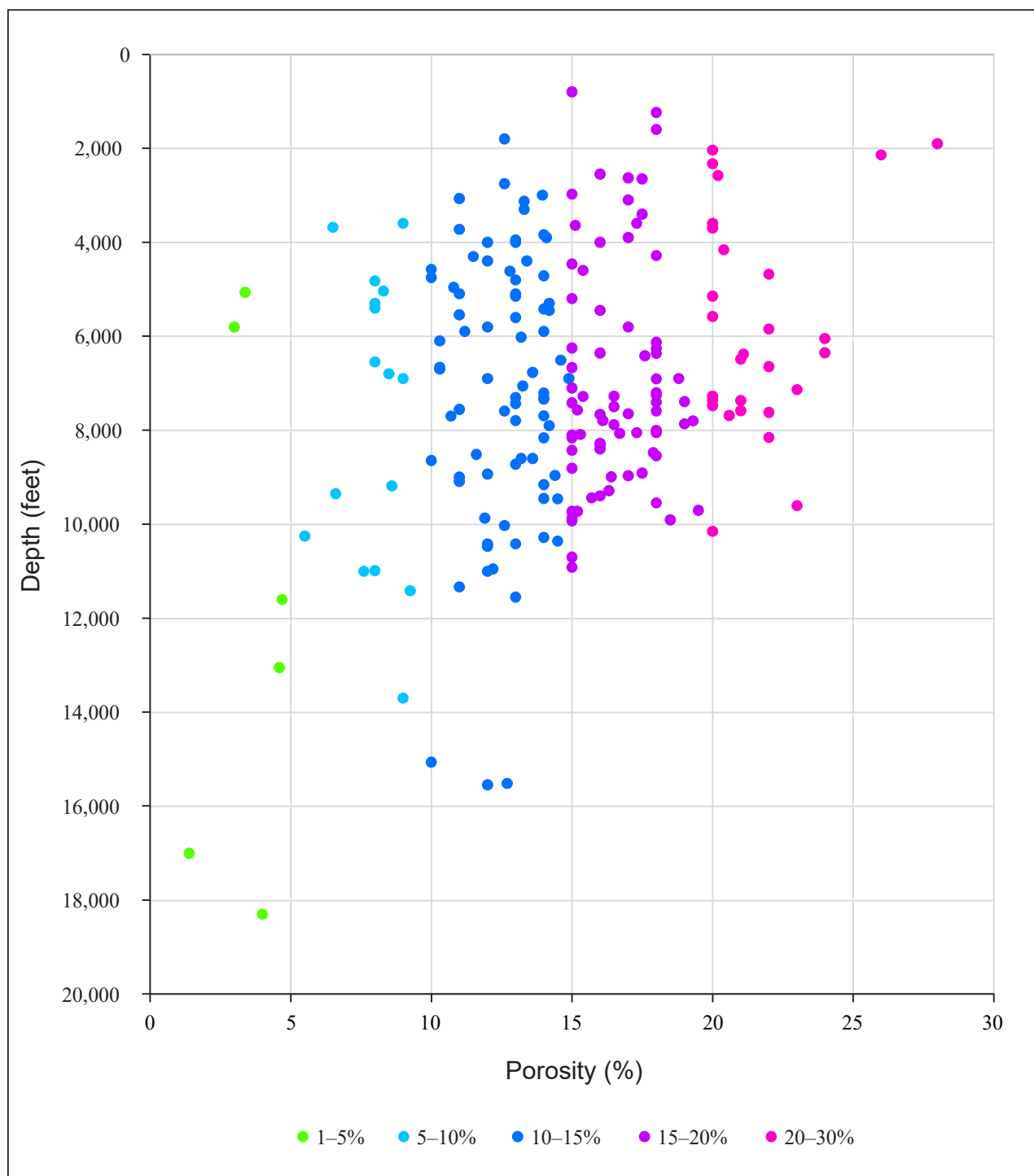


Figure 6. Plot showing depth versus average porosity in the Tensleep reservoirs in oil and gas fields across Wyoming. Data are from the Wyoming Geological Association's oil and gas field volumes. Colors match those in figure 4.

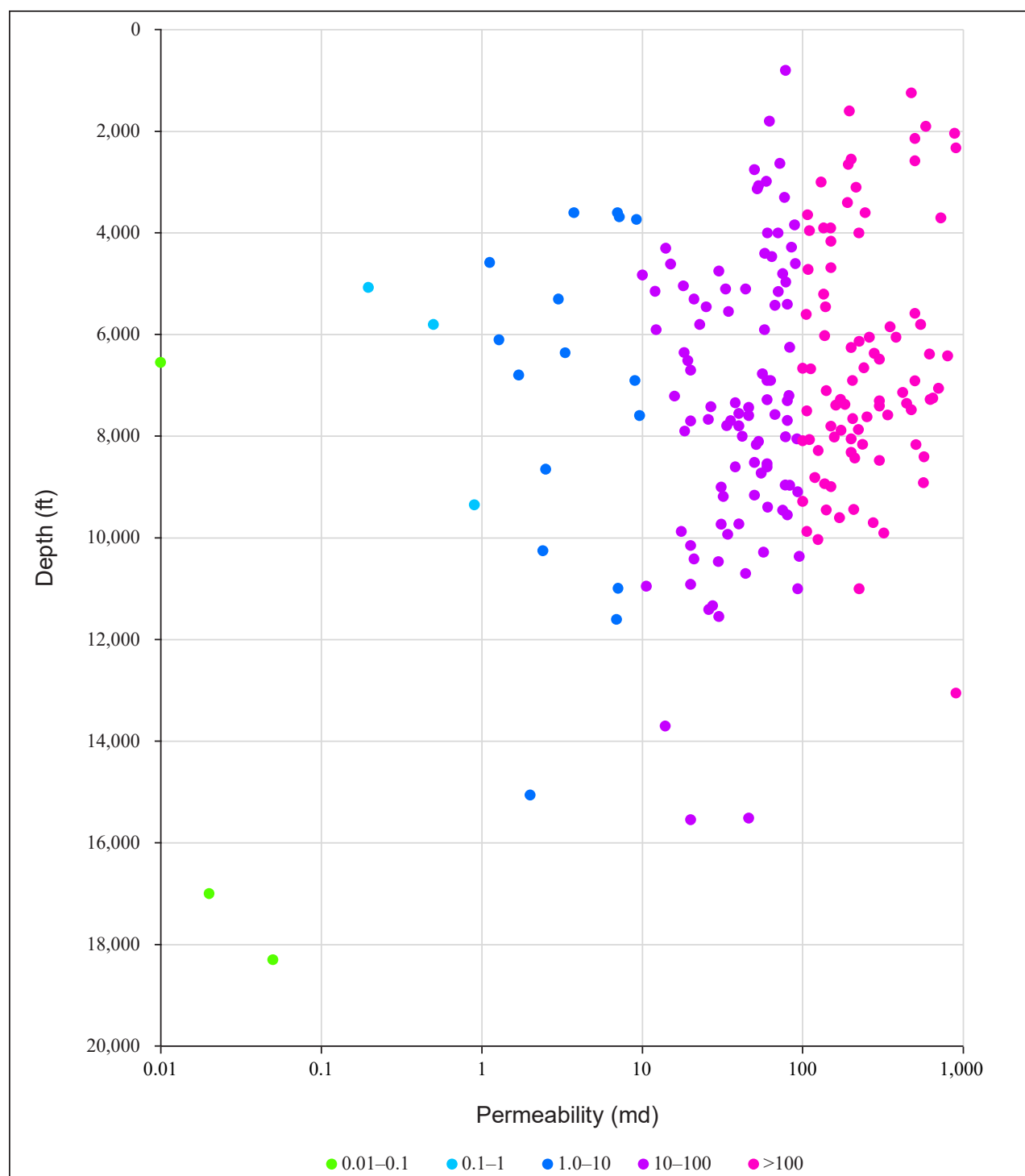


Figure 7. Plot showing depth versus average permeability in the Tensleep reservoirs in oil and gas fields across Wyoming. Data are from the Wyoming Geological Association’s oil and gas field volumes. Colors match those in figure 5.

High porosity does not always correlate with high permeability. Figure 8 illustrates the relationship between average porosity and average permeability. The permeability axis uses a logarithmic scale, while the porosity axis is linear. The plot indicates that as porosity decreases, permeability generally follows a decreasing trend, but with significant scatter. Below 5 percent porosity, permeability consistently falls below 10 md. Above 10 percent porosity, permeability spans a broader range, from 1 md to nearly 1,000 md. For a given porosity value, observed permeability can vary by two to three orders of magnitude.

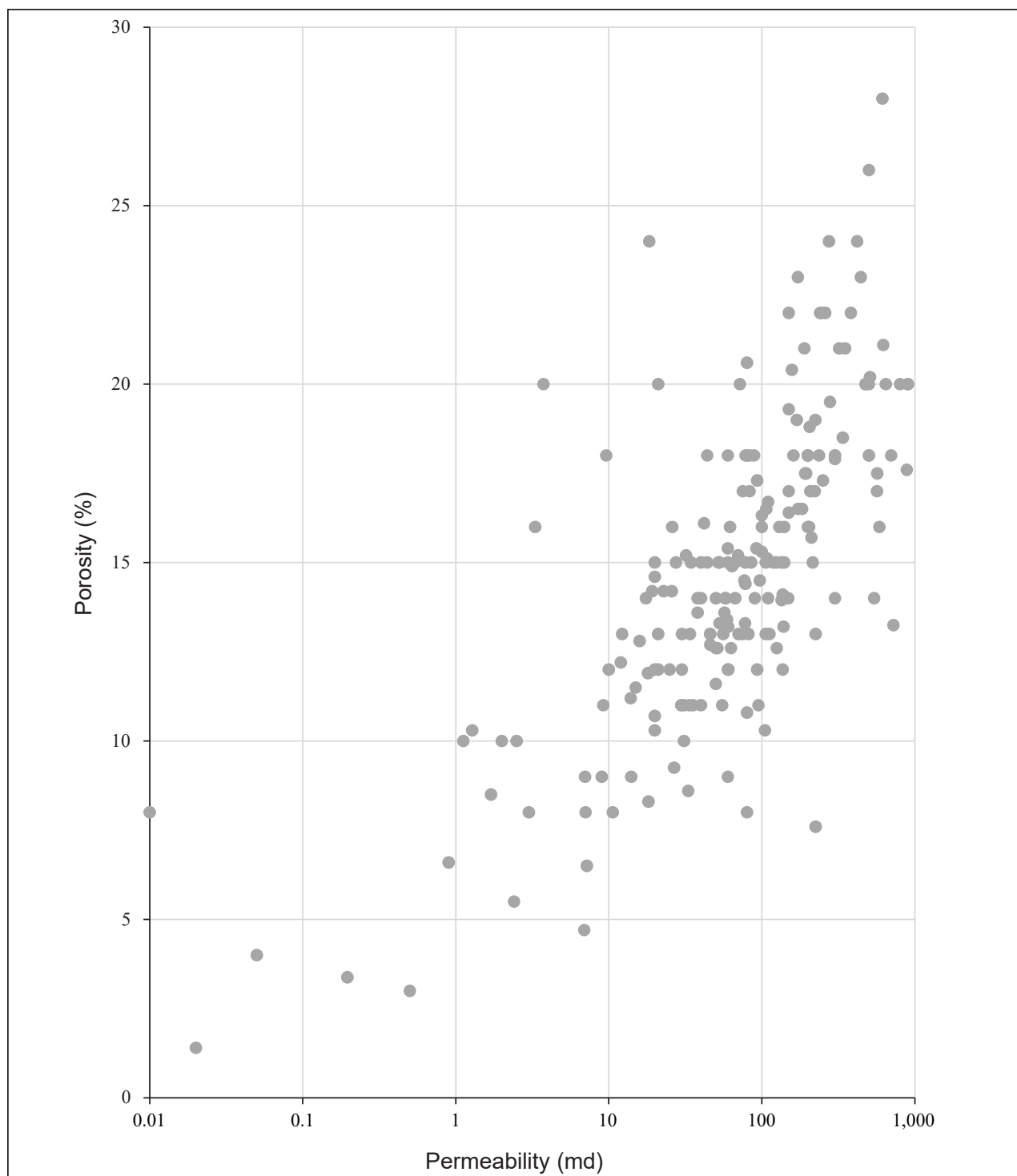


Figure 8. Plot of average porosity versus average permeability in the Tensleep reservoirs in oil and gas fields across Wyoming. Data are from the Wyoming Geological Association's oil and gas field volumes.

Recharge

Recharge is the process of water entering an aquifer. Recharge estimates were developed for spatial groupings of Tensleep outcrops. Table 5 provides the groupings, abbreviations, and long-term average recharge estimate for each outcrop group shown in figure 9.

Recharge measurement poses significant challenges (Bredehoeft, 2007). One approach is to estimate baseflow, the portion of streamflow sustained by groundwater discharge, assuming it represents long-term average recharge. Taboga and Stafford (2016) used this method, applying a USGS model to estimate evapotranspiration and a simplified water balance for baseflow calculation. They developed an algorithm for estimating long-term average recharge across Wyoming using land cover and climate data. In this study, we applied their algorithm to the Tensleep outcrops to estimate long-term average recharge (figure 10).

Recharge estimates were classified into five categories for presentation. These categories are in the legend for figure 10. Several areas exhibit the highest recharge estimates, including:

- The central-western Bighorn Mountains, which supply recharge to the Bighorn Basin (A in figure 10).
- The central Wyoming Range (B in figure 10), characterized by thin Tensleep outcrops, high precipitation, and low evapotranspiration.
- The northwestern Gros Ventre Mountains (C in figure 10), northwest of the Greater Green River Basin.
- The southeastern Bighorn Mountains (D in figure 10), which contribute recharge to the Casper Arch.

Table 5. Abbreviations of Tensleep outcrop groups and long-term average recharge (baseflow) estimates.

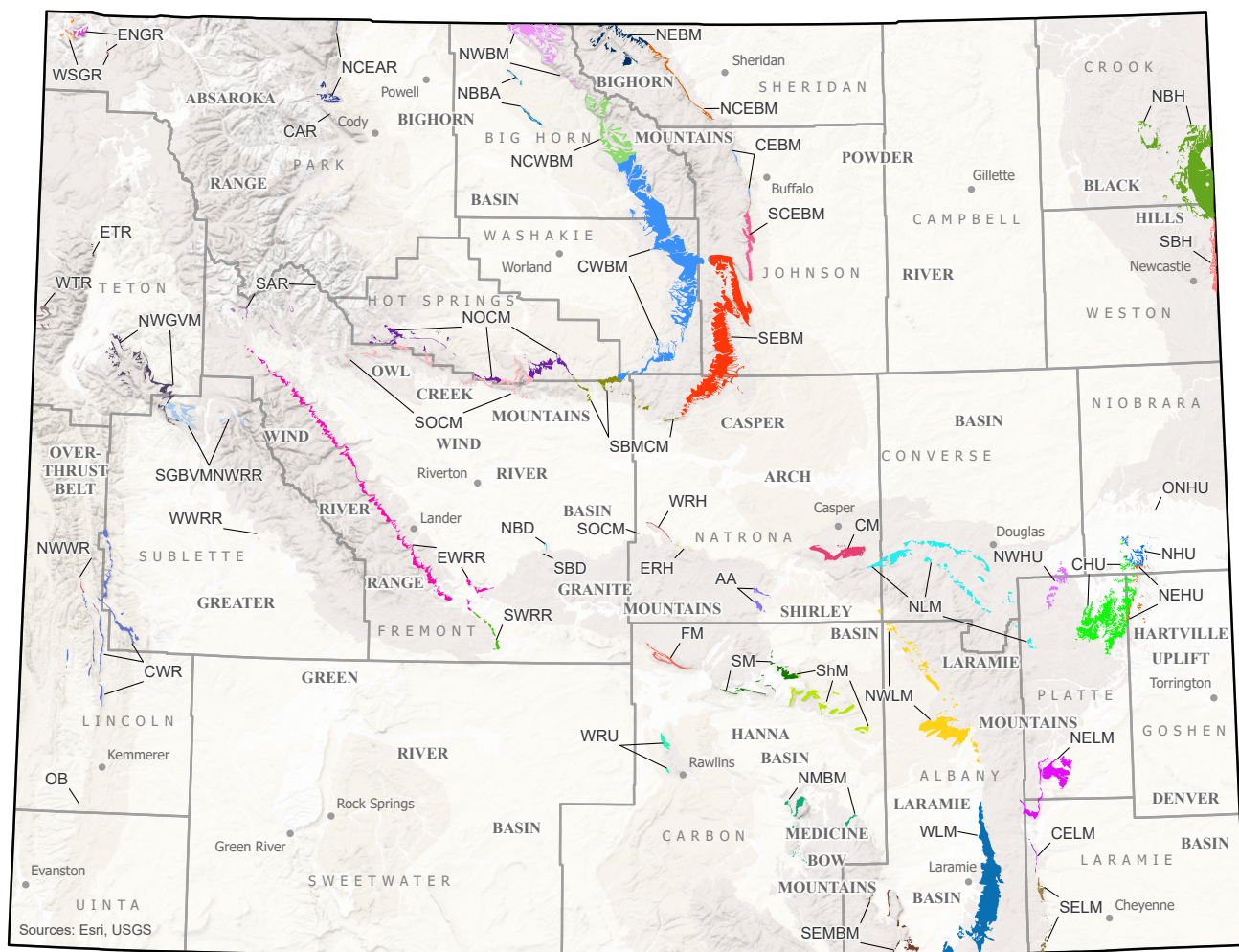
Abbreviation of Tensleep Outcrop Group	Tensleep Outcrop Group	Long-Term Average Estimate of Recharge (Baseflow) (acre-feet/year)
AA	Alcova Area	5.6
CAR	Central Absaroka Range	44.9
CEBM	Central-Eastern Bighorn Mountains	139.1
CELM	Central-Eastern Laramie Mountains	76.5
CHU	Central Hartville Uplift	2,031.7
CM	Casper Mountain	3,803.9
CWBM	Central-Western Bighorn Mountains	36,313.7
CWR	Central Wyoming Range	34,880.3
ENGR	Eastern and Northern Gallatin Range	7,835.0
ERH	Eastern Rattlesnake Hills	9.9
ETR	Eastern Teton Range	521.4
EWRR	Eastern Wind River Range	4,992.8

Table 5. Continued

Abbreviation of Tensleep Outcrop Group	Tensleep Outcrop Group	Long-Term Average Estimate of Recharge (Baseflow) (acre-feet/year)
FM	Ferris Mountains	459.2
NBBA	Northeastern Bighorn Basin Anticlines	6.1
NBD	Northern Beaver Divide	1.0
NBH	Northern Black Hills	7,654.2
NCEAR	Northeastern and Central-Eastern Absaroka Range	2,453.5
NCEBM	North-Central Eastern Bighorn Mountains	1,005.4
NCWBM	North-Central Western Bighorn Mountains	14,526.3
NEBM	Northeastern Bighorn Mountains	3,010.1
NEHU	Northeastern Hartville Uplift	218.9
NELM	Northeastern Laramie Mountains	2,708.1
NHU	Northern Hartville Uplift	447.2
NLM	Northern Laramie Mountains	2,149.6
NMBM	Northern Medicine Bow Mountains	2,791.9
NOCM	Northern Owl Creek Mountains	1,838.4
NWBM	Northwestern Bighorn Mountains	2,324.7
NWHU	Northwestern Hartville Uplift	178.8
NWGVM	Northwestern Gros Ventre Mountains	16,809.8
NWLM	Northwestern Laramie Mountains	2,373.5
NWWR	Northwestern Wyoming Range	732.2
OB	Overthrust Belt	0.4
ONHU	Outlier of Northern Hartville Uplift	1.9
SAR	Southern Absaroka Range	975.0
SBD	Southern Beaver Divide	1.1
SBH	Southern Black Hills	746.2
SBMCM	Southern Bighorn Mountains and Copper Mountain	405.9

Table 5. Continued

Abbreviation of Tensleep Outcrop Group	Tensleep Outcrop Group	Long-Term Average Estimate of Recharge (Baseflow) (acre-feet/ year)
SCEBM	South-Central Eastern Bighorn Mountains	468.4
SEBM	Southeastern Bighorn Mountains	16,464.4
SELM	Southeastern Laramie Mountains	826.0
SEMBM	Southeastern Medicine Bow Mountains	737.1
SGBVMNWRR	Southeastern Gros Ventre Mountains and Northwestern Wind River Range	12,257.6
ShM	Shirley Mountains	2,352.3
SM	Seminole Mountains	2,024.6
SOCM	Southern Owl Creek Mountains	1,340.2
SWRR	Southern Wind River Range	81.6
WLM	Western Laramie Mountains	13,974.4
WRH	Western Rattlesnake Hills	11.7
WRU	Western Rawlins Uplift	8.4
WGR	Western and Southern Gallatin Range	4,282.3
WT	Western Teton Range	12,791.1
WWRR	Western Wind River Range	0.1



Base Layers

□ County

• City

Miles 0 25 50 100

Figure 9. Tensleep outcrop groups of Wyoming. Capital letters with leaders represent abbreviations identifying Tensleep outcrop groups described in the text and listed in table 5. Leaders that appear to end in empty areas indicate outcrops that are barely visible at this scale. Colors are used to help visually distinguish outcrop groups in this figure only.

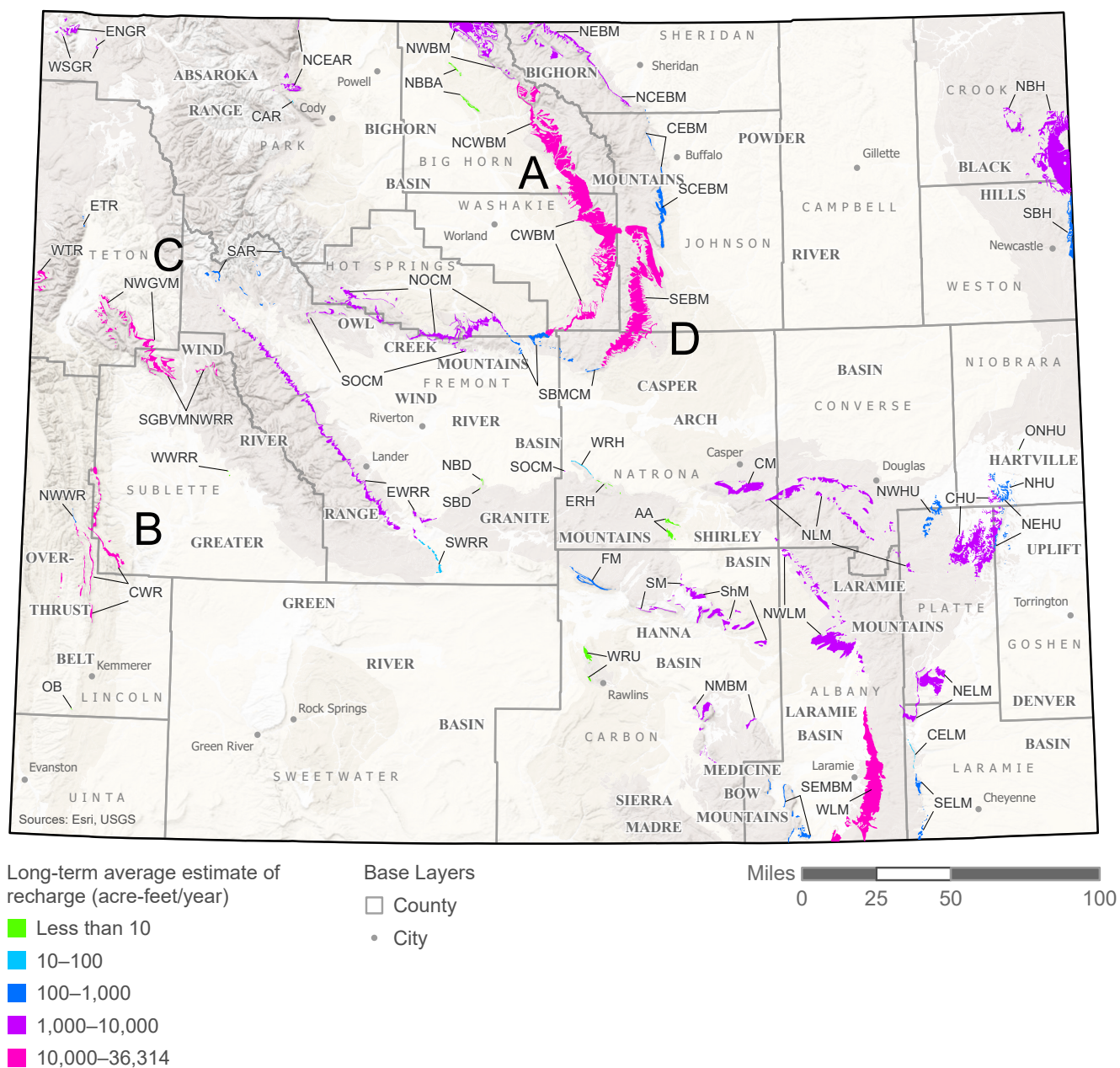


Figure 10. Map showing long-term average recharge estimates in the Tensleep outcrop groups in Wyoming. Regions A, B, C, and D indicate areas with high recharge; see text for further explanation.

Figures 11 and 12 graphically illustrate the long-term average recharge estimates (baseflow), emphasizing the key role of these areas in Tensleep recharge. They also reveal low recharge in other parts of Wyoming, often due to limited outcrop area and arid climate. Figure 11 is a normal plot, while figure 12 is a logarithmic plot.

An area of uncertainty involves the connections between the Wells Formation, which is in the Overthrust Belt (B in figure 10) and the Tensleep Sandstone farther east. Any Wells Formation riding above a thrust fault appears not to have any hydrogeologic communication with its Tensleep equivalent farther east in the deeper Greater Green River Basin.

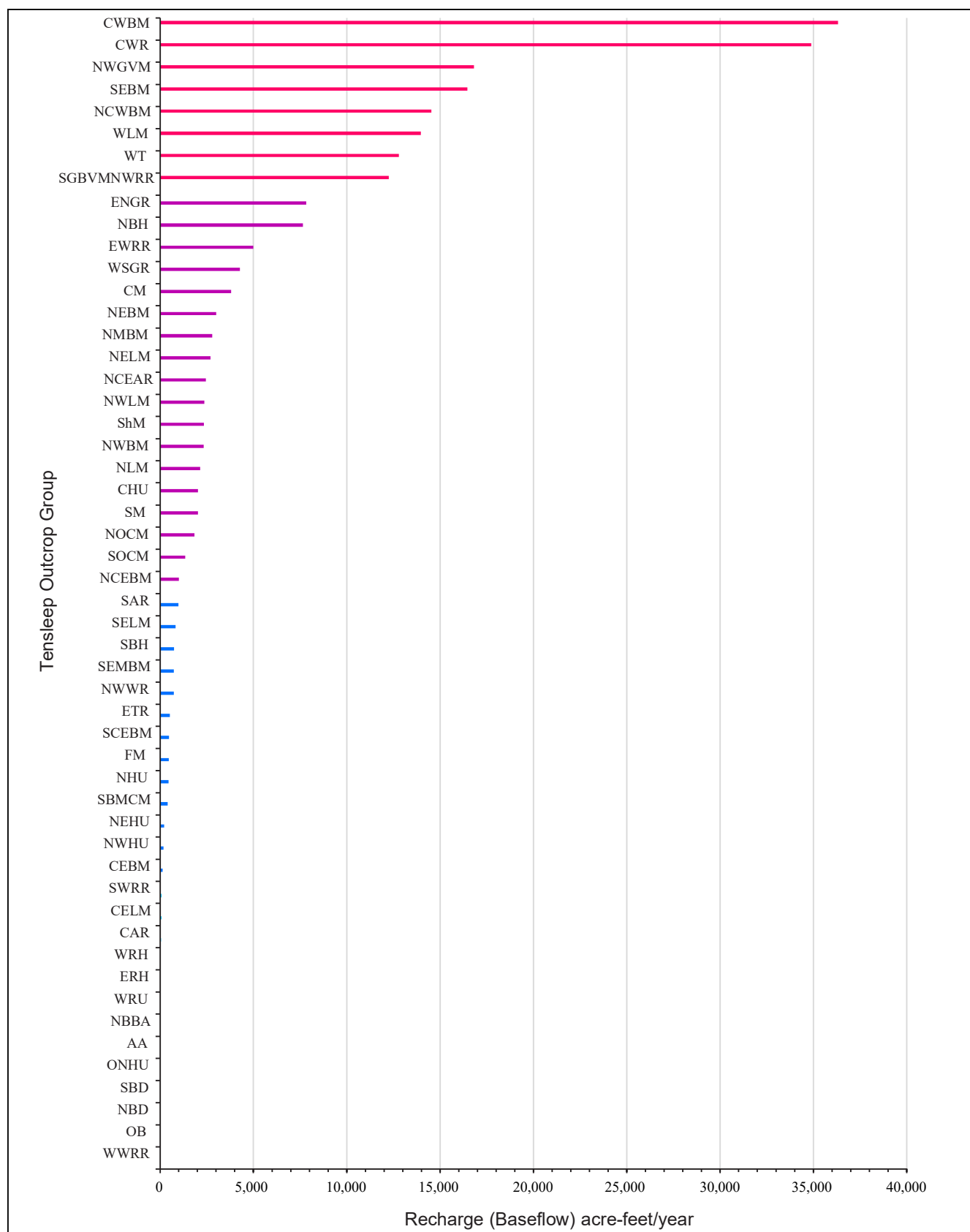


Figure 11. Plot showing a normal scale of long-term average recharge estimates in the Tensleep outcrop groups in Wyoming. Colors match the colors of figure 10.

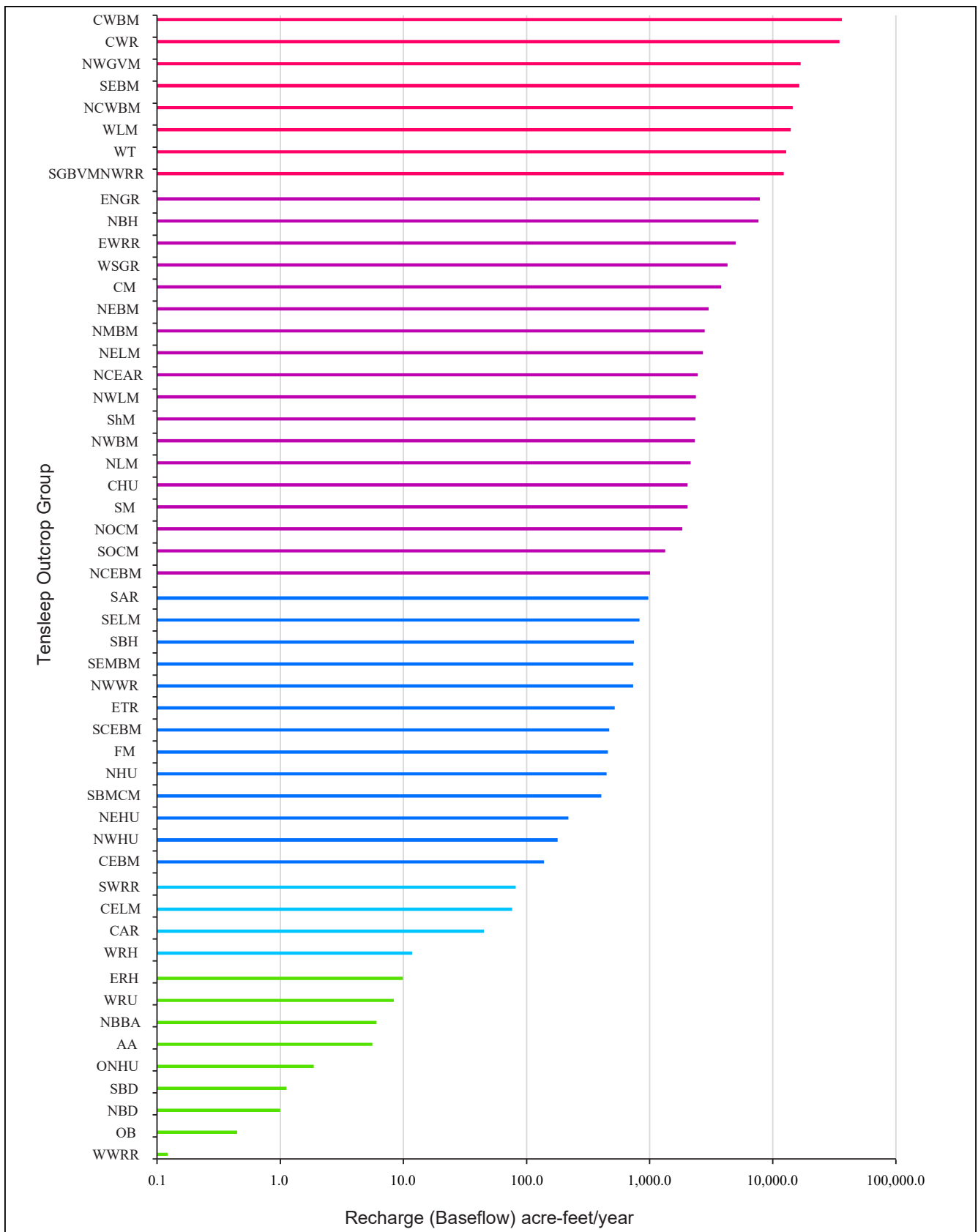


Figure 12. Plot showing a logarithmic scale of long-term average recharge estimates in the Tensleep outcrop groups in Wyoming. Colors match colors of figure 10.

Rejected Recharge

Huntoon (1985b) hypothesized that decreasing permeability in deeply buried formations, such as the Madison and Tensleep, restricts water flow in deep aquifers. Evidence for this decreasing permeability primarily comes from the spacing of potentiometric contours in deep basins. This reduced permeability leads to rejected recharge from the aquifer at basin margins, usually in the form of springs (Huntoon, 1985b). Rahn and Gries (1973) made similar observations for the Madison near the flanks of the Black Hills.

Water Drive in Oil Fields

Previous Work

Drive mechanisms are the forces that move oil and gas from a reservoir to a wellbore. These mechanisms can evolve over the lifespan of an oil or gas field. Water drive is one such mechanism, characterized by water movement within the reservoir that facilitates oil expulsion toward the well. In the 20th century, water drive was recognized in many Wyoming oil fields. Tilted oil-water contacts in reservoirs indicate active water flow. This phenomenon, observed in several oil fields within the Bighorn Basin, exemplifies the influence of hydrodynamics on hydrocarbon reservoirs (Summerford, 1952; Hubbert, 1953; Stone, 1967; Bredehoeft and Bennett, 1972; Pedry, 1975; Bredehoeft and others, 1992; Dahlberg, 1995). Notably, Zapp (1956) mapped the approximate direction of groundwater flow and quantified the dip magnitude of the probable oil-water contact in feet per mile at the time of oil pool discovery within the Bighorn Basin. Lawson and Smith (1966) presented an argument that the tilted oil-water contacts in the Bighorn Basin may be the result of stratigraphic variables. It is beyond the scope of this report to settle this argument.

This Study

The drive mechanisms for producing formations in oil fields are from the Wyoming Geological Association's oil and gas field symposium volumes. Figure 13 depicts fields exhibiting water drive within the Tensleep and its equivalent rock units. The drive mechanism for each field reflects the status at the time of publication of the Wyoming Geological Association's volumes, which varies by basin. Drive mechanisms can change over time, and some fields described in the volumes had mixed drive mechanisms. This report includes only fields where water drive was the sole drive mechanism at the time of publication.

Figure 13 also depicts springs mapped within the Tensleep Formation and its equivalent outcrops based on data from Stafford and others (2017), utilizing spring data from the Wyoming SEO's database. Although the association between these springs and the Tensleep Formation requires field verification, their proximity to water-driven oil fields suggests groundwater flow persists within the Tensleep Formation and its equivalents, basinward of areas with rejected recharge.

Bighorn Basin

Several water-driven oil fields lie basinward of numerous springs identified on the western flank of the Bighorn Mountains (A in figure 13). Interestingly, water-driven oil fields are also present along the west side of the Bighorn Basin (B in figure 13), despite limited exposure of adjacent Tensleep outcrops to potential recharge. The source of this recharge remains unclear.

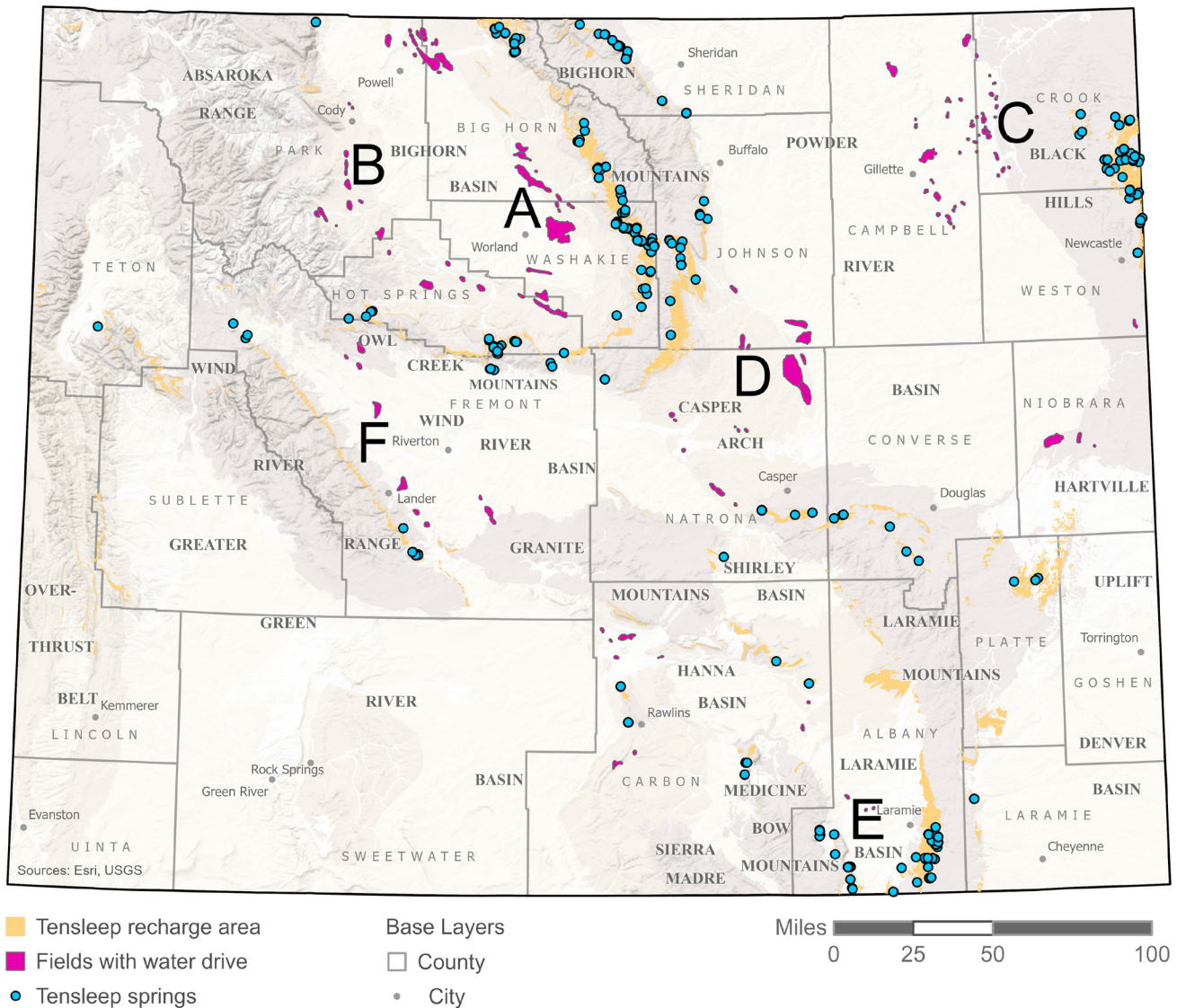


Figure 13. Map showing Wyoming oil fields with water drive in the Tensleep aquifer as of the publication date of the Wyoming Geological Association’s Oil and Gas Field volumes. Letters A–F refer to areas described in the text.

Powder River Basin

On the eastern side of the Powder River Basin, many small water-driven fields are situated approximately 40 miles from the Tensleep (Minnelusa) outcrops on the western side of the Black Hills (C in figure 13). In the western Powder River Basin, water-driven fields are located on the Casper Arch or along the western edge of the Powder River Basin, near the Casper Arch (D in figure 13). As in the Bighorn Basin, no water-driven fields are in the deeper parts of the Powder River Basin.

Laramie Basin

Three small fields are located in the Laramie Basin (E in figure 13), where the Precambrian basement lies approximately 5,000 feet to 10,000 feet below ground surface (Ring, 2025). As shown in figure 5, permeability at these depths may support fluid flow.

Wind River Basin

In the Wind River Basin, water-driven oil fields are offset from recharge outcrops and springs along the flank of the Wind River Range (F in figure 13). It is important to note that the association between these springs and the Tensleep Formation still requires field verification. However, the presence of water drive in deeper Tensleep reservoir rocks suggests water flow may occur farther basinward of areas with rejected recharge. Further investigation is necessary to understand these systems.

Water Quality

Previous Work

Tensleep water chemistry has been the subject of numerous publications. The River Basin Plans compiled and analyzed the water quality of the Tensleep and its equivalent aquifers (Bartos and others, 2010, 2012, 2013, 2014a, 2014b, 2019). Since the release of these reports, several reports on Wyoming's groundwater salinity have been published (Taboga and others, 2016, 2018, 2020, 2022; Taboga and Stafford, 2020). Earlier reports included plates depicting total dissolved solids (TDS) in the Casper-Tensleep aquifer in the Laramie, Shirley, and Hanna basins (Richter, 1981a), Tensleep aquifer system in the Wind River Basin (Richter, 1981b), and Minnelusa/Tensleep aquifer in the Powder River Basin (Feathers and others, 1981). In the Greater Green River Basin, Geldon (2003b) presented a modified map of Lindner-Lunsford and others (1989) highlighting high salinities in the Tensleep and Weber formations within the deep basin. These generalized maps cover a region extending from southwest Wyoming to Arizona.

Salinity

This report presents water-chemistry data from two datasets. The first dataset comprises water-chemistry data from oil and gas wells provided by the Wyoming Oil and Gas Conservation Commission (WOGCC). The U.S. Geological Survey (USGS) (Blondes and others, 2018, 2023) also compiled these data separately. However, for this project, the USGS obtained the data directly from the WOGCC. The second dataset is the USGS environmental water-samples database (U.S. Geological Survey, 2023). This report includes only wells sourced from the Tensleep. Figure 14 illustrates TDS data across Wyoming, with classifications following the USGS salinity-classification system as described by Heath (1983, table 2, remarks column, p. 65) (table 6). Consistent with Taboga and Stafford (2020), this report uses “total dissolved solids” and “salinity” interchangeably.

Bighorn Basin

The Bighorn Basin exhibits low salinity values in the same area (A in figure 14) identified on recharge maps as having high potential for groundwater recharge into the basin. Salinities increase basinward, with scattered values ranging from 10,000 mg/L to 35,000 mg/L (B in figure 14). Most oil field salinity values range from 3,000 mg/L to 10,000 mg/L. Salinity data are unavailable for the center of the Bighorn Basin.

Laramie Basin

Salinities in the Laramie Basin follow an east-to-west gradient of increasing concentration. As shown previously, potential recharge is greatest on the eastern side of the basin, near the western flank of the Laramie Mountains. Recharge areas exhibit the lowest salinities (C in figure 14), which increase westward (D in figure 14). The highest salinities occur farthest from recharge areas, coinciding with the deepest parts of the basin.

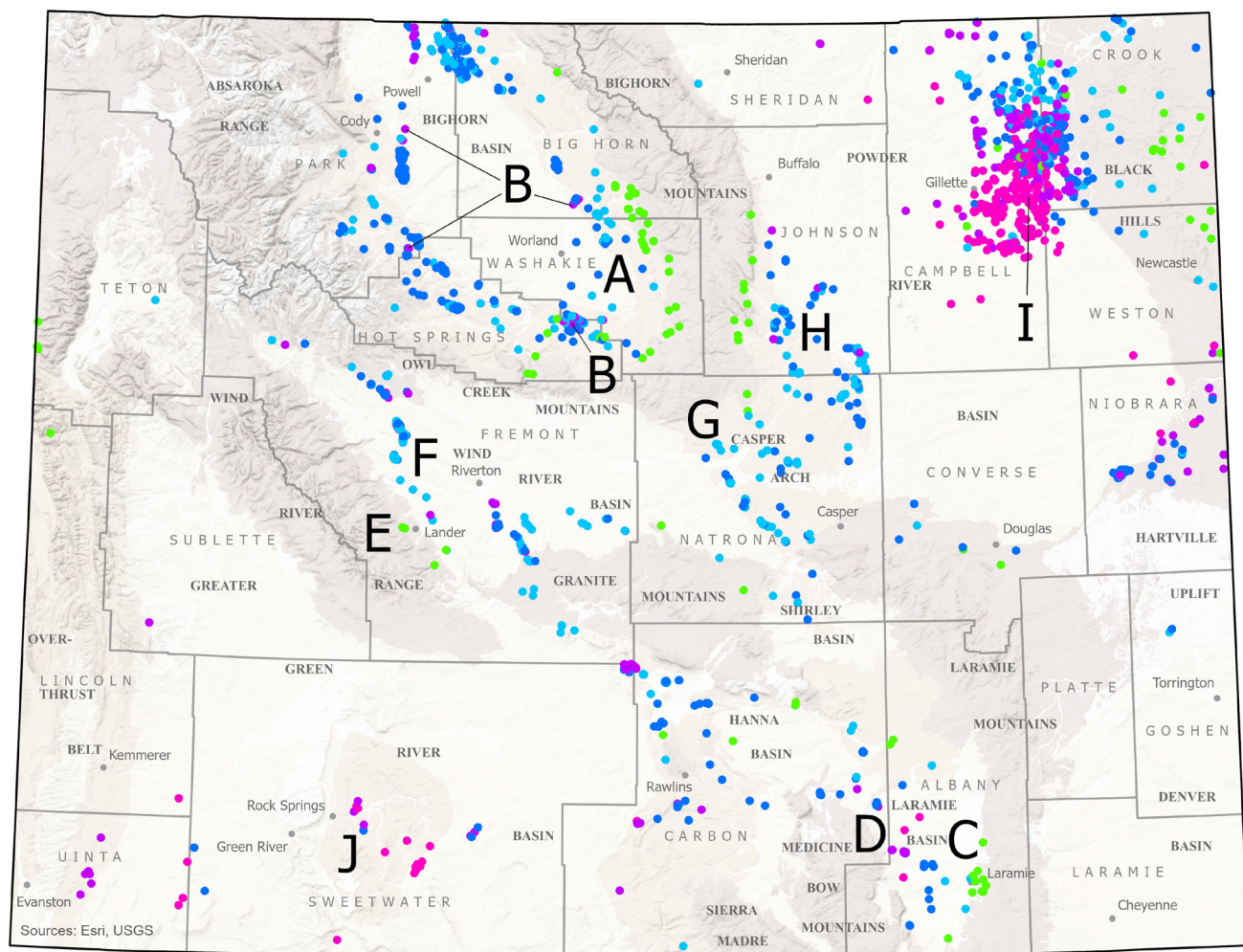


Figure 14. Map showing salinities in the Tensleep aquifer in Wyoming from two sources: production water from oil and gas wells and water-quality samples from water wells. Letters A–J refer to areas described in the text.

Table 6. Classification of water by total dissolved solids (Heath, 1983).

Classification	Total Dissolved Solids (mg/L)
Fresh	Less than 1,000
Slightly saline	1,000–3,000
Moderately saline	3,000–10,000
Very saline	10,000–35,000
Briny	More than 35,000

Wind River Basin and Casper Arch

Low salinity values are observed along the eastern flank of the Wind River Range (E in figure 14). Water samples from the anticlines paralleling the Wind River Range (F in figure 14) generally fall into two salinity ranges: 1,000 mg/L to 3,000 mg/L and 3,000 mg/L to 10,000 mg/L. East of these areas, the basin deepens rapidly toward the Wind River Basin axis south of the Owl Creek Mountains, and no additional water samples are available. Several samples from the Casper Arch, east of the Wind River Basin, exhibit predominantly moderate salinities (G in figure 14). Very few samples are available east of the Casper Arch, corresponding to the deepest part of the Powder River Basin (H in figure 14).

Powder River Basin

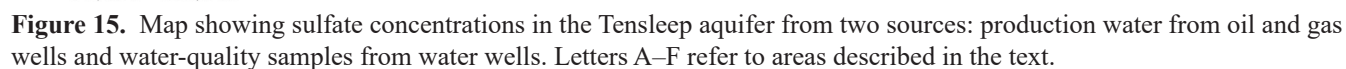
The northeastern Powder River Basin exhibits the highest salinity values within the Tensleep Formation and its equivalents in Wyoming, with particularly high salinities recorded in the Minnelusa Formation. These values reach up to 307,700 mg/L (I in figure 14). Lower salinity values occur in the deeper portions of the Powder River Basin (H in figure 14), though some still fall within the high range of 10,000 mg/L to 34,999 mg/L. Taboga and Stafford (2020) attributed the elevated mean salinity in the Minnelusa Formation to extensive evaporite beds rather than to mean sample depth.

Greater Green River Basin

The Greater Green River Basin also exhibits high salinity values, reaching up to 162,989 mg/L (J in figure 14). These high values may be consistent with the limited presence of Tensleep outcrops that receive abundant long-term average recharge, which would be needed to flush high salinities from the Tensleep in the deeper parts of the basin (figures 9 and 10). Therefore, it might be that the Greater Green River Basin may have poor water quality in the Tensleep; however, most areas in the Greater Green River Basin lack samples, as indicated by the scarcity of wells with water chemistry from the Tensleep. With such limited sampling, conclusions about water quality in this basin remain preliminary and tentative.

Sulfate

Sulfate concentrations in groundwater generally decrease near recharge areas and become enriched farther from basin margins (figure 15). This trend is observed in the Powder River Basin (A in figure 15), eastern Bighorn Basin (B in figure 15), eastern Laramie Basin (C in figure 15), and western Wind River Basin (D in figure 15). However, sulfate chemistry appears mixed in certain areas, such as the Casper Arch (E in figure 15). In the northeastern Powder River Basin (F in figure 15), sulfate concentrations are predominantly moderate (1,000 mg/L to 3,000 mg/L), with some values less than 1,000 mg/L and others ranging from 3,000 mg/L to 10,000 mg/L. Some values are high (10,000 mg/L to 35,000 mg/L), with one exceptionally high value of 150,000 mg/L.



Statewide, calcium concentrations range from less than 1,000 mg/L to as high as 24,515 mg/L, with four samples in the highest range (figure 16). Figure 16 indicates that concentrations are primarily less than 1,000 mg/L in areas such as the Bighorn Basin (A in figure 16) and Casper Arch (B in figure 16). Other areas, such as the Hartville Uplift (C in figure 16) and the northeastern Powder River Basin (D in figure 16), predominantly show values less than 1,000 mg/L, with some ranging from 1,000 mg/L to 3,000 mg/L. In the northeastern Powder River Basin, a few samples exhibit calcium concentrations ranging from 10,000 mg/L to 24,515 mg/L.

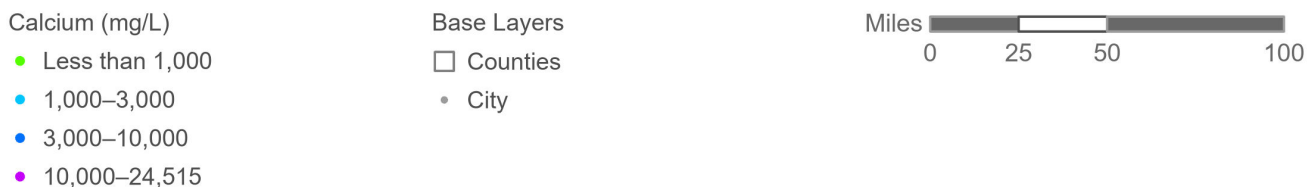
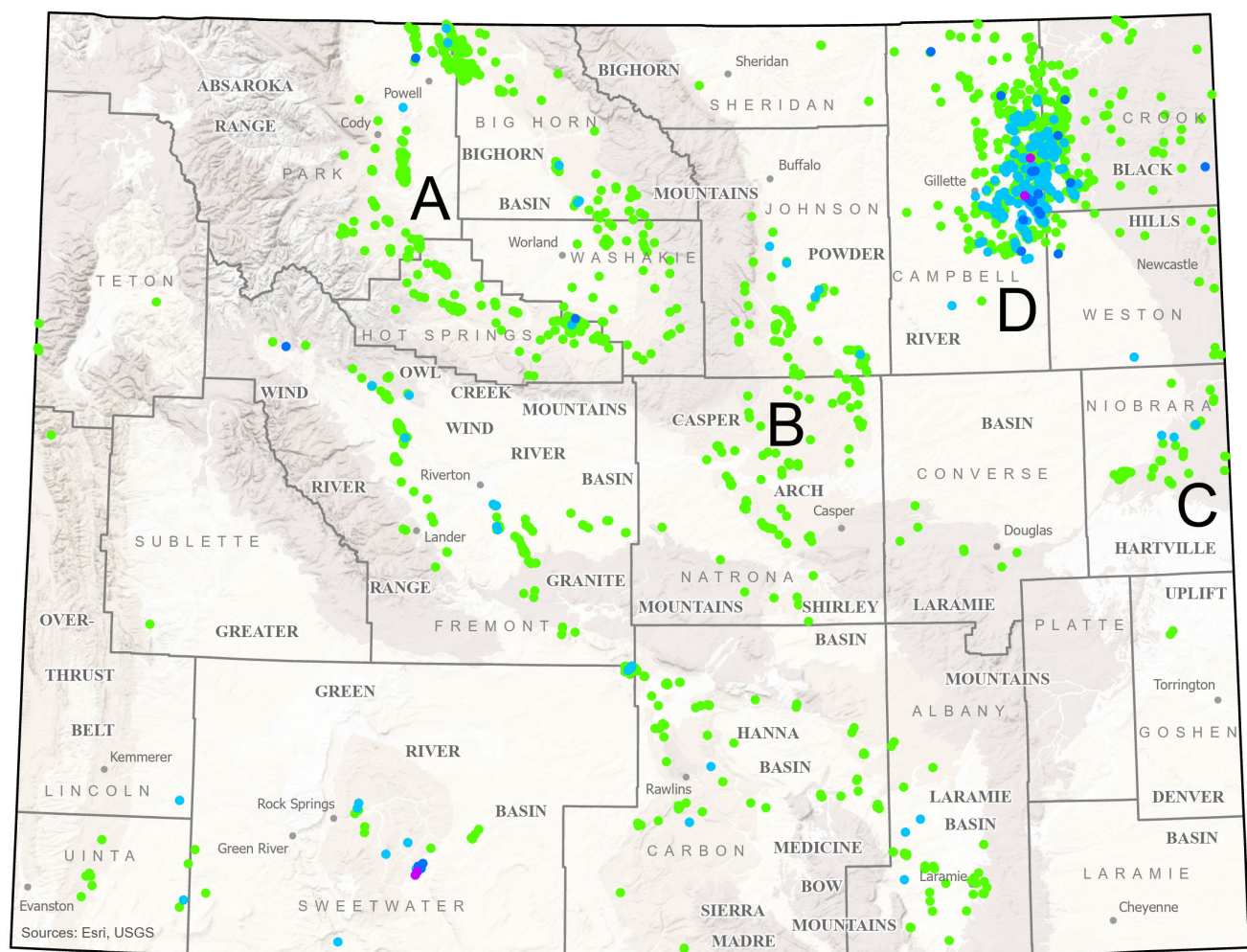


Figure 16. Map showing calcium concentrations in the Tensleep aquifer from two sources: production water from oil and gas wells and water-quality samples from water wells. Letters A–D refer to areas described in the text.

Chloride

Chloride concentrations are notably high in the northeastern Powder River Basin (A in figure 17) and the Greater Green River Basin (B in figure 17). The Bighorn Basin (C in figure 17) contains a few high chloride values ranging from 10,000 mg/L to 35,000 mg/L, but most are below 1,000 mg/L, with some values ranging from 1,000 mg/L to 3,000 mg/L. The Wind River Basin exhibits a similar distribution, with values below 1,000 mg/L along the eastern flank of the Wind River Range (D in figure 17) and some higher values along the anticline trend (E in figure 17) farther out in the basin. No samples are available from the deeper parts of the basin. The Laramie Basin follows a trend similar to salinity, with low values near the western margin of the Laramie Mountains (F in figure 17) and higher values in the basin’s deeper western region (G in figure 17). The Casper Arch shows low chloride values, mostly below 1,000 mg/L (H in figure 17). In the western Powder River Basin (I in figure 17) and the eastern Casper Arch (H in figure 17), most values are less than 1,000 mg/L, with only

a few higher values. The Hartville Uplift (J in figure 17) and adjacent Powder River Basin contain some high chloride values, both within the basin and along the arch's edge. Farther south in the Hartville Uplift, low chloride values appear in the northernmost Denver Basin (K in figure 17).

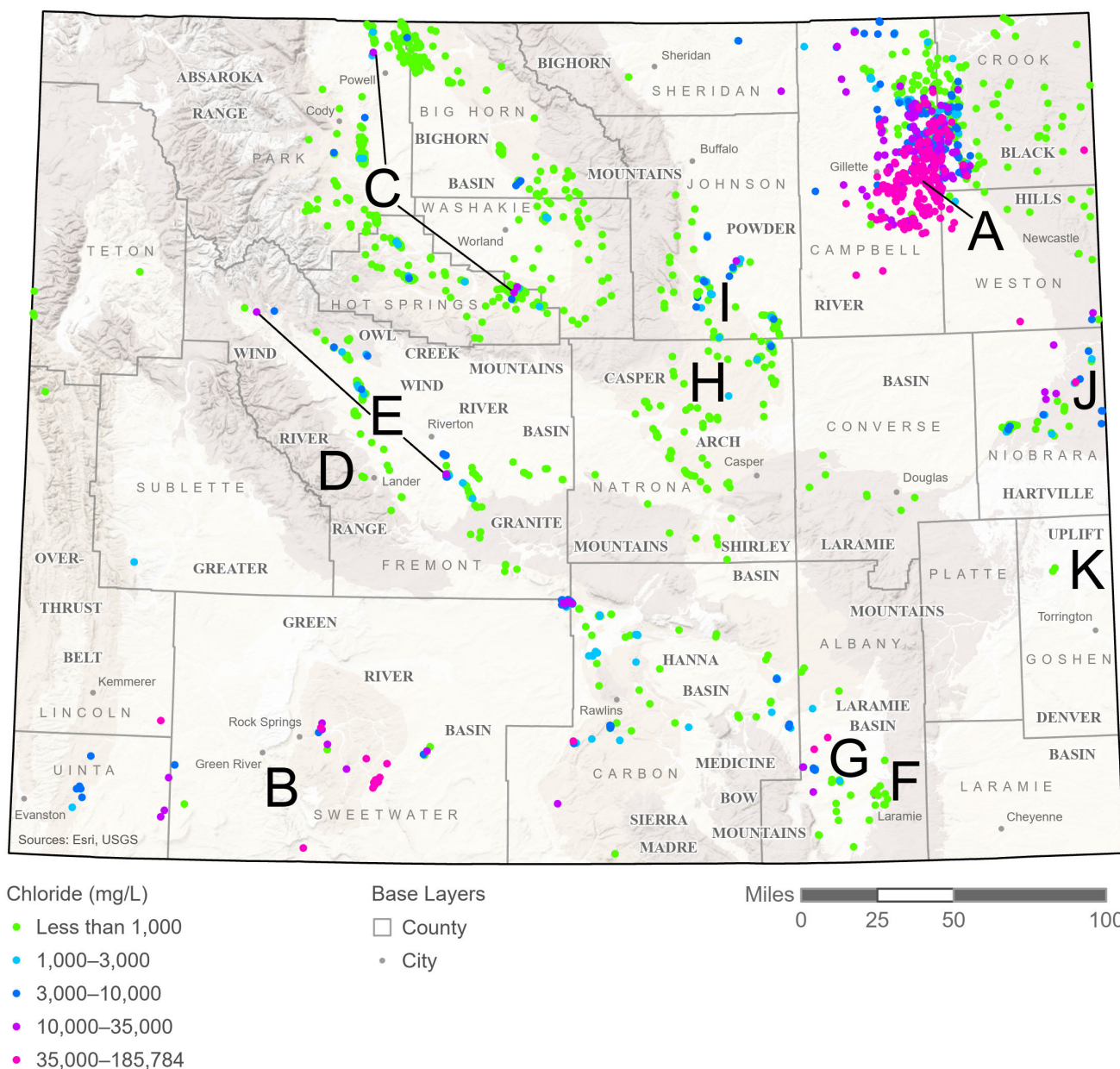


Figure 17. Map showing chloride concentrations in the Tensleep aquifer from two sources: production water from oil and gas wells and water-quality samples from water wells. Letters A–K refer to areas described in the text.

Sodium

The spatial distribution of sodium (figure 18) closely mirrors that of chloride (figure 17). Sodium concentrations are notably high in the northeastern Powder River Basin (A in figure 18) and Greater Green River Basin (B in figure 18). The Bighorn Basin (C in figure 18) contains a few high sodium values ranging from 10,000 mg/L to 35,000 mg/L, but the majority are below 1,000 mg/L. In the Wind River Basin, values below 1,000 mg/L occur along the eastern flank of the Wind River Range (D in figure 18), with some higher values along the anticline trend (E in figure 18) farther out in the basin. No samples are available from the deeper parts of the basin. The Laramie Basin shows low concentrations near the western margin of the Laramie Mountains (F in figure 18) and higher concentrations in the deeper, western region of the Laramie Basin (G in figure 18). The Casper Arch shows mostly low sodium values, below 1,000 mg/L (H in figure 18). In the western Powder River Basin and the eastern Casper Arch (I in figure 18), sodium values are mostly below 1,000 mg/L, with a few moderate values. In the Hartville Uplift (J in figure 18) and adjacent Powder River Basin, some high sodium values occur in the basin and at the edge of the arch, reflecting the chloride distribution. Farther south, the northern extent of the Denver Basin exhibits lower sodium values (K in figure 18).

Lithium

Garrett (2004) documented the global distribution of lithium, and Taboga and others (2015) produced a detailed report on lithium resources in Wyoming. This report adds to this body of knowledge by providing a statewide map of lithium concentrations in water samples from the Tensleep Sandstone and its equivalent formations (figure 19). Notably, only one sample, located in the northeastern Powder River Basin, exceeds 100 mg/L. However, limited data availability hinders a complete characterization of lithium concentrations in the deeper regions of many basins.

Sodium-Adsorption Ratio

Sodium-adsorption ratio (SAR) data were not available from the WOGCC oil and gas produced-water chemistry dataset. To address this, SAR was calculated using a formula from Hem (1992), attributed to the United States Salinity Laboratory Staff (1954). Conversion factors for milligrams per liter to milliequivalents per liter were also taken from Hem (1992). This calculation method was verified by comparing calculated SAR values from the NWIS data with reported SAR values in the same dataset, which produced consistent results. The plotted NWIS values represent SAR values greater than zero (figure 20).

Figure 20 depicts the spatial distribution of SAR values for wells completed in the Tensleep Sandstone and its equivalents. The lowest SAR values occur near the basin margins. Higher SAR values, often exceeding 10 and sometimes 25, are common in the Powder River Basin (A in figure 20), Laramie Basin (B in figure 20), Greater Green River Basin (C in figure 20), and the western and southern Bighorn Basin (D in figure 20). The Casper Arch (E in figure 20) exhibits moderate SAR values with a few high SAR values. In the Hartville Uplift (F in figure 20), most water samples from the Tensleep Formation and its equivalents exhibit very high SAR values.

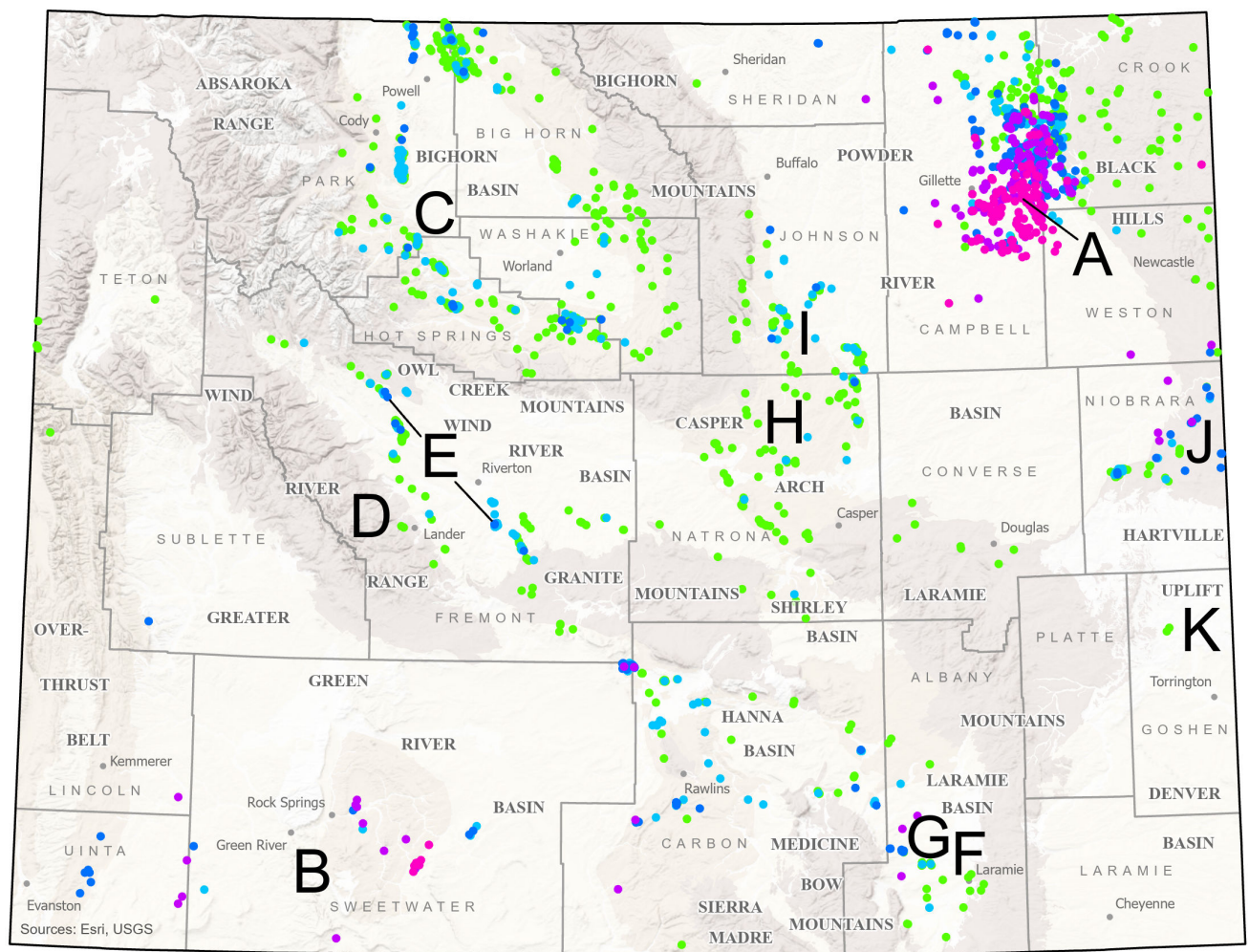


Figure 18. Map showing sodium concentrations in the Tensleep aquifer from two sources: production water from oil and gas wells and water-quality samples from water wells. Letters A–K refer to areas described in the text.

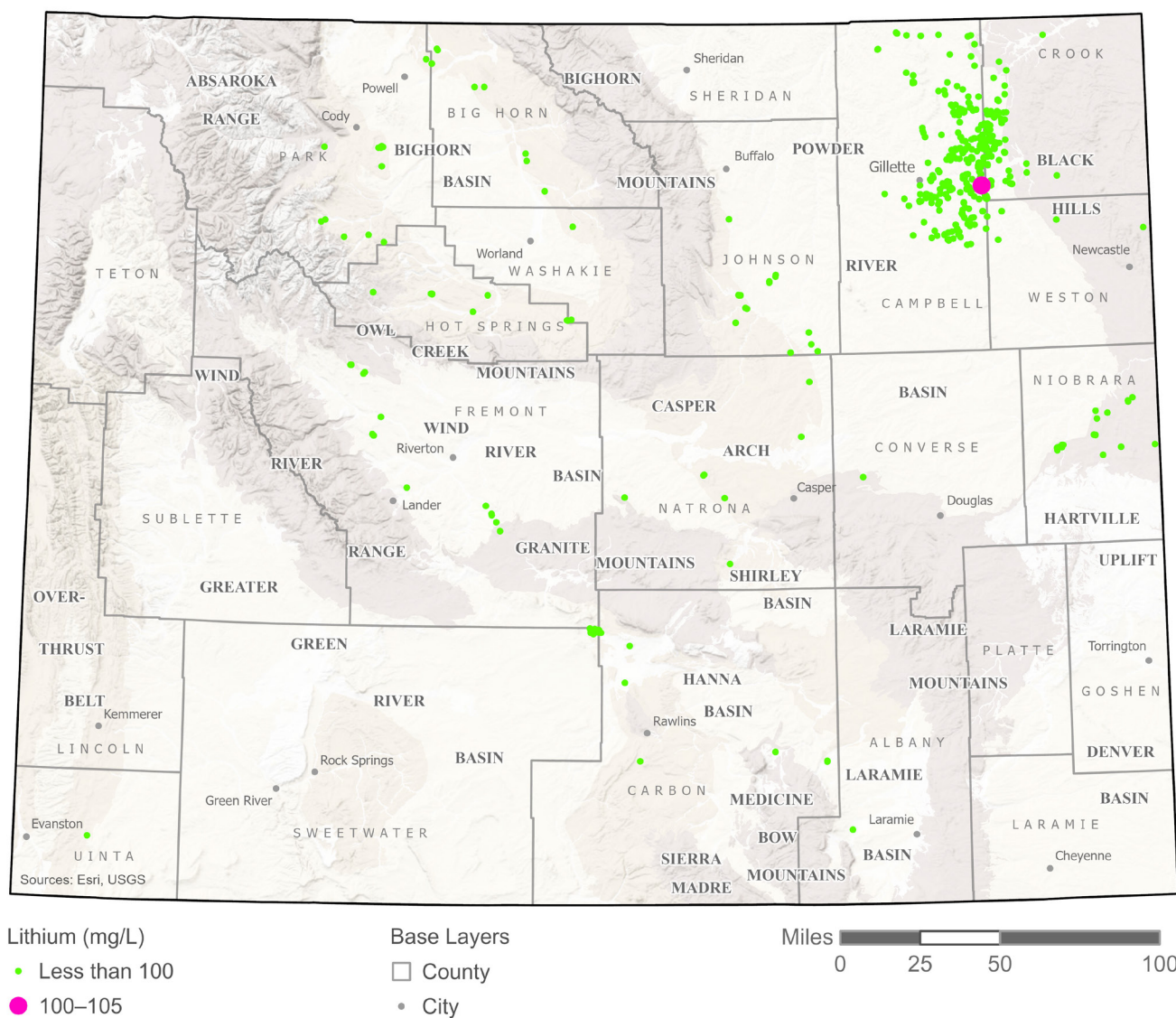


Figure 19. Map showing lithium concentrations in the Tensleep aquifer from two sources: production water from oil and gas wells and water-quality samples from water wells. Additional details about this figure are provided in the text.

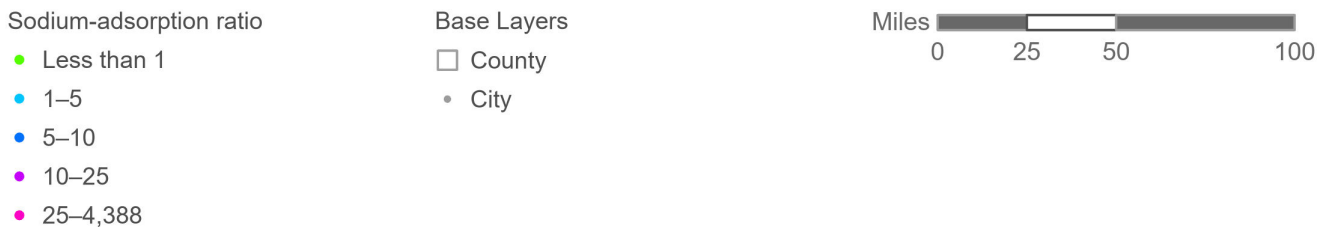
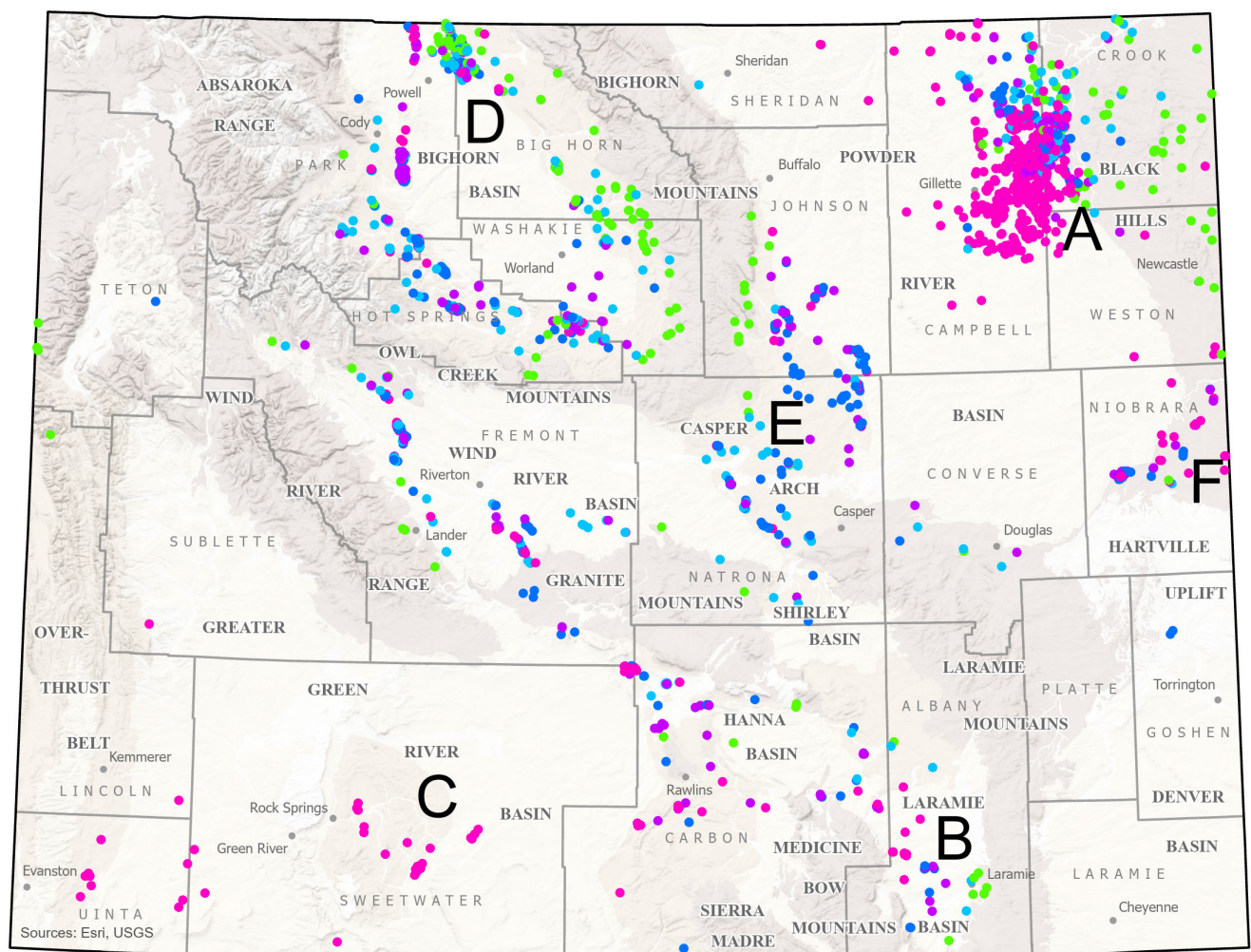


Figure 20. Map showing SAR in the Tensleep aquifer from two sources: production water from oil and gas wells and water-quality samples from water wells. Letters A–F refer to areas described in the text.

Temperature

Previous Work

Few reports addressed geothermal resources in Wyoming before the mid-1980s (Decker, 1976; Hale, 1976; Kilty, 1983). Head and others (1979) mapped fluctuating temperature contours in the Minnelusa Formation near the Gillette area but did not include closed low contours. In the mid-1980s, the WSGS published several reports detailing geothermal resources in Wyoming basins (Hinckley and Heasler, 1984; Heasler and Hinckley, 1985; Spencer and others, 1985; Buelow and others, 1986; Hinckley and Heasler, 1987). Although these reports included detailed temperature and depth data, they did not analyze spatial-temperature variations by specific geologic units.

This Study

Figure 21 presents data from two distinct datasets. Bottom-hole temperatures from the Southern Methodist University Geothermal Laboratory database (SMU Geothermal Laboratory, 2023) represent temperatures in deeper basin wells, while the USGS Environmental Water Chemistry Database (U.S. Geological Survey, 2023) provides temperatures from the mountain flanks. The latter dataset represents temperatures from springs or shallow wells, rather than bottom-hole temperatures.

Around the Bighorn Mountains, temperatures exhibit an expected pattern, with colder water near the mountains (A in figure 21) and increasing bottom-hole temperatures moving away from the mountain flanks (C in figure 21). This pattern is also observed on the Casper Arch (B in figure 21), extending from the Bighorn Mountains. In the northeastern Powder River Basin, cooler temperatures occur near the Black Hills (E in figure 21), while temperatures increase as wells sample deeper water within the basin (F in figure 21). However, a large cluster of cooler temperatures (D in figure 21) is observed deeper in the basin, west of the north-south blue circles. These cooler temperatures are unusual given the increasing depths.

Figure 22 shows a statewide graph of Tensleep temperatures and depths, highlighting several data clusters. Figure 23 focuses on one cluster, depicting temperature and depth, with Gillette-area temperatures (figure 21, area D) represented by gold circles around black dots, and temperatures from the rest of the state by gray dots. Few temperatures in the Gillette area exceed 50 °C, as shown in figure 21. In figure 23, the cluster of sub-50 °C temperatures is generally found between 7,000 feet and 12,000 feet deep. The gray dots indicate that temperatures at equivalent depths in other areas of Wyoming can reach up to 140 °C. Temperatures generally decrease west of approximately -105 °W (near F in figure 21), as highlighted in figure 23.

In the northeastern Powder River Basin, temperatures increase basinward from the flanks of the Black Hills, yet decrease in the deeper basin generally west of approximately -105 °W (near F in figure 21; figure 24).

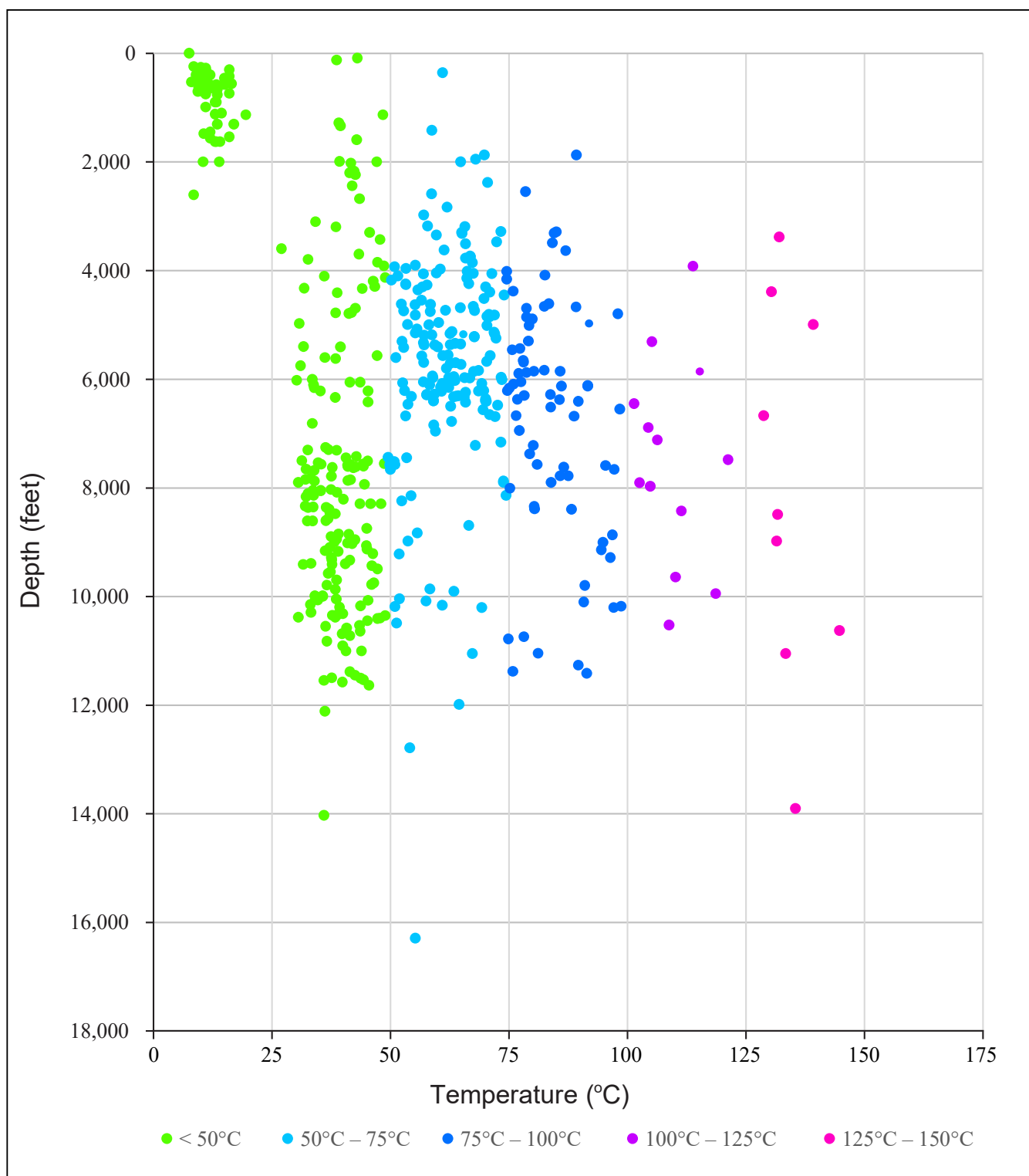


Figure 22. Plot showing temperature as a function of depth in the Tensleep aquifer, collected from two sources: the Southern Methodist University Geothermal Laboratory (SMU Geothermal Laboratory, 2023) and the USGS Environmental Water Chemistry Database (U.S. Geological Survey, 2023). Colors match those in figure 21.

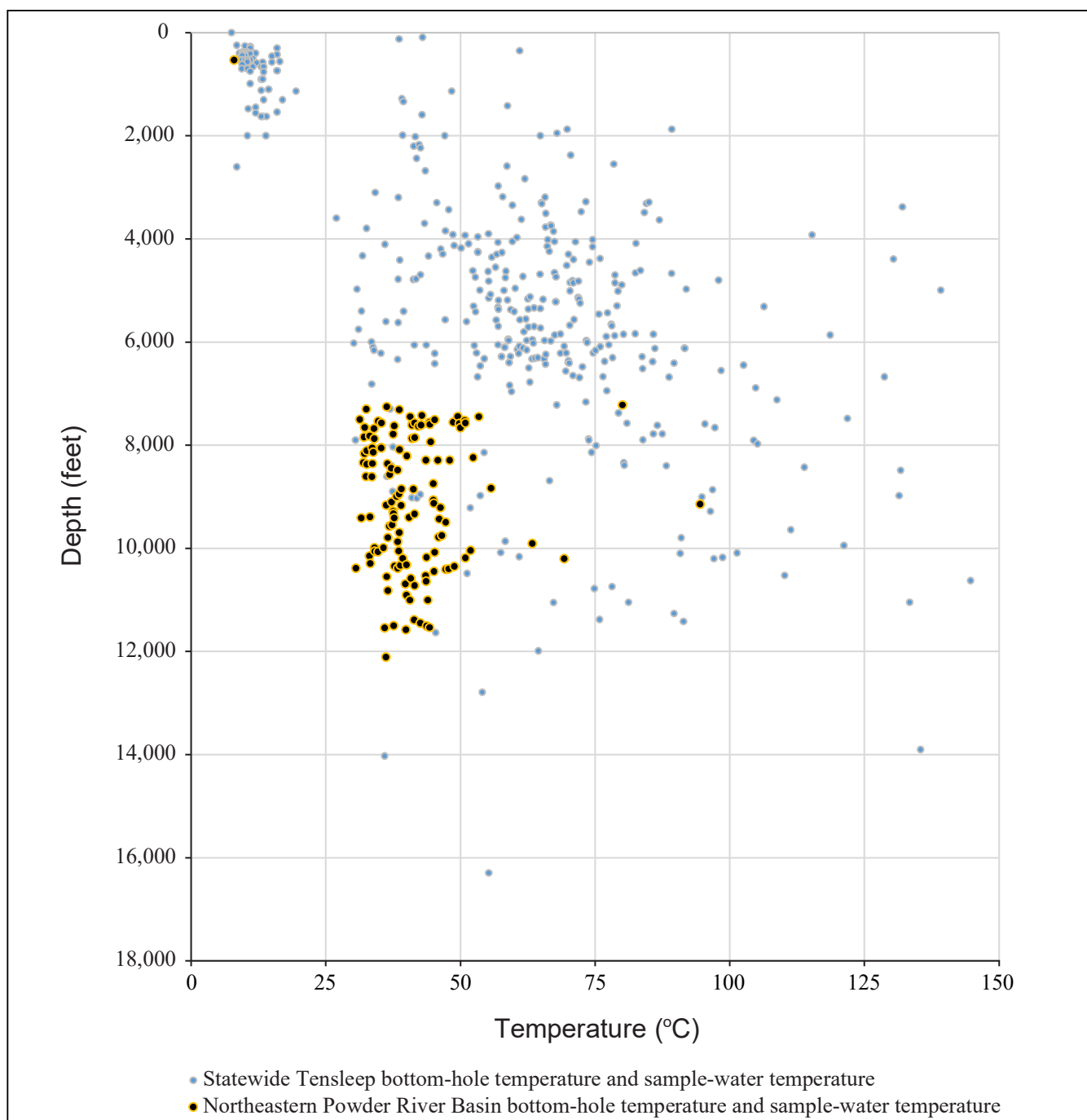


Figure 23. Plot comparing the Tensleep aquifer groundwater temperatures between the northeastern Powder River Basin near Gillette and all of Wyoming.

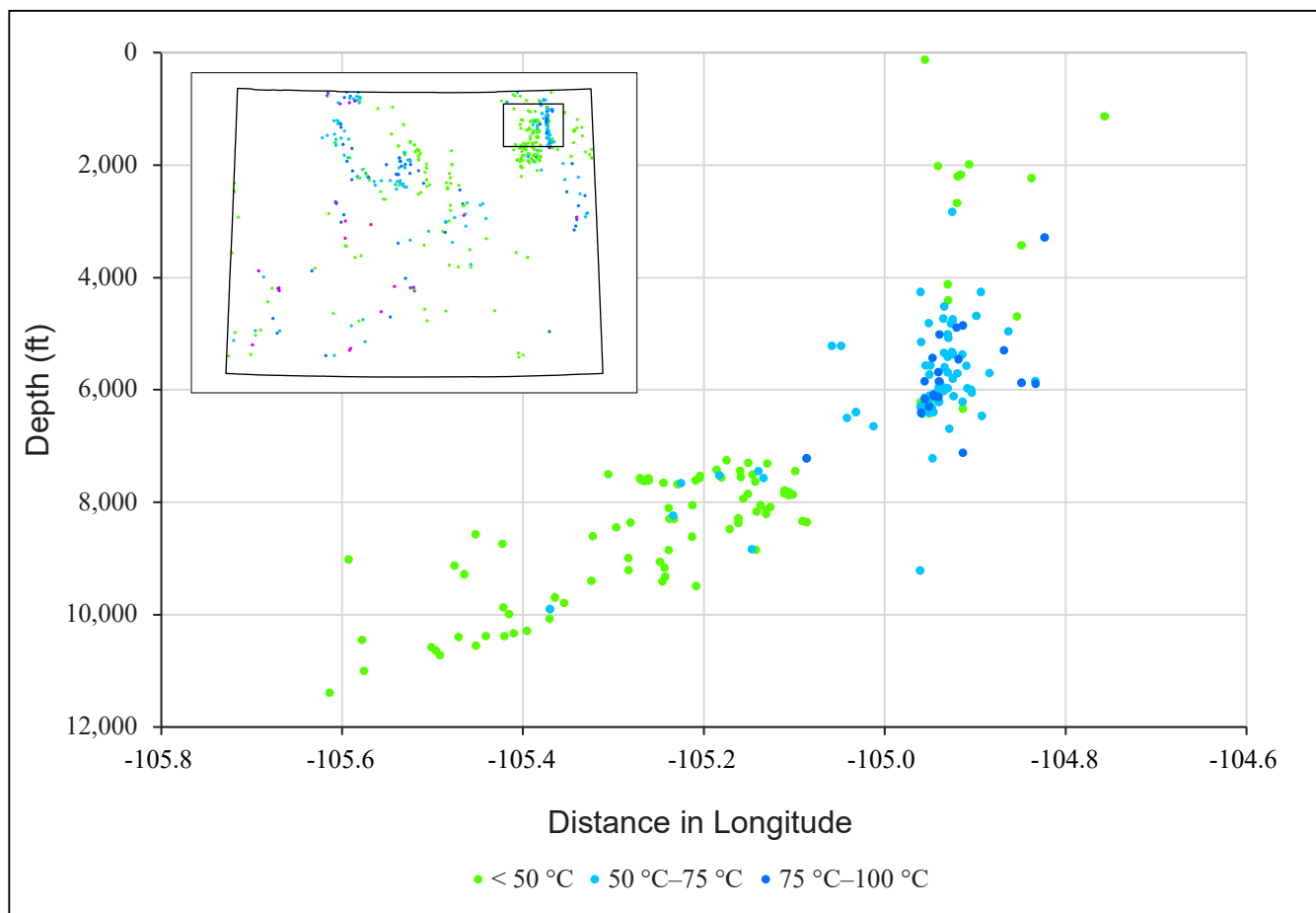


Figure 24. Plot showing an east–west profile of temperatures from a box in the northeastern Powder River Basin near Gillette. The map shows the location (given as longitude in the graph) of the temperature points. The north–south distance is not shown. All of the points in the box are collapsed onto a single east–west profile. Colors match those in figure 21.

DISCUSSION

The purpose of this section is to discuss the implications of the compiled data and suggest areas for future research.

Zapp's (1956) map of the Bighorn Basin depicts flow direction and the dip magnitude of oil–water contacts. The map shows that flow direction varies across the basin; in some areas, it is directed into the deeper parts of the basin, while in other areas, it flows roughly parallel to the basin flanks. These observations raise questions about the factors influencing flow direction and the implications of varying dip magnitudes. For example, does a greater dip magnitude indicate a stronger connection to recharge areas or areas of higher recharge?

The source of the high sodium and chloride values in the Minnelusa Formation raises important questions for further investigation. Previous research by Parker (1967) and Rasmussen and Bean (1984) documented the presence of halite deposits in the overlying Goose Egg Formation and explored the potential for salt dissolution. While Rasmussen and Bean (1984) suggested that salt dissolution likely ceased after the deposition of Cretaceous shales, the observed water drive in some Minnelusa oil and gas fields (figure 13) suggests ongoing horizontal water flow. However, this does not conclusively confirm whether water is currently reaching the salt deposits.

Several questions emerge from these observations: Do the high sodium and chloride values indicate ongoing salt dissolution, with brine actively infiltrating the Minnelusa Formation? What is the timescale over which brine dilution occurs? Could the density of the brine facilitate vertical flow, even without a favorable potentiometric gradient? Furthermore, can brines persist in the subsurface for tens of millions to nearly one hundred million years after the deposition of the Cretaceous shales? Answering these questions could provide valuable insights into the hydrogeochemical processes influencing the Minnelusa Formation.

Low temperatures in this part of the Powder River Basin align roughly with areas of high salinities (I in figure 14). However, spatial correlation does not imply causation. Although salt dissolution is an endothermic reaction, no studies have demonstrated its ability to buffer groundwater temperature against the geothermal gradient. If, as Rasmussen and Bean (1984) suggest, salt dissolution has ceased, then another mechanism must be responsible for cooling the water in the Minnelusa. One hypothesis suggests that dissolving salt creates caverns that collapse, fracturing overlying strata and forming pathways for cooler meteoric water to infiltrate vertically. Alternatively, an unrecognized mechanism could explain the low Tensleep temperatures in this part of the Powder River Basin.

Another factor to consider when analyzing temperature and geochemistry is the groundwater flow paths in the Tensleep. As noted above, Zapp (1956) demonstrated flow directions in the Bighorn Basin that run parallel to the basin flanks. In aquifers with constant permeability and thickness, flow direction is typically perpendicular to potentiometric head contours. However, in basins with sharp permeability contrasts, flow direction may be altered due to refraction of streamlines (Fetter, 1988). Could decreasing permeability in the deep basins cause flow refraction away from zones of low permeability? This idea is speculative. However, actual heads and detailed permeability data for the deep basins are not well known. This uncertainty complicates efforts to contour head, temperature, and groundwater chemistry.

SUMMARY

This report compiles porosity and permeability data from the Wyoming Geological Association's oil and gas field symposia volumes. Graphs of these parameters show that porosity and permeability generally decrease with increasing depth. This trend persists despite a decrease in sample size with depth, indicating that it is not solely attributable to sampling bias. Long-term average recharge estimates, based on a baseflow study, were calculated for Tensleep outcrops across the state. The central-western Bighorn Mountains, the main Wyoming Range, the northwestern Gros Ventre Range, and the southeastern Bighorn Mountains show the highest estimated long-term recharge.

This report also compiles a list of oil fields with water drive, as documented in the Wyoming Geological Association's oil and gas field symposium volumes. The drive mechanisms in these fields may have changed since the publication dates of these volumes. At the time of publication, several oil fields in the Bighorn, Wind River, Laramie, and Powder River basins exhibited water drive in the Tensleep aquifer. These water-driven fields lie basinward of the Tensleep outcrops, where recharge occurs. Moreover, most—if not all—are beyond zones of rejected recharge, as suggested by the presence of springs that likely originate from the Tensleep aquifer or its equivalents.

Water-quality data from the WOGCC database of produced water from oil and gas fields and the USGS environmental sample database were analyzed to assess regional water-quality trends. Statewide salinity assessments show an expected increase from mountain flanks to deeper parts of the basins, with the exception of the northeastern Powder River Basin. This area exhibits the state's highest salinity values, with peak chloride

and sodium concentrations. These elevated values may result from halite dissolution in sediments located 100 feet to 200 feet above the Minnelusa Formation. SAR values also increase with distance from the mountain ranges. In many areas, high SAR values render the Tensleep aquifer and its equivalents unsuitable for irrigation. Lithium concentrations in sampled groundwater were unremarkable, though data from deeper sedimentary basins remain limited.

Finally, temperatures in the Tensleep were compiled from borehole temperature data and sample-water temperature data for Tensleep wells. The maps show a general increase in temperature with depth in the sedimentary basins. However, an area of cooler water temperatures represents an unusual temperature anomaly in the northeastern Powder River Basin.

REFERENCES

- Bartos, T.T., Hallberg, L.L., and Ogle, K.M., 2002, Potentiometric Surfaces, Altitudes of the Tops, and Hydrogeology of the Minnelusa and Madison Aquifers, Black Hills Area, Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-748, 4 sheets, scale 1:100,000, accessed April 2024, at <https://pubs.usgs.gov/ha/ha748/>.
- Bartos, T.T., Hallberg, L.L., and Clark, M., 2010, Groundwater Quality, Chapter 6, in Clarey, K.E., Bartos, T.T., Copeland, D., Hallberg, L.L., Clark, M.L., and Thompson, M., eds., Available Groundwater Determination—WWDC Green River Basin Water Plan I, Groundwater Study, Level I (2008–2009): Wyoming State Geological Survey Technical Memorandum 2, 471 p., 8 pls.
- Bartos, T.T., Hallberg, L.L., and Clark, M.L., 2012, WRBR Hydrologic Units—Physical and Chemical Characteristics, Chapter 7, in Taucher, P., Bartos, T.T., Clarey, K.E., Quillinan, S.A., Hallberg, L.L., Clark, M.L., Thompson, M., Gribb, N., Worman, B., and Gracias, T., eds., Wind/Bighorn River Basin Water Plan Update, Groundwater Study, Level I (2008–2011)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 1, 381 p., 15 pls.
- Bartos, T.T., Hallberg, L.L., and Clark, M.L., 2013, Physical and Chemical Characteristics of Hydrogeologic Units in the Platte River Basin, Chapter 7, in Taucher, P., Bartos, T.T., Taboga, K.G., Hallberg, L.L., Clark, M.L., Stafford, J., Gracias, T., Hinckley, B., Worman, B., Clarey, K., Lindemann, L., Quillinan, S.A., Copeland, D., Hays, R., and Thompson, M., eds., Platte River Basin Water Plan Update, Level I (2009–2013)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 5, 289 p., 11 pls.
- Bartos, T.T., Clarey, K.E., Hallberg, L.L., and Clark, M.L., 2014a, Physical and Chemical Characteristics of Hydrogeologic Units in the Bear River Basin, Chapter 7, in Taboga, K.G., Bartos, T.T., Taucher, P., Hallberg, L.L., Clark, M.L., Stafford, J., Gracias, T., and Wittke, S.J., eds., Bear River Basin Water Plan Update, Groundwater Study, Level I (2010–2014)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 6, 262 p., 6 pls.
- Bartos, T.T., Hallberg, L.L., and Clark, M.L., 2014b, Physical and Chemical Characteristics of Hydrogeologic Units in the Snake-Salt River Basin, Chapter 7, in Taboga, K.G., Bartos, T.T., Taucher, P., Hallberg, L.L., Clark, M.L., Stafford, J., Larsen, M.C., and Gracias, T., eds., Snake/Salt River Basin Water Plan Update, Groundwater Study, Level I (2011–2014)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 7, 424 p.
- Bartos, T.T., Hallberg, L.L., and Clark, M.L., 2019, Physical and Chemical Characteristics of Hydrogeologic Units in the Powder/Tongue/Northeast River Basins (NERB), Chapter 7, in Taboga, K.G., Bartos, T.T., Hallberg, L.L., Clark, M.L., Stafford, J.E., and Loveland, A.M., eds., Powder/Tongue/Northeast River Basins Water Plan Update, Groundwater Study, Level I (2002–2016)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 8, 479 p., 3 pls.
- Blondes, M.S., Gans, K.D., Engle, M.A., Kharaka, Y.K., Reidy, M.E., Saraswathula, V., Thordsen, J.J., Rowan, E.L., and Morrissey, E.A., 2018, U.S. Geological Survey National Produced Waters Geochemical Database (Version 2.3, January 2018): U.S. Geological Survey data release, accessed March 2025, at <https://doi.org/10.5066/F7J964W8>.
- Blondes, M.S., Knierim, K.J., Croke, M.R., Freeman, P.A., Doolan, C., Herzberg, A.S., and Shelton, J.L., 2023, U.S. Geological Survey National Produced Waters Geochemical Database (Version 3.0, December 2023): U.S. Geological Survey data release, accessed March 2025, at <https://doi.org/10.5066/P9DSRCZJ>.
- Biggs, P., and Espach, R.H., 1960, Petroleum and Natural Gas Fields in Wyoming: U.S. Bureau of Mines Bulletin 582, 538 p.

- Bredehoeft, J.D., 1964, Variation of Permeability in the Tensleep Sandstone in the Bighorn Basin, Wyoming, as Interpreted from Core Analyses and Geophysical Logs, in Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-D, p. D166–D170.
- Bredehoeft, J., 2007, It Is the Discharge: Ground Water, v. 45, no. 5, p. 523.
- Bredehoeft, J.D., Belitz, K., and Sharp-Hansen, S., 1992, The Hydrodynamics of the Bighorn Basin—A Study of the Role of Faults: American Association of Petroleum Geologists Bulletin, v. 76, no. 4, p. 530–546.
- Bredehoeft, J.D., and Bennett, R.R., 1972, Potentiometric Surface of the Tensleep Sandstone in the Bighorn Basin, West-Central Wyoming: U.S. Geological Survey Open-File Report 72-461, scale 1:250,000.
- Buelow, K.L., Heasler, H.P., and Hinckley, B.S., 1986, Geothermal Resources of the Southern Powder River Basin, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations 36, 32 p., 4 pls.
- Cardinal, D.F., and Holmes, K.H., 1984, Lower Permian and Pennsylvanian Stratigraphy and Structure of the Tri-State Area, Southeastern Wyoming, Western Nebraska, and Southwestern South Dakota, in Goolsby, J., and Morton, D., eds., The Permian and Pennsylvanian Geology of Wyoming: Wyoming Geological Association, 35th Annual Field Conference Guidebook, p. 333–340.
- Cardinal, D.F., Miller, T., Stewart, W.W., and Trotter, J.F., eds., 1989, Wyoming Oil and Gas Fields Symposium—Bighorn and Wind River Basins: Wyoming Geological Association, 558 p.
- Cardinal, D.F., and Stewart, W.W., eds., 1979, Wyoming Oil and Gas Fields Symposium—Greater Green River Basin: Wyoming Geological Association, 2 v., 428 p.
- Chamberlin, T.C., 1885, Requisite and Qualifying Conditions of Artesian Wells: U.S. Geological Survey Fifth Annual Report, p. 131–175; reprinted in part in Freeze, R.A., and Back, W., eds., 1983, Benchmark Papers in Geology, v. 72, p. 297–307.
- Condra, G.E., and Reed, E.C., 1950, Correlation of the Formations of the Laramie Range, Hartville Uplift, Black Hills, and Western Nebraska: Nebraska Geological Survey Bulletin 13A, 52 p.
- Cooley, M.E., 1986, Artesian Pressures and Water Quality in Paleozoic Aquifers in the Ten Sleep Area of the Bighorn Basin, North-Central Wyoming: U.S. Geological Survey Water-Supply Paper 2289, 54 p., 5 pls.
- Crysdale, B.L., 1990, Map Showing Contours on Top of the Pennsylvanian and Permian Minnelusa Formation and Equivalents, Powder River Basin, Wyoming and Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2140-B, scale 1:500,000.
- Dahlberg, E.C., 1995, Applied Hydrodynamics in Petroleum Exploration: New York, Springer-Verlag, 295 p.
- Davis, R.W., 1984, Hydrodynamics of the Fountain and Casper Formations, Laramie Basin, Wyoming, in Goolsby, J., and Morton, D., eds., The Permian and Pennsylvanian Geology of Wyoming: Wyoming Geological Association, 35th Annual Field Conference Guidebook, p. 389–399.
- Darton, N.H., 1897, Preliminary Report on Artesian Waters of a Portion of the Dakotas: U.S. Geological Survey 17th Annual Report, pt. 2, p. 609–694; reprinted in part in Freeze, R.A., and Back, W., eds., 1983, Benchmark Papers in Geology, v. 72, p. 308–316.
- Decker, E.R., 1976, Geothermal Resources, Present and Future Demand for Power, and Legislation in the State of Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Public Information Circular 1, 21 p.

- Doremus, D.M., 1986, Groundwater Circulation and Water Quality Associated with the Madison Aquifer in the Northeastern Bighorn Basin, Wyoming: Laramie, University of Wyoming, M.S. thesis, 81 p.
- Feathers, K.R., Libra, R.D., and Stephenson, T.R., 1981, Occurrence and Characteristics of Ground Water in the Powder River Basin, Wyoming: Laramie, University of Wyoming Water Resources Research Institute, v. I-A and I-B, variously paged, accessed April 14, 2023, at <http://library.wrds.uwyo.edu/occurrences/occurrences.html>.
- Fetter, C.W., 1988, Applied Hydrogeology, 2nd ed.: Merrill Publishing Company, 592 p.
- Fetter, C.W., 2018, Applied Hydrogeology, 4th ed.: Waveland Press, Inc., 598 p.
- Finley, A.K., and Miller, T.S., 2000, Wyoming Oil and Gas Fields Symposium—Powder River Basin: Wyoming Geological Association, 2 v., 566 p.
- Finley, G., ed., 2011, Southeast Wyoming Oil and Gas Fields Symposium—Laramie, Hanna, and Denver-Julesburg Basins: Wyoming Geological Association, 135 p.
- Foster, D.I., 1958, Summary of the Stratigraphy of the Minnelusa Formation, Powder River Basin, Wyoming, in Strickland, J., ed., Powder River Basin: Wyoming Geological Association, 13th Annual Field Conference Guidebook, p. 39–44.
- Fox, J.E., Lambert, P.W., Mast, F.F., Nuss, N.W., and Rein, R.D., 1975, Porosity Variation in the Tensleep and Its Equivalent in the Weber Sandstone, Western Wyoming—A Log and Petrographic Analysis, in Bolyard, D.W., ed., Deep Drilling Frontiers of the Central Rocky Mountains: Denver, Rocky Mountain Association of Geologists Guidebook, p. 185–216.
- Fox, J.E., and Higley, D.K., 1987, Structure at the Top of the Permian Minnelusa Formation, Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report 87-340-N, scale 1:500,000.
- Garland, R.F., 1996, Permeability Architecture and Groundwater Circulation in the Fault-Severed Casper Aquifer, Southern Powder River Basin, Converse County, Wyoming: Laramie, University of Wyoming, M.S. thesis, 165 p., 5 pls.
- Garrett, D.E., 2004, Handbook of Lithium and Natural Calcium Chloride—Their Deposits, Processing, Uses, and Properties, 1st ed.: Amsterdam and Boston, Elsevier Academic Press, 476 p.
- Geldon, A.L., 2003a, Geology of the Paleozoic Rocks in the Upper Colorado River Basin in Arizona, Colorado, New Mexico, Utah, and Wyoming, Excluding the San Juan Basin: U.S. Geological Survey Professional Paper 1411-A, 85 p., 17 pls., accessed April 2024, at <https://pubs.usgs.gov/publication/pp1411A>.
- Geldon, A.L., 2003b, Hydrologic Properties and Groundwater Flow Systems of the Paleozoic Rocks in the Upper Colorado River Basin in Arizona, Colorado, New Mexico, Utah, and Wyoming, Excluding the San Juan Basin: U.S. Geological Survey Professional Paper 1411-B, 153 p., 13 pls., accessed April 2024, at <https://pubs.usgs.gov/publication/pp1411B>.
- Hale, B., 1976, State of Wyoming Temperature Gradients During Electrical Logging Conditions for Wells Over 10,000: Geological Survey of Wyoming [Wyoming State Geological Survey] Map Series 3, scale 1:1,000,000.
- Haun, J.D., 1984, Pressure Analysis in Petroleum Exploration—Examples from North America [abs.]: 27th International Geological Congress Proceedings, v. VII, sections 13–16, p. 53.

- Head, W.J., Kilty, K.T., and Knottek, R.K., 1979, Maps Showing Formation Temperatures and Configurations of the Minnelusa Formation and the Madison Limestone, Powder River Basin, Wyoming, Montana, and Adjacent Areas: U.S. Geological Survey Miscellaneous Investigations Series Map I-1159, scale 1:1,000,000.
- Head, W.J., and Merkel, R.H., 1977, Hydrologic Characteristics of the Madison Limestone, the Minnelusa Formation, and Equivalent Rocks as Determined by Well-Logging Formation Evaluation, Wyoming, Montana, South Dakota, and North Dakota: U.S. Geological Survey Journal of Research, v. 5, no. 4, p. 473–485.
- Heath, R.C., 1983, Basic Groundwater Hydrology: U.S. Geological Survey Water-Supply Paper 2220, 86 p., revised 2004, accessed July 2023, at <https://pubs.usgs.gov/wsp/2220/report.pdf>.
- Heasler, H.P., and Hinckley, B.S., 1985, Geothermal Resources of the Bighorn Basin, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations 29, 27 p., 4 pls.
- Hem, J.D., 1992, Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd ed.: U.S. Geological Survey Water-Supply Paper 2254, 263 p., 3 pls., accessed March 2025, at <https://pubs.usgs.gov/publication/wsp2254>.
- Hinckley, B.S., and Heasler, H.P., 1984, Geothermal Resources of the Laramie, Hanna, and Shirley Basins, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations 26, 26 p., 4 pls.
- Hinckley, B.S., and Heasler, H.P., 1987, Geothermal Resources of the Wind River Basin, Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Report of Investigations 38, 30 p., 4 pls.
- Hiscock, K.M., and Bense, V.F., 2014, Hydrogeology—Principles and Practice, 2nd ed.: Wiley Blackwell, 519 p.
- Hollis, S.H., and Potter, E.C., eds., 1984, Southeast Wyoming Oil and Gas Fields Symposium: Wyoming Geological Association, 133 p.
- Huntoon, P.W., 1985a, Fault-Severed Aquifers Along the Perimeters of Wyoming Artesian Basins: Groundwater, v. 23, no. 2, p. 176–181.
- Huntoon, P.W., 1985b, Rejection of Recharge Water from the Madison Aquifer Along the Eastern Perimeter of the Bighorn Artesian Basin, Wyoming: Ground Water [Groundwater], v. 23, no. 3, p. 345–353.
- Hubbert, M.K., 1953, Entrapment of Petroleum Under Hydrodynamic Conditions: Bulletin of the American Association of Petroleum Geologists, v. 37, no. 8, p. 1954–2026.
- Indiana Department of Natural Resources, 2023, Potentiometric Surface Mapping (1:48,000) Overview, accessed September 2023, at <https://www.in.gov/dnr/water/ground-water-wells/assessment-maps-and-publications/potentiometric-surface-mapping-148000/potentiometric-surface-mapping-148000-overview/>.
- Jarvis, W.T., 1986, Regional Hydrogeology of the Paleozoic Aquifer System, Southeastern Bighorn Basin, Wyoming, with an Impact Analysis on Hot Springs State Park: Laramie, University of Wyoming, M.S. thesis, 227 p., 7 pls.
- Johnson, S.A., 1994, Permeability Architecture and Groundwater Circulation Along a Fault-Severed Margin, Northern Hanna Basin, Carbon County, Wyoming: Laramie, University of Wyoming, M.S. thesis, 115 p., 5 pls.

- Keefer, W.R., and Van Lieu, J.A., 1966, Paleozoic Formations in the Wind River Basin, Wyoming: U.S. Geological Survey Professional Paper 495-B, 60 p., 6 pls., accessed November 2025, at <https://pubs.usgs.gov/publication/pp495B>.
- Kilty, K.T., 1983, Subsurface Temperatures in Northeastern Wyoming Measured by Bottom-Hole Temperature Records: Geological Survey of Wyoming [Wyoming State Geological Survey] Open-File Report 83-4, 43 p.
- Kyllonen, D.P., and Peter, K.D., 1986, Geohydrology and Water Quality of the Inyan Kara, Minnelusa, and Madison Aquifers of the Northern Black Hills, South Dakota and Wyoming, and Bear Lodge Mountains, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 86-4158, 61 p., accessed September 2023, at <https://pubs.usgs.gov/wri/1986/4158/report.pdf>.
- Lawson, D.E., and Smith, J.R., 1966, Pennsylvanian and Permian Influence on Tensleep Oil Accumulation, Bighorn Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 50, no. 10, p. 2197–2220.
- Lawyer, G.F., Newcomer, J., and Eger, C., eds., 1981, Powder River Basin Oil and Gas Fields: Casper, Wyo., Wyoming Geological Association, 2 v.
- Lee, W.T., 1927, Correlation of Geologic Formations Between East-Central Colorado, Central Wyoming, and Southern Montana: U.S. Geological Survey Professional Paper 149, 80 p., 1 pl.
- Libra, R., Doremus, D., and Goodwin, C., 1981, Occurrence and Characteristics of Groundwater in the Bighorn Basin, Wyoming, Volume II-A: Laramie, University of Wyoming Water Resources Research Institute, 114 p., 5 pls., accessed July 2023, at <http://library.wrds.uwyo.edu/occurrences/occurrences.html>.
- Lindner-Lunsford, J.B., Kimball, B.A., Chafin, D.T., and Bryant, C.G., 1989, Hydrogeology of Aquifers of Paleozoic Age, Upper Colorado River Basin—Excluding the San Juan Basin—in Colorado, Utah, Wyoming, and Arizona: U.S. Geological Survey Hydrologic Atlas 702, 2 pls.
- Love, J.D., Christiansen, A.C., and Ver Ploeg, A.J., 1993, Stratigraphic Chart Showing Phanerozoic Nomenclature for the State of Wyoming: Geological Survey of Wyoming [Wyoming State Geological Survey] Map Series 41.
- Lowry, M.E., Lowham, H.W., and Lines, G.C., 1976, Water Resources of the Bighorn Basin, Northwestern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-512, 2 sheets, accessed February 2025, at <https://pubs.usgs.gov/publication/ha512>.
- Lundy, D.A., 1978, Hydrology and Geochemistry of the Casper Aquifer in the Vicinity of Laramie, Albany County, Wyoming: Laramie, University of Wyoming, M.S. thesis, 76 p., 3 pls.
- Mallory, W.M., 1972, Regional Synthesis of the Pennsylvanian System, in Mallory, W.M., ed.-in-chief, Geologic Atlas of the Rocky Mountain Region, United States of America: Denver, Rocky Mountain Association of Geologists, p. 111–127.
- Mallory, W.M., 1975, Middle and Southern Rocky Mountains, Northern Colorado Plateau, and Eastern Great Basin Region, in McKee, E.D., and Crosby, E.J., coordinators, Paleotectonic Investigations of the Pennsylvanian System in the United States—Part 1: Introduction and Regional Analyses of the Pennsylvanian System: U.S. Geological Survey Professional Paper 853, p. 265–278, accessed June 2023, at <https://pubs.usgs.gov/pp/0853-1/report.pdf>.

- Maughan, E.K., 1975, Montana, North Dakota, Northeastern Wyoming, and Northern South Dakota, in McKee, E.D., and Crosby, E.J., coordinators, *Paleotectonic Investigations of the Pennsylvanian System in the United States—Part 1: Introduction and Regional Analyses of the Pennsylvanian System*: U.S. Geological Survey Professional Paper 853, p. 279–294, accessed June 2023, at <https://pubs.usgs.gov/pp/0853-1/report.pdf>.
- McKee, E.D., Crosby, E.J., Bachman, G.O., Bell, K.G., Dixon, G.H., Frezon, S.E., Glick, E.E., Irwin, W.P., Mallory, W.W., Mapel, W.J., Maughan, E.K., Prichard, G.E., Shideler, G.L., Stewart, G.F., Wanless, H.R., Wilson, R.F., and Glenn, M.W., 1975, Part II. Interpretive Summary and Special Features of the Pennsylvanian System, in McKee, E.D., and Crosby, E.J., coordinators, *Paleotectonic Investigations of the Pennsylvanian System in the United States*: U.S. Geological Survey Professional Paper 853, 192 p., 39 pls.
- Miller, T.S., Crockett, F.J., and Hollis, S.H., 1992, *Wyoming Oil and Gas Fields Symposium—Greater Green River Basin and Overthrust Belt*: Wyoming Geological Association, 364 p.
- Morgan, J.T., Cordiner, F.S., and Livingston, A.R., 1978, Tensleep Reservoir, Oregon Basin Field, Wyoming: *American Association of Petroleum Geologists Bulletin*, v. 62, no. 4, p. 609–632.
- Mou, D.C., and Brenner, R.L., 1982, Control of Reservoir Properties of Tensleep Sandstone by Depositional and Diagenetic Facies—Lost Soldier Field, Wyoming: *Journal of Sedimentary Petrology*, v. 52, no. 2, p. 367–381.
- National Ground Water Association, 2023a, *Confined or Artesian Groundwater*, accessed September 2023, at <https://www.ngwa.org/what-is-groundwater/About-groundwater/confined-or-artesian-groundwater>.
- National Ground Water Association, 2023b, *Unconfined or Water-Table Aquifers*, accessed September 2023, at <https://www.ngwa.org/what-is-groundwater/About-groundwater/unconfined-or-water-table-aquifers>.
- Parker, J.M., 1967, *Salt Solution and Subsidence Structures—Wyoming, North Dakota, and Montana*: *American Association of Petroleum Geologists Bulletin*, v. 51, no. 10, p. 1929–1947.
- Pedry, J.J., 1975, Tensleep Sandstone Stratigraphic-Hydrodynamic Traps, Northeast Bighorn Basin, Wyoming, in Exum, F.A., and George, G.R., eds., *Geology and Mineral Resources of the Bighorn Basin*: Wyoming Geological Association, 27th Annual Field Conference Guidebook, p. 117–127.
- Rahn, P.H., and Gries, J.P., 1973, *Large Springs in the Black Hills, South Dakota and Wyoming*: South Dakota Geological Survey Report of Investigations 107, 46 p., 4 pls.
- Rasmussen, D.L., and Bean, D.W., 1984, Dissolution of Permian Salt and Mesozoic Syndepositional Trends, Central Powder River Basin, Wyoming, in Goolsby, J., and Morton, D., eds., *The Permian and Pennsylvanian Geology of Wyoming*: Wyoming Geological Association, 35th Annual Field Conference Guidebook, p. 281–294.
- Richter, H.R., 1981a, Occurrence and Characteristics of Groundwater in the Laramie, Shirley, and Hanna Basins, Wyoming, Volume III-A: Laramie, University of Wyoming Water Resources Research Institute, 154 p., 6 pls., accessed April 2023, at <http://library.wrds.uwyo.edu/occurrences/occurrences.html>.
- Richter, H.R., 1981b, Occurrence and Characteristics of Groundwater in the Wind River Basin, Wyoming, Volume IV-A: Laramie, University of Wyoming Water Resources Research Institute, 149 p., 11 pls., accessed July 2023, at <http://library.wrds.uwyo.edu/occurrences/occurrences.html>.
- Ring, J.D., 2025, *Depth and Elevation Surfaces for the Precambrian Basement Map of Wyoming*: Wyoming State Geological Survey Data Release 2025-28, scale 1:500,000, <https://doi.org/10.15786/wyo-scholar/10095>.

- Shebl, M., 1995, The Impact of Reservoir Heterogeneity on Fluid Flow in the Tensleep Sandstone of the Bighorn Basin, in Jones, R.W., ed., Resources of Southwestern Wyoming: Wyoming Geological Association Field Conference Guidebook, p. 343–359.
- SMU Geothermal Laboratory, 2023, Geothermal Data Aggregation, accessed September 2023, at <http://geo-thermal.smu.edu/gtda/>.
- Spencer, S.A., 1986, Groundwater Movement in the Paleozoic Rocks and Impact of Petroleum Production on Water Levels in the Southwestern Bighorn Basin, Wyoming: Laramie, University of Wyoming, M.S. thesis, 165 p., 7 pls.
- Spencer, S.A., Heasler, H.P., and Hinckley, B.S., 1985, Geothermal Resources of the Green River Basin, Wyoming, Including Thermal Data for the Wyoming Portion of the Thrust Belt: Report prepared for the U.S. Department of Energy, Idaho Operations Office, by the University of Wyoming Department of Geology and Geophysics, Laramie, Wyo., 59 p., accessed April 2026, at <https://digital.library.unt.edu/ark:/67531/metadc1071557/>.
- Stacy, M.E., 1994, Karstic Groundwater Circulation in the Fault-Severed Madison Aquifer in the Casper Mountain Area of Natrona County, Wyoming: Laramie, University of Wyoming, M.S. thesis, 122 p., 5 pls.
- Stafford, J.E., Taboga, K.G., and Toner, R.T., 2017, Groundwater Atlas of Wyoming: Wyoming State Geological Survey, originally published March 2017, accessed August 2022, at <https://portal.wsgs.wyo.gov/arcgis/apps/webappviewer/index.html?id=181c32a872a346bfae3579a62230a65a>.
- Stone, D.S., 1967, Theory of Paleozoic Oil and Gas Accumulation in the Bighorn Basin, Wyoming: American Association of Petroleum Geologists Bulletin, v. 51, no. 10, p. 2056–2114.
- Strobel, M.L., Galloway, J.M., Hamade, G.R., and Jarrell, G.J., 2000, Potentiometric Surface of the Minnelusa Aquifer in the Black Hills Area, South Dakota: U.S. Geological Survey Hydrologic Atlas HA-745-C, 2 sheets, scale 1:100,000.
- Summerford, H.E., 1952, Inclined Water Levels, in Spalding, R.W., ed., Southern Big Horn Basin, Wyoming: Wyoming Geological Association, 7th Annual Field Conference Guidebook, p. 98–103.
- Taboga, K.G., and Stafford, J.E., 2016, Wyoming State Geological Survey Statewide Groundwater Baseflow Study: Wyoming State Geological Survey Open-File Report 2016-8, 16 p.
- Taboga, K.G., and Stafford, J.E., 2020, Groundwater Salinity in Wyoming: Wyoming State Geological Survey Open-File Report 2020-6, 29 p.
- Taboga, K.G., Sutherland, W.M., Gregory, R.W., Stafford, J.E., and Rodgers, J.R., 2015, Lithium Resources in Wyoming: Wyoming State Geological Survey Report of Investigations 69, 25 p.
- Taboga, K.G., Wittke, S.J., Stafford, J.E., and Rodgers, J.R., 2016, Groundwater Salinity in the Denver-Julesburg Basin, Wyoming: Wyoming State Geological Survey Open-File Report 2016-2, 12 p., 9 pls.
- Taboga, K.G., Stafford, J.E., and Rodgers, J.R., 2018, Groundwater Salinity in the Powder River Basin, Wyoming: Wyoming State Geological Survey Open-File Report 2018-5, 23 p.
- Taboga, K.G., Bartos, T.T., Hallberg, L.L., Clark, M.L., Stafford, J.E., and Loveland, A.M., 2019, Powder/Tongue/Northeast River Basins Water Plan Update, Groundwater Study, Level I (2002–2016)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 8, 479 p., 3 pls.

- Taboga, K.G., Stafford, J.E., Rodgers, J.R., Wittke, S.J., and Samra, C.P., 2020, Groundwater Salinity in the Greater Green River Basin, Wyoming: Wyoming State Geological Survey Open-File Report 2020-10, 31 p.
- Taboga, K.G., Stafford, J.E., Rodgers, J.R., and Wittke, S.J., 2022, Groundwater Salinity in the Wind River and Bighorn Basins, Wyoming: Wyoming State Geological Survey Open-File Report 2022-2, 52 p.
- Tallgrass High Plains Storage, LLC, 2023, Underground Injection Control Carbon Sequestration Class VI Permit Application, Eastern Wyoming Sequestration Hub, accessed April 2026, at https://drive.google.com/drive/folders/1pJVmX4_7HqLrj4SNOsP0XmIvA-ExUNJv.
- Taucher, P., Bartos, T.T., Clarey, K.E., Quillinan, S.A., Hallberg, L.L., Clark, M.L., Thompson, M., Gribb, N., Worman, B., and Gracias, T., 2012, Wind/Bighorn River Basin Water Plan Update, Groundwater Study, Level I (2008–2011)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 1, 381 p., 15 pls.
- Taucher, P., Bartos, T.T., Taboga, K.G., Hallberg, L.L., Clark, M.L., Stafford, J.E., Gracias, T., Hinckley, B., Worman, B., Clarey, K.E., Lindemann, L., Quillinan, S.A., Copeland, D., Hays, R., and Thompson, M., 2013, Platte River Basin Water Plan Update, Groundwater Study, Level I (2009–2013)—Available Groundwater Determination: Wyoming State Geological Survey Technical Memorandum 5, 491 p., accessed April 2026, at <https://waterplan.state.wy.us/plan/platte/2013/gw-finalrept/gw-finalrept.html>.
- Thomas, L.E., 1965, Sedimentary and Structural Development of Bighorn Basin: Bulletin of the American Association of Petroleum Geologists, v. 49, p. 1867–1877.
- Thompson, K.S., 1979, Prediction of Water-Level Declines in the Casper Aquifer in the Vicinity of Laramie, Wyoming: Laramie, University of Wyoming, M.S. thesis, 74 p., 1 pl.
- Trotter, J.F., 1984, The Minnelusa Revisited, in Goolsby, J., and Morton, D., eds., The Permian and Pennsylvanian Geology of Wyoming: Wyoming Geological Association, 35th Annual Field Conference Guidebook, p. 127–151.
- U.S. Geological Survey, 2023, USGS Water Data for Wyoming, accessed October 2023, at <https://waterdata.usgs.gov/wy/nwis/>.
- United States Salinity Laboratory Staff, 1954, Diagnosis and Improvement of Saline and Alkali Soils: U.S. Department of Agriculture Handbook 60, 160 p., accessed July 2024, at https://www.ars.usda.gov/ARSEUserFiles/20360500/hb60_pdf/hb60complete.pdf.
- Wang, H., Kou, Z., Bagdonas, D.A., Phillips, E.H.W., Alvarado, V., Johnson, A.C., Jiao, Z., McLaughlin, J.F., and Quillinan, S.A., 2022, Multiscale Petrophysical Characterization and Flow-Unit Classification of the Minnelusa Eolian Sandstones: Journal of Hydrology, v. 607, article 127466, 14 p.
- Wyoming Geological Association, 1957, Wyoming Oil and Gas Fields Symposium, Masterson, J.A., ed.: Wyoming Geological Association, 579 p.
- Wyoming State Engineer's Office, 2023, Groundwater Hydrograph, accessed September 2023, at <https://seo.wyo.gov/ground-water/hydrographs>.
- Zapp, A.D., 1956, Structural Contour Map of the Tensleep Sandstone in the Bighorn Basin, Wyoming and Montana: U.S. Geological Survey Oil and Gas Investigations Map OM-182, scale 1:250,000.
- Zhang, Ye, 2018, Groundwater Modeling of the Casper Aquifer, Belvoir Ranch, Cheyenne: Water Research Program Project Report, 17 p., accessed September 2024, at https://www.uwyo.edu/owp/_files/final-rpt48zhang.pdf.

Appendices

Appendix 1: Porosity Basin Group

Appendix 1. Porosity Basin Group

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
ALKALI ANTICLINE	A	Bighorn Basin	13.0
BIG POLECAT	A	Bighorn Basin	14.0
BYRON	A	Bighorn Basin	13.9
COWLEY	A	Bighorn Basin	14.0
GARLAND	A	Bighorn Basin	13.3
HOMESTEAD	A	Bighorn Basin	13.0
LITTLE POLECAT	A	Bighorn Basin	14.9
NORTH DANKER	A	Bighorn Basin	14.2
SILVER TIP	A	Bighorn Basin	10.0
WHISTLE CREEK	A	Bighorn Basin	14.0
DEAVER	B	Bighorn Basin	15.0
DEAVER NORTH	B	Bighorn Basin	18.0
ELK BASIN SOUTH	B	Bighorn Basin	15.0
FRANNIE	B	Bighorn Basin	17.0
SAGE CREEK	B	Bighorn Basin	15.0
SAGE CREEK WEST	B	Bighorn Basin	16.0
ELK BASIN	C	Bighorn Basin	9.0
ENIGMA	D	Bighorn Basin	15.0
FRISON	D	Bighorn Basin	11.0
MANDERSON	D	Bighorn Basin	11.2
TORCHLIGHT	D	Bighorn Basin	14.0
BONANZA	E	Bighorn Basin	17.5
COTTONWOOD CREEK	E	Bighorn Basin	18.0
FLASHLIGHT	E	Bighorn Basin	17.0
HIDDEN DOME	E	Bighorn Basin	15.4
LAMB	E	Bighorn Basin	15.1
NOWOOD	E	Bighorn Basin	18.0
WORLAND	F	Bighorn Basin	5.5
BLACK MOUNTAIN	G	Bighorn Basin	13.3
ENOS CREEK	G	Bighorn Basin	12.0
GOOSEBERRY	G	Bighorn Basin	12.0
GRASS CREEK	G	Bighorn Basin	13.0
HAMILTON DOME	G	Bighorn Basin	15.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
KING DOME	G	Bighorn Basin	11.0
LAKE CREEK	G	Bighorn Basin	11.0
LITTLE BUFFALO BASIN	G	Bighorn Basin	13.0
MURPHY DOME	G	Bighorn Basin	13.4
NEIBER DOME	G	Bighorn Basin	11.0
RAWHIDE	G	Bighorn Basin	14.2
SUNSHINE NORTH	G	Bighorn Basin	13.0
WILLOW DRAW	G	Bighorn Basin	10.0
ZIMMERMAN BUTTE	G	Bighorn Basin	12.8
GEBO	H	Bighorn Basin	8.3
GOLDEN EAGLE	H	Bighorn Basin	6.6
LITTLE SAND DRAW	H	Bighorn Basin	9.5
CODY	I	Bighorn Basin	10.7
OREGON BASIN	I	Bighorn Basin	14.0
SHOSHONE	I	Bighorn Basin	10.8
SHOSHONE NORTH	I	Bighorn Basin	13.0
FERGUSON RANCH	J	Bighorn Basin	16.5
HALF MOON	J	Bighorn Basin	17.3
SPRING CREEK SOUTH	J	Bighorn Basin	17.0
HUNT	K	Bighorn Basin	20.4
PITCHFORK	K	Bighorn Basin	20.0
FOURBEAR	L	Bighorn Basin	9.0
LAMONT	AH	Greater Green River Basin	7.0
LOST SOLDIER	AH	Greater Green River Basin	10.0
BAILEY DOME	AI	Greater Green River Basin	12.0
WERTZ	AI	Greater Green River Basin	10.3
SHERARD	AJ	Greater Green River Basin	3.4
HATFIELD	AK	Greater Green River Basin	7.0
SUGAR CREEK	AK	Greater Green River Basin	8.0
BROWNING	AL	Greater Green River Basin	15.0
HIGGINS	AM	Greater Green River Basin	4.0
TABLE ROCK	AM	Greater Green River Basin	1.4
BRADY	AQ	Greater Green River Basin	8.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
O'BRIEN SPRINGS	AH	Hanna Basin	9.0
MAHONEY DOME	AI	Hanna Basin	12.0
MAHONEY DOME EAST	AI	Hanna Basin	11.5
PASS CREEK	AO	Hanna Basin	19.8
ALLEN LAKE EAST	AP	Hanna Basin	13.0
BIG MEDICINE BOW	AP	Hanna Basin	10.3
QUEALY	T	Laramie Basin	16.0
HERRICK	U	Laramie Basin	20.0
LITTLE LARAMIE	U	Laramie Basin	23.0
WHITNEY CANYON-CARTER CREEK	AN	Overthrust Belt	4.6
DILLINGER RANCH NORTH	AA	Powder River Basin	8.6
WIDGE NORTH	AA	Powder River Basin	9.5
ANT HILLS NORTH	AB	Powder River Basin	14.3
BEAVER HOLE	AB	Powder River Basin	14.0
BRIGHT	AB	Powder River Basin	14.0
BUCK CREEK	AB	Powder River Basin	14.6
LITTLE BUCK CREEK	AB	Powder River Basin	12.0
SWEDE DRAW	AB	Powder River Basin	13.0
LANCE CREEK	AC	Powder River Basin	16.0
PINE LODGE	AC	Powder River Basin	19.0
RED BIRD	AC	Powder River Basin	17.0
DEWEY DOME	AD	Powder River Basin	25.0
HUB	AR	Powder River Basin	8.0
TISDALE EAST	AS	Powder River Basin	20.0
TISDALE NORTH	AS	Powder River Basin	20.0
CHARLES	BA	Powder River Basin	6.5
LEIMSER	BA	Powder River Basin	8.0
COLLUMS	P	Powder River Basin	13.4
SWARTZ DRAW	P	Powder River Basin	12.0
HORSE RANCH	Q	Powder River Basin	13.0
CELLARS RANCH	V	Powder River Basin	13.6
FOURMILE	V	Powder River Basin	12.7
MEADOW CREEK	V	Powder River Basin	11.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
NORTH FORK	V	Powder River Basin	13.0
PHEASANT	V	Powder River Basin	12.0
RENO EAST	V	Powder River Basin	12.0
SALT CREEK	V	Powder River Basin	14.1
SALT CREEK EAST	V	Powder River Basin	11.0
SHERWOOD	V	Powder River Basin	12.0
SUSSEX	V	Powder River Basin	14.0
TEAPOT NAVAL RESERVE	V	Powder River Basin	11.0
ADON	W	Powder River Basin	11.0
ADON ROAD NORTH	W	Powder River Basin	14.2
AM-KIRK	W	Powder River Basin	12.0
BASIN NORTHWEST	W	Powder River Basin	11.9
BONE PILE	W	Powder River Basin	12.2
BOOTON	W	Powder River Basin	14.0
CARDINAL	W	Powder River Basin	12.0
CLABAUGH	W	Powder River Basin	10.2
FALCON RIDGE	W	Powder River Basin	14.5
GOLD MINE DRAW	W	Powder River Basin	12.0
GRASSLAND	W	Powder River Basin	14.0
GUTHREY	W	Powder River Basin	13.3
HALVERSON	W	Powder River Basin	13.0
HAWK POINT	W	Powder River Basin	13.0
HILIGHT	W	Powder River Basin	14.0
LONG TREE	W	Powder River Basin	14.0
MALLARD	W	Powder River Basin	12.0
MORAN	W	Powder River Basin	14.4
OK	W	Powder River Basin	13.0
PICKREL RANCH	W	Powder River Basin	14.0
RAVEN CREEK	W	Powder River Basin	11.6
REEL	W	Powder River Basin	13.6
ROBINSON RANCH	W	Powder River Basin	13.2
ROURKE GAP	W	Powder River Basin	14.5
ROYAL DRAW	W	Powder River Basin	12.0
SHARP	W	Powder River Basin	13.0
SLATTERY	W	Powder River Basin	12.0
SPRING HOLE	W	Powder River Basin	13.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
STEWART EAST	W	Powder River Basin	13.0
T.A. BUTTES	W	Powder River Basin	14.0
VICTOR	W	Powder River Basin	13.0
WD	W	Powder River Basin	12.6
WHISLER	W	Powder River Basin	14.0
WIDGE	W	Powder River Basin	11.0
WOLF DRAW	W	Powder River Basin	14.0
CRAZY WOMAN SOUTH	X	Powder River Basin	4.0
RENO	X	Powder River Basin	10.0
ADON ROAD	Y	Powder River Basin	18.0
AG FARM	Y	Powder River Basin	18.5
ALPHA	Y	Powder River Basin	19.0
AMMO	Y	Powder River Basin	15.5
BASIN	Y	Powder River Basin	17.5
BIG MAC	Y	Powder River Basin	19.3
BISHOP RANCH	Y	Powder River Basin	15.2
BISHOP RANCH SOUTH	Y	Powder River Basin	16.0
BRACKEN	Y	Powder River Basin	16.5
BREEN	Y	Powder River Basin	15.0
BRENNAN	Y	Powder River Basin	16.0
BRONCO	Y	Powder River Basin	18.0
BULL CREEK	Y	Powder River Basin	17.5
BULL CREEK NORTH	Y	Powder River Basin	17.5
BULLMARCH	Y	Powder River Basin	15.0
CAMBRIDGE	Y	Powder River Basin	18.0
CAMP CREEK	Y	Powder River Basin	18.0
CANDY DRAW	Y	Powder River Basin	16.5
DEADMAN CREEK	Y	Powder River Basin	17.6
DEER FLY	Y	Powder River Basin	16.0
DILLINGER RANCH	Y	Powder River Basin	16.3
DONKEY CREEK	Y	Powder River Basin	16.1
DONKEY CREEK NORTH	Y	Powder River Basin	15.3
DOUBLE SHIELD	Y	Powder River Basin	17.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
DRISCOLL CREEK	Y	Powder River Basin	15.8
DRY GULCH	Y	Powder River Basin	17.5
DUTCH	Y	Powder River Basin	16.4
DUVALL RANCH	Y	Powder River Basin	16.0
EDSEL	Y	Powder River Basin	19.6
EITEL	Y	Powder River Basin	18.0
GLO	Y	Powder River Basin	18.0
GRASSLAND WEST	Y	Powder River Basin	16.0
GRAY SOUTH	Y	Powder River Basin	17.0
HAIGHT	Y	Powder River Basin	17.5
INDIAN TREE	Y	Powder River Basin	15.0
KANE	Y	Powder River Basin	15.0
KUEHNE RANCH	Y	Powder River Basin	15.0
KUEHNE RANCH NORTHEAST	Y	Powder River Basin	17.6
KUEHNE RANCH SOUTHEAST	Y	Powder River Basin	16.7
KUMMERFELD	Y	Powder River Basin	17.0
LAD	Y	Powder River Basin	18.0
LITTLE MISSOURI	Y	Powder River Basin	17.0
LITTLE MITCHELL CREEK	Y	Powder River Basin	19.0
LONE CEDAR	Y	Powder River Basin	18.0
MAYSDORF	Y	Powder River Basin	15.0
MELLOTT RANCH	Y	Powder River Basin	18.0
MOORCROFT WEST	Y	Powder River Basin	16.0
PIERCE	Y	Powder River Basin	15.0
POWNALL RANCH	Y	Powder River Basin	15.2
PRAIRIE CREEK SOUTH	Y	Powder River Basin	18.0
RAINBOW RANCH	Y	Powder River Basin	16.5
RAINBOW RANCH NORTH	Y	Powder River Basin	15.6
ROBINSON RANCH SOUTH	Y	Powder River Basin	18.0
ROEHRS	Y	Powder River Basin	17.3
ROEHRS SOUTH	Y	Powder River Basin	17.0
ROZET	Y	Powder River Basin	17.5
RULE	Y	Powder River Basin	18.2

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
SANDBAR EAST	Y	Powder River Basin	17.9
SHIPPY	Y	Powder River Basin	18.0
SIMPSON RANCH	Y	Powder River Basin	18.0
SPRINGEN RANCH	Y	Powder River Basin	17.0
STEWART	Y	Powder River Basin	16.0
SUPERHORNET	Y	Powder River Basin	19.5
TEXAS TRAIL	Y	Powder River Basin	15.0
THOLSON	Y	Powder River Basin	17.0
THORSON	Y	Powder River Basin	18.8
TIMBER CREEK	Y	Powder River Basin	18.0
TIMBER CREEK NORTH	Y	Powder River Basin	15.7
TIMBER CREEK NORTHWEST	Y	Powder River Basin	15.0
WAGON SPOKE	Y	Powder River Basin	18.0
WALLACE	Y	Powder River Basin	17.3
WALLACE NORTH	Y	Powder River Basin	18.0
WALLACE SOUTH	Y	Powder River Basin	16.5
Y	Y	Powder River Basin	19.0
YELLOW HAMMER NW	Y	Powder River Basin	15.0
YORK	Y	Powder River Basin	15.4
ART CREEK	Z	Powder River Basin	20.0
BERGER HILL	Z	Powder River Basin	24.0
BERGER HILL NORTH	Z	Powder River Basin	24.0
BIG HAND	Z	Powder River Basin	20.0
BREAKS	Z	Powder River Basin	21.0
C-H	Z	Powder River Basin	20.6
CORRAL CREEK	Z	Powder River Basin	24.0
COUNTY LINE	Z	Powder River Basin	22.0
GIBBS	Z	Powder River Basin	20.0
GIBBS SOUTH	Z	Powder River Basin	20.0
GLO NORTH	Z	Powder River Basin	20.0
HAMM	Z	Powder River Basin	22.0
HEATH	Z	Powder River Basin	20.0
HIGH ROAD	Z	Powder River Basin	23.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
JEWEL	Z	Powder River Basin	24.0
KIEHL	Z	Powder River Basin	21.0
KIEHL WEST	Z	Powder River Basin	23.0
KUEHNE RANCH EAST	Z	Powder River Basin	22.0
LILY	Z	Powder River Basin	22.0
M-D	Z	Powder River Basin	21.0
MITCHELL CREEK	Z	Powder River Basin	20.0
OSHOTO	Z	Powder River Basin	22.0
PLEASANT VALLEY	Z	Powder River Basin	20.0
PRONG CREEK	Z	Powder River Basin	21.1
R.T.	Z	Powder River Basin	20.0
REYNOLDS RANCH	Z	Powder River Basin	30.0
ROBINSON RANCH EAST	Z	Powder River Basin	22.0
ROCKY POINT	Z	Powder River Basin	20.0
SEMLEK	Z	Powder River Basin	23.0
SEMLEK WEST	Z	Powder River Basin	20.0
SODA WELL	Z	Powder River Basin	20.0
TERRACE	Z	Powder River Basin	27.0
WELL CREEK	Z	Powder River Basin	20.0
WHEAT DRAW	Z	Powder River Basin	23.0
YELLOW HAMMER	Z	Powder River Basin	26.0
RIVERTON DOME	AE	Wind River Basin	4.7
BEAVER CREEK	AF	Wind River Basin	8.0
BIG SAND DRAW	AG	Wind River Basin	12.6
SAND DRAW NORTH	AG	Wind River Basin	11.0
SAND DRAW SOUTH	AG	Wind River Basin	13.2
CIRCLE RIDGE	M	Wind River Basin	15.0
DALLAS	M	Wind River Basin	18.0
DERBY	M	Wind River Basin	18.0
LANDER	M	Wind River Basin	15.0
PILOT BUTTE	M	Wind River Basin	15.0
MAVERICK SPRINGS	N	Wind River Basin	12.6
STEAMBOAT BUTTE	N	Wind River Basin	12.0
WINKLEMAN	N	Wind River Basin	14.0

Appendix 1. Continued

Field Name	Group Porosity	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Porosity (%)
SHELDON	O	Wind River Basin	8.5
SHELDON NORTHWEST	O	Wind River Basin	8.0
EMERALD	Q	Wind River Basin	12.0
NOTCHES	R	Wind River Basin	19.0
OKIE DRAW	R	Wind River Basin	15.0
CASPER CREEK SOUTH	S	Wind River Basin	25.0
CLARK RANCH	S	Wind River Basin	22.0
OIL MOUNTAIN	S	Wind River Basin	20.2
PINE MOUNTAIN	S	Wind River Basin	20.8
POISON SPIDER	S	Wind River Basin	26.0

Appendix 2: Permeability Basin Group

Appendix 2. Permeability Basin Group

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
BIG POLECAT	A	Bighorn Basin	67.00
BYRON	A	Bighorn Basin	78.00
ELK BASIN	A	Bighorn Basin	60.00
FRANNIE	A	Bighorn Basin	75.00
GARLAND	A	Bighorn Basin	53.00
HOMESTEAD	A	Bighorn Basin	46.00
LITTLE POLECAT	A	Bighorn Basin	64.00
NORTH DANKER	A	Bighorn Basin	25.80
WHISTLE CREEK	A	Bighorn Basin	58.00
ALKALI ANTICLINE	B	Bighorn Basin	105.94
COWLEY	B	Bighorn Basin	110.00
DEAVER	B	Bighorn Basin	135.00
DEAVER NORTH	B	Bighorn Basin	89.00
ELK BASIN SOUTH	B	Bighorn Basin	140.00
SAGE CREEK	B	Bighorn Basin	192.00
SAGE CREEK WEST	B	Bighorn Basin	100.00
SILVER TIP	C	Bighorn Basin	2.50
ENIGMA	D	Bighorn Basin	67.00
FRISON	D	Bighorn Basin	35.50
HIDDEN DOME	D	Bighorn Basin	92.00
MANDERSON	D	Bighorn Basin	13.90
BONANZA	E	Bighorn Basin	195.00
LAMB	E	Bighorn Basin	108.00
NOWOOD	E	Bighorn Basin	200.00
WORLAND	F	Bighorn Basin	2.40
BLACK MOUNTAIN	G	Bighorn Basin	77.90
CODY	G	Bighorn Basin	20.00
GEBO	G	Bighorn Basin	18.20
GOOSEBERRY	G	Bighorn Basin	25.00
HAMILTON DOME	G	Bighorn Basin	60.00
KING DOME	G	Bighorn Basin	55.00
LITTLE BUFFALO BASIN	G	Bighorn Basin	75.00
MURPHY DOME	G	Bighorn Basin	59.20

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
NEIBER DOME	G	Bighorn Basin	12.00
PITCHFORK	G	Bighorn Basin	45.00
RAWHIDE	G	Bighorn Basin	22.80
SHOSHONE	G	Bighorn Basin	80.00
SUNSHINE NORTH	G	Bighorn Basin	70.35
ZIMMERMAN BUTTE	G	Bighorn Basin	15.90
OREGON BASIN	Gm	Bighorn Basin	90.00
FOURBEAR	H	Bighorn Basin	7.00
GOLDEN EAGLE	Hi	Bighorn Basin	0.90
LAKE CREEK	H	Bighorn Basin	9.20
LITTLE SAND DRAW	H	Bighorn Basin	1.28
WILLOW DRAW	H	Bighorn Basin	1.12
GRASS CREEK	I	Bighorn Basin	112.00
HALF MOON	I	Bighorn Basin	251.00
HUNT	I	Bighorn Basin	157.00
SPRING CREEK SOUTH	I	Bighorn Basin	150.00
HIGGINS	DA	Greater Green River Basin	0.05
TABLE ROCK	DA	Greater Green River Basin	0.02
BROWNING	EE	Greater Green River Basin	225.01
HATFIELD	FAL	Greater Green River Basin	0.50
SHERARD	FAL	Greater Green River Basin	0.20
SUGAR CREEK	FA	Greater Green River Basin	4.00
BRADY	GA	Greater Green River Basin	37.05
LOST SOLDIER	GA	Greater Green River Basin	31.00
WERTZ	GA	Greater Green River Basin	20.00
ALLEN LAKE EAST	EA	Hanna Basin	224.50
BIG MEDICINE BOW	FA	Hanna Basin	55.00
O'BRIEN SPRINGS	FA	Hanna Basin	9.00
MAHONEY DOME	GA	Hanna Basin	10.00
MAHONEY DOME EAST	GA	Hanna Basin	15.00
HERRICK	YA	Laramie Basin	800.00
QUEALY	YA	Laramie Basin	140.00
ADON	AA	Powder River Basin	95.00

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
ADON ROAD NORTH	AA	Powder River Basin	19.20
AM-KIRK	AA	Powder River Basin	21.00
ART CREEK	AA	Powder River Basin	72.00
BASIN NORTHWEST	AA	Powder River Basin	18.00
BERGER HILL	AA	Powder River Basin	18.40
BERGER HILL NORTH	AA	Powder River Basin	18.40
BIG HAND	AA	Powder River Basin	21.00
BISHOP RANCH	AA	Powder River Basin	32.00
BISHOP RANCH SOUTH	AA	Powder River Basin	62.00
BONE PILE	AA	Powder River Basin	12.00
BREEN	AA	Powder River Basin	20.00
BRONCO	AA	Powder River Basin	60.00
BULLMARCH	AA	Powder River Basin	27.50
C-H	AA	Powder River Basin	80.00
DEER FLY	AA	Powder River Basin	26.00
DILLINGER RANCH NORTH	AA	Powder River Basin	33.00
DONKEY CREEK	AA	Powder River Basin	42.00
FALCON RIDGE	AA	Powder River Basin	77.00
GLO	AA	Powder River Basin	44.00
GRASSLAND	AA	Powder River Basin	38.00
HALVERSON	AA	Powder River Basin	56.00
HAWK POINT	AA	Powder River Basin	30.00
KUEHNE RANCH	AA	Powder River Basin	53.00
MALLARD	AA	Powder River Basin	93.00
MAYSDORF	AA	Powder River Basin	44.00
MORAN	AA	Powder River Basin	78.00
OK	AA	Powder River Basin	52.00
PICKREL RANCH	AA	Powder River Basin	50.00
POWNALL RANCH	AA	Powder River Basin	70.00
PRAIRIE CREEK SOUTH	AA	Powder River Basin	83.00
RAVEN CREEK	AA	Powder River Basin	50.00
REEL	AA	Powder River Basin	38.00
ROEHRS	AA	Powder River Basin	92.00

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
ROURKE GAP	AA	Powder River Basin	97.00
ROYAL DRAW	AA	Powder River Basin	30.00
SHARP	AA	Powder River Basin	21.00
STEWART EAST	AA	Powder River Basin	70.00
T.A. BUTTES	AA	Powder River Basin	57.70
THOLSON	AA	Powder River Basin	83.00
TIMBER CREEK	AA	Powder River Basin	80.00
TIMBER CREEK NORTHWEST	AA	Powder River Basin	40.00
VICTOR	AA	Powder River Basin	34.00
WALLACE	AA	Powder River Basin	93.00
WALLACE NORTH	AA	Powder River Basin	78.50
WHISLER	AA	Powder River Basin	22.00
WIDGE	AA	Powder River Basin	29.75
WIDGE NORTH	AA	Powder River Basin	27.00
Y	AA	Powder River Basin	64.00
YELLOW HAMMER NW	AA	Powder River Basin	34.50
YORK	AA	Powder River Basin	60.00
HILIGHT	BA	Powder River Basin	0.18
ADON ROAD	CA	Powder River Basin	160.80
AG FARM	CA	Powder River Basin	338.00
ALPHA	CA	Powder River Basin	224.00
BIG MAC	CA	Powder River Basin	365.00
BRACKEN	CA	Powder River Basin	173.00
BREAKS	CA	Powder River Basin	350.00
BRENNAN	CA	Powder River Basin	585.00
BULL CREEK	CA	Powder River Basin	569.00
BULL CREEK NORTH	CA	Powder River Basin	569.00
CAMBRIDGE	CA	Powder River Basin	700.00
CAMP CREEK	CA	Powder River Basin	257.50
CANDY DRAW	CA	Powder River Basin	107.00
CORRAL CREEK	CA	Powder River Basin	420.00
COUNTY LINE	CA	Powder River Basin	260.00
DEADMAN CREEK	CA	Powder River Basin	884.00

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
DILLINGER RANCH	CA	Powder River Basin	100.00
DONKEY CREEK NORTH	CA	Powder River Basin	100.00
DUTCH	CA	Powder River Basin	150.00
DUVALL RANCH	CA	Powder River Basin	204.00
EITEL	CA	Powder River Basin	200.00
GIBBS	CA	Powder River Basin	475.00
GIBBS SOUTH	CA	Powder River Basin	475.00
GRASSLAND WEST	CA	Powder River Basin	377.00
GUTHREY	CA	Powder River Basin	725.36
HAMM	CA	Powder River Basin	240.00
HEATH	CA	Powder River Basin	554.00
INDIAN TREE	CA	Powder River Basin	124.40
JEWEL	CA	Powder River Basin	275.00
KANE	CA	Powder River Basin	215.00
KIEHL	CA	Powder River Basin	320.00
KUEHNE RANCH SOUTHEAST	CA	Powder River Basin	110.00
KUMMERFELD	CA	Powder River Basin	208.00
LILY	CA	Powder River Basin	245.00
LITTLE MISSOURI	CA	Powder River Basin	566.00
LITTLE MITCHELL CREEK	CA	Powder River Basin	169.00
M-D	CA	Powder River Basin	190.00
MELLOTT RANCH	CA	Powder River Basin	500.00
PIERCE	CA	Powder River Basin	106.00
PRONG CREEK	CA	Powder River Basin	622.50
RAINBOW RANCH	CA	Powder River Basin	130.00
RAINBOW RANCH NORTH	CA	Powder River Basin	149.00
ROBINSON RANCH	CA	Powder River Basin	138.30
ROBINSON RANCH EAST	CA	Powder River Basin	381.67
ROBINSON RANCH SOUTH	CA	Powder River Basin	300.00
ROCKY POINT	CA	Powder River Basin	500.00
ROZET	CA	Powder River Basin	522.50
SANDBAR EAST	CA	Powder River Basin	300.00
SEMLEK	CA	Powder River Basin	444.00

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
SEMLEK WEST	CA	Powder River Basin	647.00
SIMPSON RANCH	CA	Powder River Basin	200.00
STEWART	CA	Powder River Basin	130.00
SUPERHORNET	CA	Powder River Basin	279.00
SWARTZ DRAW	CA	Powder River Basin	137.00
TEXAS TRAIL	CA	Powder River Basin	119.00
THORSON	CA	Powder River Basin	205.00
TIMBER CREEK NORTH	CA	Powder River Basin	211.00
WAGON SPOKE	CA	Powder River Basin	300.00
WALLACE SOUTH	CA	Powder River Basin	133.00
WD	CA	Powder River Basin	125.00
WOLF DRAW	CA	Powder River Basin	300.00
HORSE RANCH	R	Powder River Basin	12.50
SALT CREEK	U	Powder River Basin	136.70
TISDALE EAST	U	Powder River Basin	900.00
TISDALE NORTH	U	Powder River Basin	900.00
CRAZY WOMAN SOUTH	V	Powder River Basin	1.00
RENO	V	Powder River Basin	2.00
TEAPOT NAVAL RESERVE	V	Powder River Basin	5.00
CELLARS RANCH	W	Powder River Basin	57.00
FOURMILE	W	Powder River Basin	46.00
MEADOW CREEK	W	Powder River Basin	31.00
NORTH FORK	W	Powder River Basin	46.00
PHEASANT	W	Powder River Basin	20.00
SALT CREEK EAST	W	Powder River Basin	40.00
SUSSEX	W	Powder River Basin	40.00
BEAVER HOLE	X	Powder River Basin	24.60
BRIGHT	X	Powder River Basin	17.50
BUCK CREEK	X	Powder River Basin	20.00
SWEDE DRAW	X	Powder River Basin	82.00
LEIMSER	Y	Powder River Basin	0.05
CHARLES	Z	Powder River Basin	7.20
CLABAUGH	Z	Powder River Basin	5.80

Appendix 2. Continued

Field Name	Group Permeability	Basin (Assigned by the Wyoming Oil and Gas Conservation Commission)	Permeability (md)
LANCE CREEK	Z	Powder River Basin	3.00
MOORCROFT WEST	Z	Powder River Basin	3.30
SHIPPY	Z	Powder River Basin	9.60
BIG SAND DRAW	M	Wind River Basin	50.00
CIRCLE RIDGE	M	Wind River Basin	78.20
MAVERICK SPRINGS	M	Wind River Basin	63.00
SAND DRAW NORTH	M	Wind River Basin	33.50
SAND DRAW SOUTH	M	Wind River Basin	60.20
SHELDON NORTHWEST	M	Wind River Basin	10.60
STEAMBOAT BUTTE	M	Wind River Basin	41.00
BEAVER CREEK	N	Wind River Basin	8.53
RIVERTON DOME	N	Wind River Basin	6.90
SHELDON	N	Wind River Basin	1.70
PILOT BUTTE	O	Wind River Basin	0.85
DERBY	P	Wind River Basin	500.00
WINKLEMAN	P	Wind River Basin	134.80
EMERALD	R	Wind River Basin	60.50
NOTCHES	R	Wind River Basin	51.30
CASPER CREEK SOUTH	S	Wind River Basin	1663.00
CLARK RANCH	S	Wind River Basin	150.00
OIL MOUNTAIN	S	Wind River Basin	508.00
PINE MOUNTAIN	S	Wind River Basin	615.00
POISON SPIDER	S	Wind River Basin	750.00