Appendix A

Description of GIS geologic units, Northeast River Basin (NERB), Wyoming, Montana, South Dakota, and Nebraska

This appendix describes the 75 geologic units that comprise the NERB in Wyoming and portions of neighboring states, Montana (MT), South Dakota (SD), and Nebraska (NE). The descriptions of the stratigraphy in this appendix are for the units illustrated on plate 1.

The geologic units shown in plate 1 are compiled from the 1:500,000-scale statewide geologic map (Love and Christiansen, 1985). The map provides a unit code and name of the rock units within the map area. Each state has a unique set of codes; codes nor unit boundaries necessarily match across state lines. The presence and/or variation in naming convention and/or unit code of individual units in neighboring states are noted in brackets at the end of the associated description. Stratigraphic unit descriptions for adjacent states are addressed in separate sections. This appendix provides details of the physical characteristics of the rocks shown on the map as defined in that state.

References

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WYOMING

CENOZOIC

QUATERNARY

Qa	**ALLUVIUM AND COLLUVIUM** (Holocene-Pleistocene)—Clay, silt, sand, and gravel in flood plains, fans, terraces, and slopes [Qal in MT and SD]
Qt	**GRAVEL, PEDIMENT, AND FAN DEPOSITS** (Holocene-Pleistocene)—Mostly locally derived clasts; locally includes some Tertiary gravel [SD]
Qg	**GLACIAL DEPOSITS** (Holocene-Pleistocene)—Till and outwash of sand, gravel, and boulders
Qls	**LANDSLIDE DEPOSITS** (Holocene-Pleistocene)—Local intermixed landslide and glacial deposits, talus, and rock-glacier deposits [Ql in SD]
Qs	**DUNE SAND AND LOESS** (Holocene-Pleistocene)—Includes active and dormant sand dunes
Qu	**UNDIVIDED SURFICIAL DEPOSITS** (Holocene-Pleistocene)—Mostly alluvium, colluvium, and glacial and landslide deposits

QUATERNARY-TERTIARY

QTg	**TERRACE GRAVELS** (Pleistocene and/or Pliocene)—Partly consolidated gravel above and flanking some major streams

TERTIARY

Tmu	**UPPER MIOCENE ROCKS** (Miocene)—Light-colored tuffaceous claystone, sandstone, and conglomerate; Ogallala Formation in Denver Basin
Tml	**LOWER MIOCENE ROCKS** (Miocene)—Gray, soft, poorly bedded to massive sandstone
Tmo	**LOWER MIOCENE AND UPPER OLIGOCENE ROCKS** (Miocene and Oligocene)—Light-colored, soft, porous sandstone and underlying white tuffaceous claystone and siltstone; Arikaree Formation in Denver Basin
Twr	**WHITE RIVER FORMATION** (Oligocene)—White to pale-pink blocky tuffaceous claystone and lenticular arkosic conglomerate [Tw in NE]
Tid	**DACITE AND QUARTZ LATITE INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS** (Oligocene and/or Eocene)—Light-gray porphyritic rock
Twb	**WAGON BED FORMATION** (Eocene)—Dull-green, siliceous bentonitic claystone and tuff; giant granite boulder conglomerate in tuffaceous matrix
Tai	**ALKALIC INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS** (Eocene)—Light- to greenish-gray porphyry
Tw	**WASATCH FORMATION** (Eocene)—Drab sandstone and drab to variegated claystone; numerous coal beds in lower part [MT]
Twmo	**MONCRIEF MEMBER—**Conglomerate of Precambrian clasts, interbedded with drab sandstone and claystone
Twk	**KINGBURY CONGLOMERATE MEMBER—**Conglomerate of Paleozoic clasts, interbedded with drab sandstone and variegated claystone
Tie	**INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS** (Eocene)—Incorporates masses of Mississippian through Cambrian formations; confined to the Black Hills [Tt—Trachytic intrusive rock in SD]
Twdr	**WIND RIVER FORMATION** (Eocene)—Variegated claystone and sandstone; lenticular conglomerate
Tim	**INDIAN MEADOWS FORMATION** (Eocene)—Red to variegated claystone, sandstone, and algal-ball (?) limestone; some beds of large Paleozoic boulders and detachment masses of Paleozoic and Mesozoic rocks
Tfu	**FORT UNION FORMATION** (Paleocene)—Light-colored massive sandstone, drab shale, and thick coal beds [MT]
Tftr	**TONGUE RIVER MEMBER—**Thick beds of yellow sandstone interbedded with gray and black shale and many coal beds
Tfl	**LEBO MEMBER—**Dark-gray clay shale and concretionary sandstone
Tft	**TULLOCK MEMBER—S**oft-gray sandstone, gray and brown carbonaceous shale, and thin coal beds

Tftl **TONGUE RIVER AND LEBO MEMBERS—**Undifferentiated; *TONGUE RIVER MEMBER*: Thick beds of yellow sandstone interbedded with gray and black shale and many coal beds; *LEBO MEMBER*: Dark-gray clay shale and concretionary sandstone

Tflt **LEBO AND TULLOCK MEMBERS—**Undifferentiated; *LEBO MEMBER*: Dark-gray clay shale and concretionary sandstone; *TULLOCK MEMBER*: Soft-gray sandstone, gray and brown carbonaceous shale, and thin coal beds

MESOZOIC

CRETACEOUS

Kl **LANCE FORMATION** (Upper Cretaceous)—Greenish-gray bentonitic tuffaceous sandstone and conglomerate [Khc—Hell Creek Formation in MT]

Klm **LANCE FORMATION, FOX HILLS SANDSTONE, MEETEETSE FORMATION, AND BEARPAW AND LEWIS SHALES** (Upper Cretaceous)—Undifferentiated; *LANCE FORMATION*: Greenish-gray bentonitic tuffaceous sandstone and conglomerate; *FOX HILLS SANDSTONE*: Light-colored sandstone and gray sandy shale containing marine fossils; *MEETEETSE FORMATION*: Chalky- white to gray sand stone, yellow, green, and dark-gray bentonitic claystone, white tuff, and thin coal beds; *BEARPAW SHALE*: Dark greenish-gray shale containing thin gray sandstone partings

Kfh **FOX HILLS SANDSTONE** (Upper Cretaceous)—Light-colored sandstone and gray sandy shale containing marine fossils [MT]

Kfl **FOX HILLS SANDSTONE AND LEWIS SHALE** (Upper Cretaceous)—Undifferentiated; *FOX HILLS SANDSTONE*: Light-colored sandstone and gray sandy shale containing marine fossils; *LEWIS SHALE*: Gray marine shale containing many gray and brown lenticular concretion-rich sandstone beds

Kfb **FOX HILLS SANDSTONE AND BEARPAW SHALE** (Upper Cretaceous)—Undifferentiated; *FOX HILLS SANDSTONE*: Light-colored sandstone and gray sandy shale containing marine fossils; *BEARPAW SHALE*: Dark greenish-gray shale containing thin gray sandstone partings [MT]

Kml **MEETEETSE FORMATION AND LEWIS SHALE** (Upper Cretaceous)—Undifferentiated; *MEETEETSE FORMATION*: Chalky-white to gray sandstone, yellow, green, and dark-gray bentonitic clay stone, white tuff, and thin coal beds; *LEWIS SHALE*: Gray marine shale containing many gray and brown lenticular concretion-rich sandstone beds

Kmv **MESAVERDE GROUP** (Upper Cretaceous)—Light-colored, massive to thin-bedded sandstone, gray sandy shale, and coal beds

Kc **CODY SHALE** (Upper Cretaceous)—Dull-gray shale, gray siltstone, and fine-grained gray sandstone

Kf **FRONTIER FORMATION** (Upper Cretaceous)—Gray sandstone and sandy shale

Kft **FRONTIER FORMATION, AND MOWRY AND THERMOPOLIS SHALES** (Upper and Lower Cretaceous)—Undifferentiated; *FRONTIER FORMATION*: Gray sandstone and sandy shale; *MOWRY SHALE*: Silvery-gray hard siliceous shale containing abundant fish scales and bentonite beds; *THERMOPOLIS SHALE*: Black soft fissile shale

Kp	**PIERRE SHALE** (Upper Cretaceous)—Dark-gray concretionary marine shale; contains several bentonite beds [MT, SD, NE]
Kn	**NIOBRARA FORMATION** (Upper Cretaceous)—Light-colored limestone and gray- to yellow-specked limy shale [MT, SD]
Knc	**NIOBRARA FORMATION AND CARLILE SHALE** (Upper Cretaceous)—Undifferentiated; *NIOBRARA FORMATION*: Light-colored limestone and gray- to yellow-specked limy shale; *CARLILE SHALE*: Dark-gray sandy shale
Kcl	**CARLILE SHALE** (Upper Cretaceous)—Dark-gray sandy shale
Kg	**GREENHORN FORMATION** (Upper Cretaceous)—Light-colored limestone, marl, and limy sandstone interbedded with gray concretionary shale
Kgb	**GREENHORN FORMATION AND BELLE FOURCHE SHALE** (Upper Cretaceous)—Undifferentiated; *GREENHORN FORMATION*: Light-colored limestone, marl, and limy sandstone interbedded with gray concretionary shale; *BELLE FOURCHE SHALE*: Black soft bentonitic concretionary shale
Kgbm	**GREENHORN FORMATION AND BELLE FOURCHE AND MOWRY SHALES** (Upper and Lower Cretaceous)—Undifferentiated; *GREENHORN FORMATION*: Light-colored limestone, marl, and limy sandstone interbedded with gray concretionary shale; *BELLE FOURCHE SHALE*: Black soft bentonitic concretionary shale
Kmr	**MOWRY SHALE** (Lower Cretaceous)—Silvery-gray hard siliceous shale containing abundant fish scales and bentonite beds
Kmt	**MOWRY AND THERMOPOLIS SHALES** (Lower Cretaceous)—Undifferentiated; *MOWRY SHALE*: Silvery-gray hard siliceous shale containing abundant fish scales and bentonite beds; *THERMOPOLIS SHALE*: Black soft fissile shale
Kns	**NEWCASTLE SANDSTONE AND SKULL CREEK SHALE** (Lower Cretaceous)—Undifferentiated; *NEWCASTLE SANDSTONE*: Gray sandstone and sandy shale containing some bentonite and coal; *SKULL CREEK SHALE*: Black soft fissile shale

CRETACEOUS-JURASSIC

KJ	**CLOVERLY AND MORRISON FORMATIONS (W/SW) or INYAN KARA GROUP AND MORRISON FORMATION (E/SE)** (Lower Cretaceous-Upper Jurassic)—Undifferentiated; *CLOVERLY FORMATION*: Rusty to light-gray sandstone containing lenticular chert-pebble conglomerate interbedded with variegated bentonitic claystone; *MORRISON FORMATION*: Dully variegated siliceous claystone, nodular white limestone, and gray silty sandstone; *INYAN KARA GROUP*: Rust to light-gray sandstone containing lenticular chert-pebble conglomerate interbedded with variegated bentonitic claystone
KJs	**CLOVERLY, MORRISON, AND SUNDANCE FORMATIONS** (Lower Cretaceous-Upper Jurassic)—Undifferentiated; *CLOVERLY FORMATION*: Rusty to light-gray sandstone containing lenticular chert-pebble conglomerate interbedded with variegated bentonitic claystone; *MORRISON FORMATION*: Dully variegated siliceous claystone, nodular white limestone, and gray silty sandstone; *SUNDANCE FORMATION*: Greenish-gray glauconitic sandstone and shale, underlain by red and gray non-glauconitic sandstone and shale

KJg	**CLOVERLY, MORRISON, SUNDANCE, AND GYPSUM SPRING FORMATIONS** (Lower Cretaceous-Upper Jurassic)—Undifferentiated; *CLOVERLY FORMATION*: Rusty to light-gray sandstone containing lenticular chert-pebble conglomerate interbedded with variegated bentonitic claystone; *MORRISON FORMATION*: Dully variegated siliceous claystone, nodular white limestone, and gray silty sandstone; *SUNDANCE FORMATION*: Greenish-gray glauconitic sandstone and shale, underlain by red and gray non-glauconitic sandstone and shale; *GYPSUM SPRING FORMATION*: Interbedded red shale, dolomite, and gypsum

JURASSIC

Jsg	**SUNDANCE AND GYPSUM SPRING FORMATIONS** (Jurassic)—Undifferentiated; *SUNDANCE FORMATION*: Greenish-gray glauconitic sandstone and shale, underlain by red and gray non-glauconitic sandstone and shale; *GYPSUM SPRING FORMATION*: Interbedded red shale, dolomite, and gypsum

TRIASSIC

Ꞧcd	**CHUGWATER AND DINWOODY FORMATIONS** (Triassic)—Undifferentiated; *CHUGWATER FORMATION*: Red siltstone and shale with thin gypsum partings near base; *DINWOODY FORMATION*: Olive-drab hard dolomitic thin-bedded siltstone
Ꞧc	**CHUGWATER FORMATION** (Triassic)—Red siltstone and shale with thin gypsum partings near base

TRIASSIC-PERMIAN

ꞦPcg	**CHUGWATER AND GOOSE EGG FORMATIONS** (Lower Triassic-Permian)—Undifferentiated; *CHUGWATER FORMATION*: Red siltstone and shale with thin gypsum partings near base; *GOOSE EGG FORMATION*: Red sandstone and siltstone, white gypsum, halite, and purple to white dolomite and limestone
ꞦPs	**SPEARFISH FORMATION** (Triassic-Permian)—Red shale, red siltstone, and white gypsum beds; gypsum beds especially abundant near base [SD]
ꞦPg	**GOOSE EGG FORMATION** (Lower Triassic-Permian)—Red sandstone and siltstone, white gypsum, halite, and purple to white dolomite and limestone

PALEOZOIC

Pzr	**UNDIVIDED PALEOZOIC UNITS** (Cambrian-Permian)—Undifferentiated rocks of Cambrian to Permian age

PERMIAN

Pp	**PHOSPHORIA FORMATION AND RELATED ROCKS** (Permian)—Brown sandstone and dolomite, cherty phosphatic and glauconitic dolomite, phosphatic sandstone and dolomite, and greenish-gray to black shale
Pmo	**MINNEKAHTA LIMESTONE AND OPECHE SHALE** (Permian)—Undifferentiated; *MINNEKAHTA LIMESTONE*: Gray slabby hard limestone; locally is a member of the Goose Egg Formation; *OPECHE SHALE*: Red, soft, sandy shale; locally is a member of the Goose Egg Formation [SD]

PERMIAN-PENNSYLVANIAN

PIPh **HARTVILLE FORMATION** (Lower Permian-Pennsylvanian)—Red and white sandstone underlain by gray dolomite and limestone, red shale, and red and gray sandstone; lowermost unit may be Late Mississippian in age

PIPm **MINNELUSA FORMATION** (Lower Permian-Pennsylvanian)—Buff and red limy sandstone; some thin limestone beds, solution breccias, and gypsum [SD]

PERMIAN-MISSISSIPPIAN

PM **TENSLEEP SANDSTONE AND AMSDEN FORMATION** (Lower Permian-Upper Mississippian)—Undifferentiated; *TENSLEEP SANDSTONE*: White to gray sandstone containing thin limestone and dolomite beds. Permian fossils have been found in the topmost beds of the Tensleep at some localities in Washakie Range, Owl Creek Mountains, and southern Bighorn Mountains; *AMSDEN FORMATION*: Red and green shale and dolomite; at base is brown sandstone [PNu in MT]

MISSISSIPPIAN

Mm **MADISON LIMESTONE OR GROUP** (Upper and Lower Mississippian)—Group includes Mission Canyon Limestone (blue-gray massive limestone and dolomite), underlain by Lodgepole Limestone (gray cherty limestone and dolomite)

MISSISSIPPIAN-DEVONIAN

MD **MADISON LIMESTONE OR DARBY FORMATION** (Upper Mississippian-Upper Devonian)—Undifferentiated; *MADISON LIMESTONE OR GROUP*: Group includes Mission Canyon Limestone (blue-gray massive limestone and dolomite), underlain by Lodgepole Limestone (gray cherty limestone and dolomite); *DARBY FORMATION*: Yellow and greenish-gray shale and dolomitic siltstone underlain by fetid brown dolomite [Mu in MT]

MDg **GUERNSEY FORMATION** (Lower Mississippian-Upper Devonian)—Blue-gray massive cherty limestone and dolomite; locally includes unnamed dolomite and sandstone of Devonian and Cambrian (?) age

MDe **PAHASAPA AND ENGLEWOOD LIMESTONES** (Lower Mississippian-Upper Devonian)—Undifferentiated; *PAHASAPA LIMESTONE*: Gray massive dolomitic limestone; *ENGLEWOOD LIMESTONE*: Pink slabby dolomitic limestone [MDpe in SD]

MISSISSIPPIAN-ORDOVICIAN

MO **MADISON LIMESTONE AND BIGHORN DOLOMITE** (Mississippian-Middle and Upper Ordovician)—Undifferentiated; MADISON LIMESTONE: Group includes Mission Canyon Limestone (blue-gray massive limestone and dolomite), underlain by Lodgepole Limestone (gray cherty limestone and dolomite); *BIGHORN DOLOMITE*: Gray massive cliff-forming siliceous dolomite and locally dolomitic limestone

ORDOVICIAN-CAMBRIAN

O€	**WHITEWOOD DOLOMITE AND WINNIPEG AND DEADWOOD FORMATIONS** (E); **OR BIGHORN DOLOMITE, GALLATIN LIMESTONE, GROS VENTRE FORMATION, AND FLATHEAD SANDSTONE (W)** (Upper Ordovician-Upper/Middle Cambrian)—Undifferentiated; *WHITEWOOD DOLOMITE*: Buff massive fossiliferous dolomite; *WINNIPEG FORMATION*: Pink to yellow siltstone and shale; *DEADWOOD FORMATION*: Red and brown quartzite sandstone; *BIGHORN DOLOMITE*: Light-gray massive siliceous dolomite; *GALLATIN LIMESTONE*: Blue-gray and yellow mottled hard dense limestone; *GROS VENTRE FORMATION*: Soft-green micaceous shale (Upper and Middle Cambrian Park Shale Member), underlain by blue-gray and yellow mottled hard dense limestone (Middle Cambrian Death Canyon Limestone Member), and soft-green micaceous shale (Middle Cambrian Wolsey Shale Member); *FLATHEAD SANDSTONE*: Dull-red quartzite sandstone [Ou in MT; O€wd in O€wd in SD]

ORDOVICIAN

Ob	**BIGHORN DOLOMITE** (Upper and Middle Ordovician)—Light-gray massive siliceous dolomite

CAMBRIAN

€r	**CAMBRIAN ROCKS** (Cambrian)—Blue-gray and yellow mottled hard dense limestone interbedded with soft-green micaceous shale; dull-red quarzitic sandstone at base

PRECAMBRIAN

EARLY PROTEROZOIC

Xsv	**METASEDIMENTARY AND METAVOLCANIC ROCKS** (Proterozoic)—Pelitic schist; includes minor amounts of granite and amphibolite [XWgw in SD]

ARCHEAN

Wmu	**METASEDIMENTARY AND METAVOLCANIC ROCKS** (Late Archean)—Amphibolite
Wg	**GRANTITIC ROCKS OF 2,600-MA AGE GROUP** (Late Archean)—Granite and minor amounts of metasedimentary rocks
Wvsv	**METASEDIMENTARY AND METAVOLCANIC ROCKS** (Late to Middle Archean)—Amphibolite, hornblende gneiss, biotite gneiss, quartzite, iron-formation, metaconglomerate, marble, and pelitic schist; locally preserved textures and structure suggest origin to be sedimentary or volcanic
WVg	**PLUTONIC ROCKS** (Late to Middle Archean)—Quartz diorite to quartz monzonite
Ugn	**OLDEST GNEISS COMPLEX** (Early Archean)—Chiefly layered granitic gneiss, locally migmatitic; local masses of quartzite, metagraywacke, iron-formation, and other metasedimentary rocks, amphibolite, and felsic gneiss through to be volcanic; dates of metamorphism in the Bighorn Mountains 3,000+ Ma

MONTANA

CENOZOIC

QUATERNARY

Qal	**ALLUVIUM** (Quaternary)—Mainly valley fill consisting of silt, sand, and gravel; includes terrace deposits and glacial drift of Pleistocene age in some areas; locally includes hot spring tufa; the older part of the alluvium, where present, is probably of Pliocene age [SD, Qa in WY] [SD, Qa in WY]

TERTIARY

Tw	**WASATCH FORMATION** (Tertiary)—Light-colored massive sandstone; drab-colored shale and coal in southeastern Montana; variegated, dominantly red beds of clay and sandstone in north-central Montana [WY]

TERTIARY-CRETACEOUS

Tfu	**FORT UNION FORMATION** (Tertiary-Cretaceous)—Clay shale, siltstone, and sandstone; local lenses of impure limestone and numerous lignitic beds; contains Tertiary plant and animal fossils but no dinosaurs; base generally placed at the lowest of the succession of lignite beds within it; includes the Tongue River, Lebo shale, and Tullock members [WY]

MESOZOIC

CRETACEOUS

Khc	**HELL CREEK FORMATION** (Cretaceous-Late Tertiary)—Somber-gray sandstone and greenish shaly clay and mudstone containing dinosaur bones; a few thin lignite and subbituminous coal beds [Kl—Lance Formation in WY]
Kfh	**FOX HILL SANDSTONE** (Late Cretaceous)—Typically shaly sandstone grading upward into massive brownish sandstone with white sandstone of the Colgate member locally at top [WY]
Kp	**PIERRE SHALE** (Late Cretaceous)—Dark-gray clay shale with calcareous and ferruginous concretions and sandy members [SD, NE, WY]
Kfb	**FOX HILL SANDSTONE AND BEARPAW SHALE** (Late Cretaceous)—Undifferentiated; *FOX HILL SANDSTONE*: Typically shaly sandstone grading upward into massive brownish sandstone with white sandstone of the Colgate member locally at top; *BEARPAW SHALE*: Dark-gray and brownish clay shale; thick units of non-fissile bentonitic shale; calcareous and ferruginous concretions throughout; contains thick bentonite beds [WY]
Kjr	**JUDITH RIVER FORMATION** (Late Cretaceous)—Light-colored sandstone at top; lower third somber-gray siltstone and sandy shale; greenish-gray clay and some lignite beds; includes the Parkman sandstone member of south-central Montana
Kn	**NIOBRARA FORMATION** (Late Cretaceous)—Chiefly calcareous shale with limestone concretions; many thin bentonite beds locally [SD, WY]

Kce	**CARLILE SHALE** (Late Cretaceous)—Dark-gray shale with calcareous and ferruginous concretions; middle part commonly sandy
Kg	**GREENHORN FORMATION** (Late Cretaceous)—Mainly light-gray marl and calcareous shale [SD]
Kbf	**BELLE FOURCHE SHALE** (Cretaceous)—Dark blue-gray siliceous shale with many calcareous and ferruginous concretions and intercalated thin layers of bentonite [Kb in SD] [Kb in SD]
Kmo	**MOWRY SHALE** (Early Cretaceous)—Chiefly light-gray silicified shale and claystone with minor amounts of sandy shale and sandstone; contains some thick beds of bentonite

TRIASSIC

TRu	**TRIASSIC, UNDIFFERENTIATED** (Triassic)—Conglomerate, sandstone, shale, and impure limestone belonging to the Dinwoody and Thaynes formations and other units of Triassic age, and the Chugwater of Triassic and Permian age

PALEOZOIC

PERMIAN-MISSISSIPPIAN

PNu	**PENNSYLVANIAN, UNDIFFERENTIATED** (Pennsylvanian)—In western Montana is mainly the Quadrant quartzite but includes limestone and other rocks of Pennsylvanian age so far as present data permit; farther east, other formations of Pennsylvanian or possible Pennsylvanian age are included [PM—Tensleep Sandstone and Amsden Formation in WY] [PM—Tensleep Sandstone and Amsden Formation in WY]

MISSISSIPPIAN

Mu	**MISSISSIPPIAN, UNDIFFERENTIATED** (Mississippian)—Sandstone, shale, and limestone, in part dolomitic, with chert nodules, some quartzite, includes Big Snowy group in central part of Montana, Madison Group in central and southwestern parts, and Hannan and Brazer Limestones in the northwestern part; may include small amounts of Pennsylvanian rocks in areas where stratigraphic studies are incomplete [Mm—Tensleep Sandstone and Amsden Formation in WY]

ORDOVICIAN

Ou	**ORDOVICIAN, UNDIFFERENTIATED** (Ordovician)—Mainly Bighorn dolomite; near Idaho, Kinnikinic quartzite [Ob in WY]

SOUTH DAKOTA

CENOZOIC

QUATERNARY

Qal **ALLUVIUM** (Quaternary)—Clay to boulder-size clasts with locally abundant organic material [MT; Qa in WY]

Qt **TERRACE DEPOSITS** (Quaternary)—Clay to boulder-size clasts deposited as pediments, paleochannels, and terrace fills of former flood plains [WY]

Ql **LANDSLIDE DEPOSITS** (Quaternary)—Landslide, slump, and collapsed material composed of chaotically mixed boulders and finer- grained rock debris [Qls in WY]

TERTIARY

Tt **TRACHYTIC INTRUSIVE ROCKS** (Paleocene-Eocene)—Tan to reddish-brown, iron-stained stocks, laccoliths, sills, and dikes of trachyte, quartz trachyte, and alkalic rhyolite; contains phenocrysts of sanidine, orthoclase, anorthoclase, aegirine-augite, and biotite in a finely-crystalline orthoclase-quartz biotite groundmass [Tie —Intrusive and extrusive igneous rocks in WY]

MESOZOIC

CRETACEOUS

Kp **PIERRE SHALE** (Late Cretaceous)—Blue-gray to dark-gray, fissile to blocky shale with persistent beds of bentonite, black organic shale, or light-brown chalky shale. Contains minor sandstone, conglomerate, and abundant carbonate and ferruginous concretions [NE, WY, MT]

Kn **NIOBRARA FORMATION** (Late Cretaceous)—White to dark-gray argillaceous chalk, marl, and shale; weathers yellow to orange; contains thin, laterally continuous bentonite beds, chalky carbonaceous shale, minor sand, and small concretions [WY, MT]

Kg **GREENHORN FORMATION** (Late Cretaceous)—Gray shale, mudstone, marl, calcarenite, and shaley limestone grading upward into light-gray to tan, alternating marl and thin-bedded, fossiliferous limestone [MT]

Kb **BELLE FOURCHE SHALE** (Late Cretaceous)—Dark-gray to black bentonitic shale containing minor limestone lenses, bentonite layers, fossiliferous calcarenite, and large, ferruginous, carbonate concretions [Kbf in MT]

Kms **MOWRY SHALE, NEWCASTLE SANDSTONE, AND SKULL CREEK SHALE** (Early Cretaceous)—Undifferentiated; MOWRY SHALE: Black to gray, siliceous, fissile shale, and siltstone containing bentonite layers, and sparse sandstone dikes and sills; *NEWCASTLE SANDSTONE*: Gray, light-brown to yellow, discontinuously distributed siltstone, claystone, sandy shale, and fine-grained sandstone; *SKULL CREEK SHALE*: Dark-gray to blueish-gray shale containing ferruginous and carbonate concretions

Kfl **INYAN KARA GROUP** (Early Cretaceous)—Includes: *FALL RIVER FORMATION*: Variegated brown, red, gray to purple, calcareous, well-sorted, fine-grained sandstone, siltstone, and shale containing mica flakes; *LAKOTA FORMATION*: Yellow, brown, red-brown, gray to black silty shale, pebble conglomerate, and massive to thin-bedded, cross-bedded sandstone; locally interbedded with fresh-water limestone and bituminous coal beds

JURASSIC

Jms **MORRISON FORMATION, UNKPAPA SANDSTONE, SUNDANCE FORMATION, AND GYPSUM SPRING FORMATION** (Middle-Late Jurassic)—Undifferentiated; *MORRISON FORMATION* (Late Jurassic): Light-gray to green and variegated red, brown, yellow, or lavender, siliceous claystone, shale, and siltstone containing interbedded sandstone and fresh-water limestone lenses; *UNKPAPA SANDSTONE* (Late Jurassic): White, massive to thin-bedded, fine-grained, argillaceous sandstone; may be variegated to banded red, yellow, brown, or lavender; *SUNDANCE FORMATION* (Late to Middle Jurassic): Greenish-gray, yellow, tan, red to orange, and white, variegated, interbedded, fine- to coarse-grained sandstone, siltstone, clay, and limestone; *GYPSUM SPRING FORMATION* (Middle Jurassic): Massive white gypsum and minor maroon siltstone and shale

TRIASSIC-PERMIAN

TRPs **SPEARFISH FORMATION** (Permian-Triassic)—Red sandy shale, siltstone, sandstone, and minor limestone; interbedded with abundant gypsum [WY]

PALEOZOIC

PERMIAN

Pmo **MINNEKAHTA LIMESTONE AND OPECHE SHALE** (Permian)—Undifferentiated; *MINNEKAHTA LIMESTONE*: Purple to gray, finely-crystalline, thin- to medium-bedded limestone with varying amounts of red shale; *OPECHE SHALE*: Red siltstone, argillaceous sandstone, and shale interbedded with caliche layers [WY]

PERMIAN-PENNSYLVANIAN

PIPm **MINNELUSA FORMATION** (Pennsylvanian-Permian)—Variegated, yellow to red, gray to brown, pink to purple, and black, interbedded sandstone, siltstone, shale, limestone, dolomite, calcarenite, chert and brecciated beds [WY]

MISSISSIPPIAN-DEVONIAN

MDpe **MADISON GROUP** (Devonian-Mississippian)—Includes: *PAHASAPA LIMESTONE* (Mississippian): White, light-gray to tan, fine- to medium-crystalline limestone and dolomite containing brown to gray chert; solution features including collapse breccia, sinkholes, and caves are prevalent; *ENGLEWOOD FORMATION* (Mississippian to Devonian): Pink, lavender to light-gray, thin- to medium-bedded, finely-crystalline, argillaceous, dolomitic limestone [MDe —Pahasapa and Englewood limestones in WY]

ORDOVICIAN-CAMBRIAN

O€wd **WHITEWOOD LIMESTONE, WINNIPEG FORMATION, AND DEADWOOD FORMATION** (Ordovician-Cambrian)—Undifferentiated; *WHITEWOOD LIMESTONE* (Ordovician): Mottled, tan, gray to lavender, fine- to medium-crystalline, sparsely fossiliferous limestone, and dolomite; *WINNIPEG FORMATION*: (Ordovician): Gray and light-green, fissile shale, and tan, calcareous siltstone, sandy shale, and limestone lenses; *DEADWOOD FORMATION* (Ordovician to Cambrian): Variegated, yellow to red, brown, gray, and green, glauconitic, conglomerate, sandstone, shale, dolomitic limestone, and dolomite [O€ in WY; Ou in MT] [O€ in WY; Ou in MT]

EARLY PROTEROZOIC-ARCHEAN

XWp **PEGMATITE** (Archean(?)-Paleoproterozoic)—Light-tan to pink pegmatite

XWb **METABASALT** (Archean(?)-Paleoproterozoic)—Dark-green amphibolite and amphibolite schist

XWgw **METAGRAYWACKE** (Archean(?)-Paleoproterozoic)—Gray, siliceous mica schist and impure quartzite [Xsv in WY]

NEBRASKA

CENOZOIC

TERTIARY

Ta **ARIKAREE GROUP** (Oligocene-Miocene)—Consists mainly of gray, fine, loose to compact sand that has layers of hard, fine-grained dark-gray concretions, which vary from a few inches to 15 inches and commonly have tabular form; includes a large amount of volcanic ash mixed in with the sand; contains a number of channels filled with coarse conglomerate along ridge south of North Platte River

Tw **WHITE RIVER GROUP** (Oligocene)—Clay, some claystone, silt and siltstone; predominantly greenish gray and volcaniclastic; other occurrences are greenish gray to white and bentonitic; local channel sandstone at base [Twr in WY]

CRETACEOUS

Kp **PIERRE SHALE** (Late Cretaceous)—Mostly medium- to dark-gray, brownish-gray, and black, fissile clay shale; locally grades to thin beds of calcareous, silty shale or claystone, marl, shaly sandstone, and sandy shale; locally contains thin seams of gypsum and sparse selenite crystals [WY, MT, SD]

Appendix B

WWDC groundwater studies

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Wyoming River Basins				
Wyoming Water Planning Program, 1973, Wyoming's groundwater supplies: Cheyenne, Wyoming State Engineer's Office, Wyoming Water Planning Program Report, [variously paged].	All aquifers	Summary of available groundwater and groundwater sources.	Predictions of aquifer water quantity throughout the state of Wyoming.	Statewide river basin water planning process continues.
WWC Engineering, Inc. (in association with Hinckley Consulting, Collins Planning Associates, Greenwood Mapping, Inc., and States West Water Resources Corporation), 2007, Wyoming framework water plan: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged].	All aquifers	Summary of surface water and groundwater resources.	Estimates quantities of Wyoming's available water resources.	Wyoming Framework Water Plan completed.
Powder/Tongue/Northeast Basins				
HKM Engineering Inc. (in association with Lord Consulting and Watts and Associates), 2002a, Powder/Tongue river basin plan final report and technical memoranda: prepared for Wyoming Water Development Commission Basin Planning Program, [variously paged]. Executive summary and technical memoranda are available under separate cover.	All aquifers	Develop basin plans with participation from local interest groups that provide defensible hydrologic data to quantify surface water and groundwater uses.	Current surface water and groundwater uses, water quality, future demand projects, and future water use opportunities quantified and discussed. Continue planning process with updates every five years.	River basin water planning process continues.
HKM Engineering Inc. (in association with Lord Consulting and Watts and Associates), 2002b, Northeast Wyoming river basins plan final report and technical memoranda: prepared for Wyoming Water Development Commission Basin Planning Program, [variously paged]. Executive summary and technical memoranda are available under separate cover.	All aquifers	Develop basin plans with participation from local interest groups that provide defensible hydrologic data to quantify surface water and groundwater uses.	Current surface water and groundwater uses, water quality, future demand projects, and future water use opportunities quantified and discussed. Continue planning process with updates every five years.	River basin water planning process continues.
Aladdin and Beulah				
Soda Butte Services, Inc., 1994, Aladdin water supply project level I, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Madison Limestone	Assess adequacy of Madison aquifer to meet Aladdin's and Beulah's water supply requirements. Analyses of water rights, infrastructure, and economics. Provide conceptual design for separate municipal wells in each town, cost estimates, and funding options.	Madison aquifer should provide suitable water supplies to Aladdin Water District and Town of Beulah. Development of PWSs sourced from Madison municipal wells is technically and economically feasible. Proceed to Level II.	For Aladdin, see below. See Beulah on next page.
Soda Butte Services, Inc. (in association with Wester-Wetstein & Assoc., Inc.), 1995, Well construction, testing and conceptual design for the Aladdin water supply project level II, final report and summary: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Madison Limestone	Level II report to evaluate the hydrogeology of aquifer in Aladdin area, determine depth to groundwater and aquifer thickness, complete and test new municipal well, and assess groundwater quality.	AWD-1 well in Madison aquifer was completed, developed, and tested for aquifer hydraulics and water quality in Aladdin. PWS project is technically feasible. Level III design and construc-tion should proceed if Water District members approve monthly costs.	Aladdin uses the well under an agreement with WWDC.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Belle Fourche River Watershed				
RESPEC (in association with Anderson Consulting Engineers, Inc.), 2015, Belle Fourche River watershed study, basin wide watershed management plan, final report– Topical report RSI-2501: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. Executive summary is available under separate cover.	Alluvial depoits; Wasatch, Fort Union, and Inyan Kara Formations, Minnelusa and Madison Limestones	The four projects, shown at left, are watershed studies in the Belle Fourche drainage and Redwater Creek subbasin. Although the focus is on surface water, these reports provide overviews of commonly used aquifers in the Belle Fourche Basin and a brief discussion of groundwater impacts from CBM development. Figures include maps of springs and SEO permitted wells in the Belle Fourche Basin and its subbasins.	No recommendations regarding groundwater resources.	All reports are completed.
RESPEC (in association with Anderson Consulting Engineers, Inc.), 2015, Belle Fourche River watershed study, Redwater subbasin watershed management plan– Topical report RSI-2514: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].				
RESPEC (in association with Anderson Consulting Engineers, Inc.), 2015, Belle Fourche River watershed study, subbasin above Keyhole Reservoir watershed management plan–Topical report RSI-2512: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].				
RESPEC (in association with Anderson Consulting Engineers, Inc.), 2015, Belle Fourche River watershed study, subbasin below Keyhole Reservoir watershed management plan –Topical report RSI-2513: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].				
Beulah				
Weston Engineering, Inc. (in association with EnTech, Inc.), 2003, Beulah level I water supply study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Madison Limestone	Evaluate existing water supply, demands, and facilities. Provide conceptual designs for regional water system, cost estimates, and financing plans.	Madison aquifer will likely provide sufficient quantities of good-quality water to residents of Beulah. Likely well sites and service areas identified. Conceptual designs and cost estimates provided for three alternative distribution systems.	Beulah is not served by a municipal well.
Buffalo				
Plains Engineering, 1982, Buffalo hydrogeologic reconnaissance: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison, Wasatch, and Moncrief Formations; scoria deposits, Clear Creek Alluvium, Cretaceous sandstones, Paleozoic limestones	Hydrogeologic reconnaissance of 10-mile radius around Buffalo searching for a good-quality groundwater source adequate to meet 7 cfs peak demand.	There is no single source of groundwater available that can meet the water quality and quantity requirements of Buffalo.	Project completed.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Buffalo (cont.)				
Western Water Consultants, 1982, Municipal water supply study for the City of Buffalo, Wyoming level I reconnaissance study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison, Wasatch, and Morcrief Formatins; scoria deposits, Clear Creek Alluvium, Createaceous sandstones, Paleozoic limestones	Level I study to identify available options to develop cost effective supplemental water supplies.	Groundwater development is not a viable option at the time of the report to supplement Buffalo's water supplies.	Project completed.
WWC Engineering, 2011, Buffalo northwest water supply level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Unspecified Buffalo area aquifers that provide insufficient supplies from poorly producing, low-quality wells	Level I study to evaluate feasibility of connecting a likely development area northwest of Buffalo to the City's water distribution system. The area has insufficient supplies from poorly producing, low-quality wells.	Population and future water demands were projected. Design options for new large water lines connecting NW Buffalo to the City's existing PWS were presented. Cost estimates were provided for each option.	Proceeded to Level III; project completed in 2014.
WWC Engineering, 2015, Buffalo master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Unspecified Buffalo area aquifers that provide insufficient supplies from poorly producing low-quality wells	Level I study to evaluate feasibility of connecting surrounding areas to Buffalo Rural Area Supply System (BRASS). Residences in these areas obtain insufficient water supplies from poorly producing, low-quality wells.	Population and future water demands were projected. Design options for new transmission lines connecting target areas to BRASS were presented. Cost estimates were provided for each option.	At the time of this report, WWDC was funding a Level II Buffalo Groundwater Supply Study.
Cambria-Sweetwater				
Camp Creek Engineering, Inc. (in association with Wyoming Groundwater), 2015, Cambria/Sweetwater water supply level II feasibility study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Evaluate new water storage tank for Cambria and a transmission line for Sweetwater from Newcastle. These improvements would support the development of a regional water system sourced from Madison aquifer wells in Newcastle, (see Newcastle).	Cambria should negotiate with Newcastle for water supply and install a new storage tank. Sweetwater should consider purchasing water from Cambria or drill a Madison well.	Cambria purchases municipal water from Newcastle. Sweetwater's primary water source is a reservoir via the Horton Pipeline.
Campbell County				
Murphy, R.P., and Stockdale, R.G. (Wyoming State Engineer's Office), 2000, Campbell County coal bed methane monitor well program: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union and Wasatch aquifers	Report outlines the WSEO Campbell County Coal Bed Methane Monitoring Program, initiated in 1998 by the Wyoming State Legislature. Monitoring was intended to assess the effects of CBM development on the Fort Union and Wasatch aquifers.	Report describes monitoring wells installed to date and recommends additional wells be installed to form a regional monitoring well network.	Additional SEO monitoring wells were installed. Some have since been decommissioned in response to declines in CBM production.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Clear Creek				
States West Water Resources Corporation (in association with DOWL HKM, Anderson Consulting Engineers, Inc., RJH Consultants, Inc., Western Ecosystems Technology, Inc., and Watts and Assoc., Inc.), 2011, Clear Creek watershed level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary and appendices are available under separate cover.	Quaternary alluvial, Fort Union, Wasatch, Fox Hills, Lance, Dakota, Madison	Study examines the potential for developing surface water in the Clear Creek watershed but also describes commonly used aquifers. Tables list lithology, hydraulic characteristics, water quality, and development potential for five aquifer systems, listed at left.	Best prospects for water development lie with developing new reservoirs projects along Clear Creek.	At the time of this report, WWDC was funding a Level II Clear Creek Storage Study.
Clearmont				
Weston Engineering, Inc., 2008, Final report for the Clearmont CBM impact level I study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union/Wasatch aquifer system	Level I study evaluates existing Clearmont water supply and sustainability of municipal wells under three CBM development scenarios. Study concludes that due to high water to CBM production ratio, CBM production will decrease and water levels in municipal wells will remain consistent.	Obtain weekly static water levels and monitor specific capacities in municipal wells. Submit annual well data reports to SEO. Apply to WWDC for Level II study for a new well to replace Clearmont Well No. 1.	CBM production has declined in recent years. Clearmont is currently funded for a WWDC Level II project – Clearmont Test Well Study.
Cook Road				
HKM Associates, 1992, Final report for a proposed water supply system for Cook Road Water District, Campbell County, Wyoming: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union aquifer	Level I study to define existing water supply and system facilities, water supply needs, and alternatives. Identify water source with sufficient quantity and quality to meet current and future demands.	A deep Fort Union well could provide sufficient quantities of good-quality water. Exploratory drilling program recommended with well construction and delivery system cost estimates.	See below.
Soda Butte Services, Inc. (in association with Wester-Wetstein & Assoc., Inc.), 1994, Construction and testing of CRWD-1 well and conceptual design and cost estimation for Cook Road water supply project level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union aquifer	Described drilling, completion and testing of CRWD-1 test well in the Fort Union aquifer and water quality testing. Includes conceptual designs and cost estimates for remaining well construction and delivery system.	CRWD-1 well can yield 85 gpm continuously. Water quality meets SDWA standards except for radium, TDS, iron, and turbidity.	Cook Road is scheduled to connect to the Gillette Regional Water Supply.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Crestview-Antelope Valley				
Wester-Wetstein & Associates, 1999, Crestview/ Antelope Valley water supply project level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union aquifer	Level II study examines existing water supply, distribution, and storage systems of the Crestview Improvement and Service District and the Antelope Valley Improvement and Service District. Identify water source with sufficient quantity and quality to meet current and future demands of both communities.	Crestview water system should connect to Antelope Valley PWS while Crestview Well No. 1 is rehabilitated. Antelope Valley should sell water to Crestview. Existing Antelope Valley Well No.1 should be plugged and abandoned. Well No. 2 will become lead well, with No. 3 as a backup. Make improvements to storage tanks.	Crestview obtains water from Well #1 and purchases water from Antelope Valley, which obtains water from four Fort Union wells. Both subdivisions are scheduled to connect to Gillette Regional Water Supply.
Dayton				
EnTech, Inc. (in association with Environmental Design Engineering), 2000, Dayton master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Tongue River alluvium and unidentified geologic units	Level I and II studies examine existing water supply, distribution, and storage systems in Dayton, Ranchester, and Tongue River Valley.	The potential for groundwater development in the area of interest is restricted by the lack of high-yield wells. Surface water resources should be further developed to meet future demands.	Projects completed.
EnTech, Inc. (in association with Environmental Design Engineering), 2001, Final report for Dayton Water supply project level II study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary and appendix are available under separate cover.				
EnTech, Inc. (in association with Weston Engineering, Inc.), 2003, Final report for Dayton groundwater exploration project: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison Limestone and Bighorn Dolomite	At Dayton's request, an exploration well was drilled to 2,600 ft bgs and completed in the Madison and Bighorn aquifers.	Maximum flow rate is 75 gpm; maximum pump rate is 275 gpm; water quality met all primary and secondary SDWA standards. Post treatment productivity increased to max flow rate of 225 gpm, and maximum pump rate is 650 gpm.	Project completed.
EnTech, Inc. (in association with Weston Engineering, Inc.), 2004, Final report for Dayton groundwater exploration project acid enhancement program level II study supplement: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison Limestone and Bighorn Dolomite	Well was acid fractured to enhance productivity. Water delivery alternatives and costs were provided.	Dayton should use well to meet present and future water supply demands. A water conveyance system should be constructed to pump water directly from the well to the existing PWS.	Dayton obtains municipal water from the Tongue River and the Dayton #1 well.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Edgerton-Midwest				
TriHydro Corporation (in association with Banner Assoc. Inc.), 1988, Water supply project for the towns of Edgerton and Midwest, report of investigation: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Wasatch, Fort Union, Fox Hills, Tensleep, Madison aquifers	Study evaluates existing water system, and provides improvement alternatives, cost estimates, financing options, and permitting requirements. The Edgerton-Midwest No. 1 test well was drilled and completed in the Madison aquifer and tested.	WQ and aquifer hydraulics are poor in the Wasatch, Fort Union, and Fox Hills aquifers. Water quality in the Madison test well was good, but production was too low. WWDC declined to continue with project.	Project completed.
Worthington, Lenhart, Carpenter & Johnson (in association with Western Water Consultants, Inc., and Western Research Corporation), 1988, Edgerton/Midwest water supply project level II conceptual design report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Split Rock aquifer	This study briefly mentioned the Split Rock aquifer.	Study concluded groundwater development was not an economic option.	Project completed.
Worthington, Lenhart, Carpenter & Johnson (in association with Western Water Consultants, Inc.), 1989, Edgerton/Midwest water supply project level II conceptual design report task 15: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Tensleep, Wasatch, Fort Union, Fox Hills, and Madison aquifers	This report is an addendum to the previous report cited. It examines water development potential in the five aquifers listed at left.	A Madison aquifer supply is the most economical alternative, but monthly cost to residents is still higher than acceptable.	Project completed.
Western Water Consultants, 1990, Pre-design report and cost estimates for the Edgerton-Midwest reverse osmosis plant: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fox Hills aquifer	Report discusses reverse osmosis treatment for the town's existing Fox Hills aquifer municipal wells.	Cost of treatment is lower than other alternatives, but per capita cost would still be high.	Edgerton and Midwest purchase water from the Central Wyoming Regional Water System.
Gillette				
James M. Montgomery, Consulting Engineers, 1992, City of Gillette Madison well field, Well M-3 enhancement: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison aquifer	Report describes production and water quality enhancement of Well M-3 in the Madison aquifer by hydraulic fracturing with sand proppant.	Well production was greatly improved, and levels of fluoride, sodium, and chloride decreased following enhancement.	Project completed.
HKM Associates, 1993, Phase I interim report for Gillette area master plan, Gillette, Wyoming: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union, Fox Hills-Lance, Wasatch, and Madison aquifers	Predesign level study evaluates existing water system, and provides improvement alternatives and cost estimates, financing options, and permitting requirements.	Madison aquifer is most likely target for future development to supplement municipal water supplies. Gillette should develop a regional water supply system.	Project completed.
HKM Associates, 1993, Phase II final report for Gillette area master plan, Gillette, Wyoming: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union, Fox Hills-Lance, Wasatch, and Madison aquifers	Supplement to previous report discusses population and service areas, improvement alternatives, cost estimates, and financing options in greater depth.	Specifies development of Gillette Regional Water System.	Project completed.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Gillette (cont.)				
Wester Wetstein & Associates, 1994, Report for Gillette wells project level II feasibility study-rehabilitation: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union, Fox Hills-Lance, and Madison aquifers	Report evaluates condition of municipal wells and assesses what rehabilitative efforts should be conducted.	Rehabilitation of selected municipal wells will increase production. City should proceed with improvements to pipeline from Madison well field.	Project completed.
Wyoming State Engineer's Office, 1995, Fort Union Formation aquifer monitoring plan and preliminary aquifer management plan: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Fort Union aquifer	Document outlines the development of a monitoring program for Gillette's Fort Union municipal wells and provides a preliminary aquifer management plan.	Continue collecting water level data in monitoring well network. Start WQ monitoring during regular intervals. Install new wells to the monitoring network in the future.	Project completed.
Wester Wetstein & Associates, 2004, Coal bed methane-aquifer storage and retrieval project level II southern Ft. Union well field exploration program and development study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Interim report and executive summary are available under separate cover.*	Fort Union aquifer	Report focuses on development of a new Fort Union municipal well field south of Gillette. Well field design, water rights review, water treatment, operational plan, construction costs, and project schedule are included in the report.	Exploratory well was drilled fully penetrating Fort Union aquifer. WQ met SDWA standards. Higher than expected transmissivity (1,700 gpd/ft) indicates the well would meet productivity requirements.	Project completed.
HDR Engineering, Inc., 2009, Gillette regional master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Master plan to investigate feasibility of forming a regional water system.	Recommends formation of a regional water system sourced from further development of the Madison aquifer well field.	Gillette has developed a series of Fort Union, Fox Hills and Madison aquifer wells into the Gillette Regional Water Supply, which supplies municipal water to other cities, towns, and subdivisions in northeast Wyoming.
WLC Engineering, Surveying & Planning (in association with Weston Groundwater & Engineering), 2012, Gillette regional connections 2 level II study, Peoples Improvement & Service District, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Unknown
EnTech, Inc. (in association with Weston Groundwater & Engineering and West Plains Engineering, Inc.), 2013, Gillette regional connections 1 level II study, Bennor Estates connection, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Subdivision connected to Gillete Regional Water Supply in 2016.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Gillette (cont.)				
WLC Engineering, Surveying & Planning (in association with Weston Groundwater & Engineering), 2013, Gillette regional connections 2 level II study, South Fork Estates Improvement and Service District, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Subdivision connected to Gillete Regional Water Supply.
WLC Engineering, Surveying & Planning (in association with Weston Groundwater & Engineering), 2013, Gillette regional connections 2 level II study, Freedom Hills Improvement and Service District, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Subdivision scheduled to connect to Gillete Regional Water Supply.
EnTech, Inc. (in association with Weston Groundwater & Engineering and West Plains Engineering, Inc.), 2013, Gillette regional connections 1 level II study, Antelope Valley Connections, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Subdivision scheduled to connect to Gillete Regional Water Supply.
DOWL (in association with Weston Groundwater & Engineering), 2015, Gillette regional connection level II study, Means first extension master plan, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union and Madison aquifers	Evaluation of existing water system, and assessment of infrastructure required and construction costs associated with connection to the the Gillette Regional Water System.	Recommends infrastructure and financial alternatives to connect to Gillette Regional Water System.	Unknown
Hidden Hills				
EnTech, Inc., 2001, Final report for Hidden Hills water system level I study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Wasatch, Fort Union, Lance bedrock aquifers, and Prairie Dog Creek alluvium	Level I study to determine feasibility of establishing a PWS for the Prairie Dog Creek Valley.	Low production in Wasatch and Fort Union wells (max 20 gpm), depth of Lance (~5,000 ft bgs) and surface/groundwater connections in alluvium preclude use of groundwater in PWS. Community should seek connection with Sheridan Area Water Supply system.	Most of the Hidden Hills Area is outside of the SAWS service area. There are no records of a subdivision well in the SEO or PWS in the EPA databases.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Kaycee				
Western Water Consultants, 1983, Ground water feasibility study for Kaycee: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Tensleep Sandstone, Madison Limestone, and Bighorn Dolomite	Study to evaluate groundwater development potential, define existing and future water demands in Kaycee, identify favorable drilling sites, and provide designs and cost estimates.	Three sites were identified for Paleozoic aquifer test wells. Designs and costs for test wells were provided.	Drill and test exploratory well. See below.
Western Water Consultants, 1984, Final report on drilling and testing of the Town of Kaycee Madison #1 test well, Johnson County, Wyoming: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Tensleep and Madison aquifers	Report describes construction and testing of Kaycee Madison Test Well #1.	Test well was installed in the Tensleep Sandstone and Madison Limestone. Transmissivity of the well was estimated at 2,300 gpd/ft. WQ did not exceed any SDWA standards.	Well is now Kaycee Well #1 (P69394W).
Grizzly Engineering, Inc., 1999, Town of Kaycee water supply master plan level I: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Tensleep and Madison aquifers	Evaluation of existing water system, improvement alternatives, and cost estimates, financing options, and permitting requirements. Contains completion report for Kaycee Well #2.	Consultant suggested upgrades to existing system and extending service to Kaycee rural communities.	Kaycee Well #2 (P72663W) was installed to replace Kaycee No. 1 in July 1986.
Weston Engineering, Inc. (in association with Civil Engineering Professionals, Inc.), 2006, Town of Kaycee well and tank storage improvements level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Tensleep and Madison aquifers	Evaluation of existing water system, water demand, improvement alternatives with cost estimates, financing options, and permitting requirements.	New water supply well is not needed. Improvements to wells and storage tank recommended. Cost estimates and financing alternatives provided.	Kaycee obtains municipal water from two Madison aquifer wells, listed above.
Lance Creek				
Western Water Consultants, 1996, Lance Creek water supply master plan level I: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	White River and Inyan Kara Group aquifers	Evaluation of existing water system, water demand, improvement alternatives with cost estimates, financing options, and permitting requirements.	Storage, transmission, and distribution systems require additions and improvements with cost estimates provided.	Project completed.
WWC Engineering (in association with Wyoming Groundwater), 2011, Lance Creek water supply study level I, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	White River and Inyan Kara Group aquifers	Evaluation of existing water system, water demand, improvement alternatives with cost estimates, financing options, and permitting requirements.	Arsenic, radium and gross alpha levels are above the EPA MCL; new wells are needed.	Lance Creek Well Level II study was conducted (see next page).
Wyoming Groundwater, LLC (in association with WWC Engineering), 2013, Lance Creek well level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary and appendices are available under separate cover.*	White River Group, Inyan Kara Group, and Morrison Formations.	Described construction and testing of three test wells in the Inyan Kara aquifer to meet SDWA standards for arsenic, radium and gross alpha levels.	Water from State No. 2 Test Well meets SDWA standards for constituents of concern. Water from this well and the existing State No. 2 Well can be blended and still meet SDWA standards.	District is negotiating terms of use with the State for new well.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Little Goose				
Howard, Needles, Tammen, and Bergendoff (in association with Anderson and Kelly), 1987, Little Goose domestic water supply project study level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. *Executive summary is available under separate cover.*	Madison, Bighorn, Gallatin, Gros Ventre, and Flathead	Feasibility study of development of central water system to meet domestic requirements of Little Goose Valley. Evaluate potential of Little Goose Creek Well.	User costs of improving/installing one or two wells are excessive. Recommend studying feasibility of connection to Sheridan Water Supply system.	Most of the Little Goose Valley is outside of the SAWS service area. No record of PWS in EPA databases. Little Goose Well (P70444.0W) permit cancelled in 2012, refiled as P199097.0W in 2012.
Lusk				
Worthington, Lenhart, Carpenter, Inc., 1994, Town of Lusk water project level I master plan study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Arikaree	Evaluation of existing water system, water demand, improvement alternatives with cost estimates, financing options, and permitting requirements.	Improve water storage and delivery infrastructure. Drill a new test well near the airport and evaluate its potential to supplement water supplies from Well #8. Abandon existing Wells #3 and #4.	Project completed.
MK Centennial, 1995, Lusk water supply project level II - Lusk, Wyoming, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Arikaree	Evaluation of improvement alternatives proposed in Level I (see previous). Description of installation of new well (Lusk #9). Analysis of maintenance and operating cost.	Recommend improvements in water delivery and storage system in conjunction with construction of Well #9.	Project completed.
TriHydro Corporation, 1996, Well construction and aquifer testing level II water supply project, Lusk, Wyoming final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Arikaree	Drilling, construction, development, and testing report of Lusk #9 Well.	Well #9 produces 800 gpm of good-quality water suitable for municipal use. Town should consider developing a well field around Well #9.	Project completed.
Hinckley Consulting (in association with Wyoming Groundwater), 2009, Lusk area groundwater level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Arikaree with a hydrostratigraphic survey of other area geologic units	Evaluation of area geologic formations for groundwater resource potential.	Arikaree aquifer is only hydrostratigraphic unit with groundwater development potential.	Project completed.
AVI Professional Corporation (in association with TST and Hinckley Consulting), 2014, Lusk master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Arikaree	Evaluation of existing water system, water demand, improvement alternatives with cost estimates, financing options, and permitting requirements.	Recommendations to improve groundwater pumping, storage, and delivery systems. Town should consider replacing Well #1 and installing new well at site of old Well #3.	At the time of this report, WWDC was conducting a Lusk Level II Water Supply Study.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Manville				
Western Water Consultants, 1997, Final report on the Manville water supply project level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. Executive summary is available under separate cover.	Arikaree	Evaluation of Manville's water supply, condition of wells, and municipal water infrastructure. Prepare improvement alternatives, cost estimates, and financing options.	Manville Well #3 was drilled, completed, developed, and tested. Recommended improvements to water delivery system.	Project completed.
Olsson Associates (in association with AVI), 2008, Manville source water supply study level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Arikaree	Evaluate options to bring water supply into compliance with EPA regulations. Prepare improvement alternatives with cost estimates.	Examined treatment and water source replacement options. Recommended replacing worn water delivery infrastructure.	Project completed.
Wyoming Groundwater, LLC (in association with Gordon Marlatt, Ph.D. and WWC Engineering), 2014, Manville well level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Hartville and Arikaree aquifers	Evaluate water production and quality of the Hartville and Arikaree aquifers. Drill, install, complete, and test new well. Design infrastructure to connect to new well. Estimate costs of water supply improvement project.	Manville #4 test well was drilled and installed in Arikaree aquifer. Well produces 250 gpm of good-quality water.	At the time of this report, WWDC was conducting a Manville Level III Water Supply construction project.
Middle Fork of the Powder River				
Wright Water Engineers, Inc. (in association with Worthington, Lenhart, Carpenter, and Johnson, Inc.), 1984, Middle Fork Rural Water District domestic water system level I, reconnaissance study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Tensleep and Madison aquifers	Evaluate groundwater and surface water sources for the Middle Fork Rural Water District. Prepare cost estimates and an operating plan for water system improvements.	Cost analysis indicates the groundwater wells at the Red Fork of the Powder River site provide most cost effective option for supplying water to the water district.	Project completed.
TriHydro Corporation, 1985, Level II exploratory drilling program for the Middle Fork Rural Water District: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Amsden, Tensleep, and Madison aquifers	Drill, complete, test, and construct groundwater well in the Madison aquifer.	Test well, installed in Madison aquifer, produced up to 800 gpm of poor-quality water. Recommend long-term flow test and water treatment study.	Current status unknown. Middle Fork #1 permit (P70450.0W) was cancelled and then refiled under permit P102065.0W. No current record of Middle Fork Rural Water District.
Moorcroft				
Weston Engineering, Inc., 1991, Moorcroft water study level I: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Lance, Fox Hills, and Madison aquifers	Evaluation of Moorcroft's water supply, storage and distribution system, water requirements, and water supply alternatives.	Conduct economic analysis (Level II) of upgrading town's water supply infrastructure and obtaining new source(s) of municipal water.	Project completed.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Moorcroft (cont.)				
Weston Engineering, Inc., 1992, Moorcroft water study level I: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Lance, Fox Hills, and Madison aquifers	Economic analysis of previous study to include water supply alternatives, cost estimates, and financing.	Alternatives included construction of water storage reservoir, new well in Lance-Foxhills aquifer, and collection system to existing municipal wells.	Project completed.
Bearlodge Ltd, Inc. (in association with J.P. Gries, P.G. and Soda Butte Services), 1994, Moorcroft water study level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Lance-Fox Hills aquifer system	Reports on construction and testing of Lance-Fox Hills test well, and design and cost estimates of storage and delivery improvements suggested in Weston Engineering (1992).	New well provides sufficient quantity of good-quality water. Study recommends that town and WWDC proceed with funding and construction of planned storage and delivery infrastructure.	Project completed.
Weston Engineering, Inc., 2002, Moorcroft water study level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison	Evaluate present/future water needs, water supply alternatives, and groundwater resources, and inventory existing water supply facilities, Prepare improvement alternatives and cost estimates.	New Madison exploration well provides sufficient quantity of good-quality water. Recommend that the municipal water system connect to the new well.	Project completed.
HDR Engineering, Inc. (in association with Western Groundwater Services, LLC.), 2015, Town of Moorcroft master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Lance, Fox Hills, and Madison aquifers	Evaluate present/future water needs, existing water supply facilities and operations, water quality, and water rights. Develop hydraulic model. Prepare cost estimates and financing alternatives.	Implement a valve maintenance program and report water usage to SEO. Replace selected water mains and install a portable transmission loop.	Moorcroft obtains municipal water from one Madison aquifer and several Lance/ Fox Hills wells. Moorcroft also purchases water from the Gillette Regional Water System.
Newcastle				
RCH and Associates (in association with Wester-Wetstein and Associates), 1996, Level I water supply project, Salt Creek Water District, Newcastle, Wyoming, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Evaluate present/future water needs, existing water supply facilities, operations, and permitting. Develop hydraulic models. Prepare cost estimates and financing alternatives.	Connect facilities of West End Water District, City of Newcastle, and Salt Creek Water District systems to form area wide water system. Drill new Madison aquifer well.	Project completed.
Wester-Wetstein and Associates, Inc. (in association with States West Water Resources Corp.), 2000, Newcastle area water supply master plan, level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged].	Minnelusa and Madison aquifers	Evaluate Newcastle Area water supply delivery and storage systems. Includes West End Water District, City of Newcastle, Salt Creek Water District, and Cambria Water District systems.	Recommended infrastructure improvements made to each water system entity. Report provides a summary of Madison aquifer performance in Newcastle area.	Project completed.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Newcastle (cont.)				
Stetson Engineering, Inc. (in association with Western Groundwater Services, LLC.), 2005, Final level II study report for Canyon Improvement and Service District, Newcastle, Wyoming, includes Canyon No. 1 test well construction report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary and attachments are available under separate covers.*	Minnelusa and Madison aquifers	Evaluation of Canyon service area aquifers to meet community water demands. Canyon #1 Well drilled into Madison aquifer to TD of ~2,200 ft. Initial head was 100 PSI, max production estimated at 500 gpm.	Proceed with Level III funding to complete well and construct transmission and storage facilities. New well has potential to provide water to a regional system.	At the time of this report, WWDC was funding a Level II Newcastle Madison Well Study.
Osage				
Banner Associates, Inc. (in association with Arnjac Corp.), 1994, Osage water supply project level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Evaluate water supply, existing distribution and storage, and existing and future water demand. Analyze water supply alternatives.	Presents three alternatives that all include town purchase of the existing private water system, with infrastructure improvements supplemented by drilling one or two additional Madison wells.	Project completed.
Banner Associates, Inc. (in association with Soda Buttes Services, Inc.), 1996, Osage water supply project level II extension, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Engineering and financial evaluations of fourth alternative: acid stimulation of BHP&L Well #4 coupled with storage and delivery system improvements. Report of stimulation results.	Recommended improvements in existing delivery system and resolution of right-of-way and easement issues.	Osage Water District PWS obtains water from two Madison aquifer wells.
Pine Butte				
Centennial Engineering & Research, Inc., 1991, Level I reconnaissance information, Pine Butte Improvement and Service District, Gillette, Wyoming: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Wasatch, Fort Union, and Fox Hills aquifers	Evaluate water supply, existing distribution and storage, and existing and future water demand. Analyze water supply alternatives.	Due to the high costs of extending water supply lines from Gillette, Pine Butte should not be included in the Gillette Regional Water System, but should develop its own water supply.	Project completed.
HKM Engineering (in association with Soda Buttes Services, Inc.), 1992, Final report for a proposed water supply system for Pine Butte Improvement and Service District: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Wasatch, Fort Union, and Fox Hills aquifers	Design and estimate costs for a new community well completed in the Lower Fort Union aquifer.	Pine Butte should develop its own water supply by drilling a new community well completed in the Lower Fort Union aquifer. Nearby existing wells would supply the community in the interim.	Project completed.
Wester Wetstein & Associates, 1993, Construction, testing and conceptual completion design of the Pine Butte No. 1 well for the Pine Butte Water Supply Project level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Tullock Member of the Fort Union aquifer	Report of construction, testing, and conceptual completion design of the Pine Butte No. 1 Well.	New well produced adequate amounts of fair-quality groundwater, which exceeded EPA standards for radium, iron, and TDS. Water quality could be brought into compliance with treatment.	The Pine Butte Improvement and Service District declined to purchase the Pine Butte No 1 test well (P91808.0W) from WWDC. Permit was cancelled.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Pine Haven				
Stetson Engineering, Inc., 2000, Pine Haven master plan level I reconnaissance study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Evaluate present/future water needs, existing water supply facilities and operations, and permitting. Prepare system alternatives and cost estimates.	Recommendations to improve groundwater pumping, storage, and delivery systems. Town should consider installing new Madison well as a back-up source of supply.	Project completed.
Wester Wetstein & Associates, 2003, Pine Haven well project level II, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Report of construction and testing of the Pine Haven No. 2 Well and cost estimates for water delivery infrastructure, tying the new well to the town's water system.	New well produced adequate amounts of fair-quality groundwater, which exceeded EPA standards for sulfate, iron and TDS. Cost estimates for delivery system alternatives included.	Project completed.
Bearlodge Ltd, Inc. (in association with Tetra Tech, Inc.), 2009, Pine Haven master plan level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Evaluate present/future water needs, existing water supply facilities and operations, water quality, and permitting. Prepare system alternatives and cost estimates.	Recommended infrastructure improvements made to water storage and delivery systems. Supply wells are adequate until 2023.	Project completed.
Baker & Associates, Inc. (in association with Wyoming Groundwater, LLC), 2014, Pine Haven tank & well level II study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Madison aquifer	Evaluate present/future water needs, existing water supply facilities and operations, and permitting. Prepare system alternatives and cost estimates.	Recommended infrastructure improvements made to water storage and delivery systems. Drill and complete a new Madison aquifer well. Abandon Pine Haven #1 well and rehabilitate Pine Haven #2 Well.	Pine Haven project has not moved into Level III.
Powder River				
Harza Engineering Company, 1982, Storage developments for water supply, Powder River Basin in Wyoming, level I reconnaissance study, main report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. *Status report to Legislature and appendices are available under separate cover.*	Alluvial, Wasatch, Fort Union, and Madison aquifers	Surface water report that provides a brief evaluation of groundwater resources in the aquifers listed at left.	Groundwater resources in the interior PRB likely could serve only as an interim water supply.	Several communities in the PRB are supplied by groundwater.
Town of Powder River				
Banner Associates, Inc., 2002, Powder River water supply level I study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Quaternary alluvial aquifer	Evaluate present/future water needs, existing water supply facilities and operations, and permitting. Prepare system alternatives and cost estimates. Conduct groundwater exploration study.	Recommended that Powder River #1 Well (P107884.0W) be treated with reverse osmosis technology or that new water source be found. Quaternary alluvium aquifer is most economic supply alternative.	Businesses using Powder River #1 have closed. No PWS listed for town. Presumed that residents are served by individual domestic wells.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Prairie Dog Creek Watershed				
EnTech, Inc. (in association with Steady Stream Hydrology, Inc.), 2001, Final report for Prairie Dog Creek watershed master plan level I study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Alluvial and Wasatch aquifers	Surface water report that provides a brief evaluation of groundwater resources in the aquifers listed at left.	Form a watershed improvement district to address surface water issues. Groundwater resources are limited to individual domestic, stock, and agricultural wells.	Residents of Sheridan subdivisions located in the Prairie Dog Creek Watershed may be served by the Sheridan Area Water System SAWS). Others by individual wells.
Sheridan				
Western Water Consultants, Inc., 1982, Potential for groundwater development, City of Sheridan, Wyoming, [variously paged].	Lance-Fox Hills and Fort Union aquifers	Feasibility study to assess the potential for economic development of beneficial amounts of water for municipal use.	The Lance-Fox Hills and Fort Union Formation have variable characteristics and water quality. The economic feasibility of the groundwater supply can be better assessed after construction of a new test well.	See below.
Howard Needles Tammen and Bergendoff, 1985, Sheridan area water supply investigation, Level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. *Executive summary is available under separate cover.*	Paleozoic aquifers	Identify and evaluate alternative development programs to provide a dependable water supply for the Sheridan area through 2035. Determine water development potential of the Paleozoic aquifers west of Sheridan.	Evaluation of Little Goose Well and Big Goose Well, improvement alternatives and cost estimates. Water from Big and Little Goose wells meet primary and secondary drinking water standards.	The Sheridan Area Water System obtains its water from surface water sources.
Sleepy Hollow				
Brown and Caldwell, 2005, Drilling, construction, development, and testing of Sleepy Hollow Well No. 6: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Lance-Fox Hills and Fort Union aquifers	Report describes project where Sleepy Hollow Well #6 was drilled and tested.	Well was drilled by reverse-circulation drilling. Transmissivity of the well was estimated at 315 ft^2/day. WQ was deemed suitable for potable use and meets primary and secondary drinking-water standards for a public water system with disinfection.	Sleepy Hollow obtains its water from the project well (Well #6) and four others.
Sundance				
Bearlodge Ltd., Inc., 1986, Report for the Sundance groundwater project, Sundance No. 6 well: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Minnelusa and Pahasapa aquifers	Project provides data from the first drilling project into the Madison Formation in the Sundance area to find a new potential municipal source.	Water quality was well within EPA drinking water standards and a proposed "safe yield" for the well was recommended at 400 gpm.	See below.
TriHydro Corporation, 2013, Sundance master plan level I, Crook County, Wyoming, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary and appendices are available under separate cover.*	Minnelusa and Pahasapa aquifers	Identify solutions and alternatives for addressing water supply issues and concerns of the City of Sundance.	Generate a hydraulic model to use for master planning for water usage, transmission, and storage.	Project completed.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Sundance (cont.)				
TriHydro Corporation (in association with DOWL and DC Drilling), 2015, Sundance water system feasibility level II study, Crook County, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Minnelusa and Pahasapa aquifers	Review of Level I study recommendations and cost analysis. The Cole Well Field was evaluated to determine if the wells could be used for municipal water supply.	Complete a downhole video survey to assess condition of wells, replace the production piping in Cole Well 3A in 5-10 years. Additional well development in Cole Wells 3 and 3A may be necessary if sediment accumulation becomes an issue.	Sundance obtains municipal water from wells completed in Paleozoic aquifers.
Three Horses				
EnTech, Inc. (in association with Environmental Design Engineering and RIMCON, LLC), 2002, Three Horses watershed plan, Level I study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. Executive summary is available under separate cover.	Wasatch and Fort Union aquifers	Summarize characteristics of the watershed and evaluate potential CBM impacts and water management alternatives.	Current methods of addressing CBM water issues are best given present regulations. If proper precautions are taken, some CBM waters may be suitable for irrigation purposes.	Watershed study completed.
Thunder Basin				
Olsson Associates (in association with ESCO Associates, Inc., Wester-Wetstein Associates, and Steady Stream Hydrology, Inc.), 2009, Thunder Basin watershed management plan, level 1 watershed study, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. *Executive summary is available under separate cover.*	Alluvial, springs, Wasatch Formation, Fort Union Formation, Lance Formation (Lance-Fox Hills aquifer)	Describe Thunder Basin watershed in its current condition and make recommendations for issues/opportunities identified through this study. Contains groundwater registered well inventory map, groundwater registered yield map, and groundwater registered well depth map.	Dispersal of upland watering sources for livestock will reduce the pressure in current drainage ways where livestock currently water. Installation of shallow-moderately deep wells, solar powered pumps, stock tanks, piping, and fencing are recommended.	See below.
Olsson Associates (in association with ESCO Associates, Inc., Wester-Wetstein Associates, and Steady Stream Hydrology, Inc.), 2009, Thunder Basin Phase II watershed management plan, level I watershed study, Lance and Lightning Creek, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, 2 v., [variously paged]. Executive summary is available under separate cover.	Alluvial, springs, Arikaree Formation, Wasatch Formation, Fort Union Formation, Lance Formation	Describe current conditions of Lance Creek and Lightning Creek sub-basins and make recommendations for issues/opportunities identified through this study. Contains groundwater registered well inventory map, groundwater registered yield map, and groundwater registered well depth map.	Groundwater is suitable for livestock/wildlife watering and should be expanded in areas where watering opportunities are scarce.	Thunder Basin studies completed. Unknown if suggested improvements are being implemented.
Tongue-Little Bighorn River Basin				
Wyoming Water Development Commission, 1984, Water development potential in the Tongue River Basin, level I reconnaissance study: prepared by the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison, Lance-Fox Hills, Fort Union, Wasatch aquifers	Conduct a basin-wide development plan to provide municipal water to Sheridan and other communities in the Tongue River Basin.	Report provides a comprehensive summary of previous groundwater studies in the basin and a bibliography.	See below.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Tongue-Little Bighorn River Basin (cont.)				
Banner Associates, Inc., 1985, Tongue River level I, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged].	Madison aquifer	Investigate water availability and development potential in the Tongue River drainage.	Good-quality groundwater can be developed by constructing well fields at any of the three areas evaluated in this study.	Unknown if suggested improvements were implemented.
Upton				
Weston Engineering, Inc., 1991, Upton water supply project, level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Stimulate one of three wells serving the town of Upton to potentially enhance water supply to the community.	Well stimulation was successful and improved specific capacity of the well was improved by more than two-fold.	See below.
McLaughlin Water Engineers, Ltd, 2008, Upton Well No. 6 level II study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Investigation of contamination in Upton Well #6 which has prevented use of the well since its completion.	Contamination is due to the presence of iron fixing bacteria on the well casing and introduction of contaminants during well development. Well rehabilitation program and subsequent construction of delivery and storage systems recommended.	Upton currently draws water from Wells #2, #4, #7 and #8 all in the Madison aquifer. Water from Well #6 has been used for non-potable applications.
Vista West				
Baker and Associates, 1991, Vista West water supply project, level I study: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Madison aquifer	Find an alternative source of water for the Vista West community and assess logistics and cost.	A new Madison Formation well has the best potential for a successful water supply.	See below.
Weston Engineering, Inc., 1994, Vista West water supply project, Level II: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fractured intrusive rocks and Deadwood aquifer	Investigate the potential for purchasing water from Sundance and/or explore water production potential of fractured intrusive rocks and sedimentary rocks.	Fractured intrusive rocks yield significant quantities of water, which meets EPA primary and secondary drinking water standards. Test wells were installed and evaluated.	Test wells were developed as municipal wells Vista West #1 (P91988.0W 1nd P9189.0W) and #2 and are in use presently.
Wright				
Anderson & Kelly, Inc., 1986, Wright groundwater supply project, level III, drilling and testing of RJ-4 well, operating plan and preconstruction report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Wasatch and Fort Union aquifers	Drilling, construction, development, and testing of municipal supply well RJ-4.	Water pumped from the RJ-4 well meets EPA primary drinking water standards. Water from the Fort Union Formation meets most EPA drinking water standards except for iron.	See next page.

Citation(s)	Aquifer/ Formation	Project description	Results/Recommendations	Current status
Wright (cont.)				
Stetson Engineering, Inc. (in association with Wester-Wetstein & Associates), 2009, Wright master plan, level I study final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Wasatch and Fort Union aquifers	Establish a water master plan for the Wright Water and Sewer District and make plans for expansion to meet increasing demand.	Water levels are declining in wells in the Wright area. It is recommended that future wells be separated by at least one mile to avoid interference between wells. Drill an additional well (RJ-7) in the Wright area to meet increasing need for water supply.	Project completed.
HDR, 2012 (in association with Western Groundwater Services), Wright Water and Sewer District water supply level II study, Well no. RJ-7, final report: prepared for the Wyoming Water Development Commission, Cheyenne, Wyoming, [variously paged]. *Executive summary is available under separate cover.*	Fort Union aquifer	Drilling, construction, development, and testing of municipal supply well RJ-7.	The RJ-7 well yields 300 gpm and has water quality similar to the other RJ-wells in the system.	Wright draws municipal water from five– active wells including RJ-4. EPA and SEO data suggest that RJ-7 is not yet in operation.

Appendix C

GIS dataset sources for figures and plates

Dataset	Presented in	Source
GEOLOGY		
Powder, Tongue, and Northeast river basins geology	Plate I, various figures	Modified from Stoeser, D.B., et al., 2007, and Love, J.D., Christiansen, A.C., 1985
Precambrian basement structure contour	Plate I	Modified from Blackstone, 1993
Precambrian basement faults	Plate I	Modified from Blackstone, 1993
Cross-section lines	Plate I	WSGS
Lineaments	Plate I	Cooley, M. E., 1986
Faults, Wyoming	Plate I, Plate II	Modified from Stoeser, D.B., et al., 2007, and Love, J.D., Christiansen, A.C., 1985
Faults, Montana	Plate I, Plate II	Modified from Stoeser, D.B., et al., 2007
Faults, South Dakota	Plate I, Plate II	Modified from Stoeser, D.B., et al., 2007
Hydrogeology (includes aquifer outcrop areas)	Plate II, Figures 6-1, 6-2, 6-3, 6-4, 6-5, 6-6, 6-7	Bartos, T., USGS, 2017
GROUNDWATER		
Aquifer recharge as a percent of precipitation	Figure 6-8	Taboga and Stafford, WSGS, 2016
Aquifer sensitivity	Figure 5-3	Hamerlinck and Arneson, 1998
Average annual precipitation, 1981–2010	Figure 3-3	PRISM Climate Group, Oregon State University
Estimated net annual aquifer recharge	Figure 5-2	Taboga and Stafford, WSGS, 2016
Springs		Stafford and Gracias, WSGS, 2009
SWAP locations	Figure 5-11	Modified from Trihydro Corporation, 2004
Permitted wells	Figures 8-1, 8-2, 8-3, 8-4, 8-5, 8-6, 8-7	Wyoming State Engineer's Office, 2015 Montana Groundwater Information Center, 2015 Nebraska Department of Natural Resources South Dakota Department of Environment and Natural Resources, 2015
POTENTIAL GROUNDWATER CONTAMINANTS		
Abandoned mine sites	Figure 5-7	Created from WDEQ Abandoned Mine Land table of 2016
Active coal mine	Figure 5-8	WDEQ, Land Quality Division, 2015
Active disposal and injection wells	Figure 5-5	Modified from WOGCC well header data as of 2016
Small, Limited, and Regular Mining Permits	Figure 5-8	WDEQ LQD, 2016
Non Coal Mines	Figure 5-8	WDEQ LQD, 2016
Storage tanks	Figure 5-10	Modified from WDEQ Solid and Hazardous Waste Division (SHWD) storage tank table of 2016
Active Wyoming Pollutant Discharge Elimination System (WYPDES) outfalls	Figure 5-6	WDEQ Water Quality Division (WQD) WYPDES GIS dataset of 2016
Commercial oil and gas disposal pits	Figure 5-10	WDEQ/WQD commercial oil and gas disposal pit GIS dataset of 2016
Pollution Control Facilities	Figure 5-6	WDEQ/WQD Groundwater Program known contaminated areas GIS dataset of 2016
Oil and gas fields	Figure 5-4	Toner et al. 2016

Dataset	Presented in	Source
Pipelines	Figure 5-4	Wyoming Pipeline Authority 2016
Solid and hazardous waste facilities	Figure 5-10	Modified from WDEQ SHWD solid and hazardous waste facilities table of 2016
Underground Injection Control (UIC) Class I and V wells	Figure 5-5	Modified from WDEQ/WQD UIC GIS dataset of 2016
Voluntary Remediation Program (VRP) sites	Figure 5-10	Modified from WDEQ SHWD VRP tables and GIS datasets of 2016
WSGS mines, pits, mills, and plants	Figure 5-9	Harris, 2004
	BASE DATA	
Basin boundary	Plate I, various figures	Modified from USGS National Hydrography Dataset hydrologic units
Elevation	Plate I, various figures	Modified from USGS, 1999
Hillshade	Plate I, various figures	USGS, 1999
Lakes	Plate I, various figures	USGS, National Hydrologic Dataset
Rivers	Plate I, various figures	USGS, National Hydrologic Dataset
State boundaries	Plate I, various figures	U.S. Department of Commerce, U.S. Census Bureau, Geography Division, 2010
Wyoming, Monatana, South Dakota, and Nebraska counties	Plate I, various figures	U.S. Department of Commerce, U.S. Census Bureau, Geography Division, 2010
Wyoming, Monatana, South Dakota, and Nebraska townships	Plate I, various figures	Premier Data Services, 2008
Mountain peaks	Physiographic features figure	WSGS, unpublished mountain peaks GIS dataset of 2008
Roads	Plate I, various figures	U.S. Department of Commerce, U.S. Census Bureau, Geography Division, 2010
Places (cities, towns, etc.)	Plate I, various figures	Modified from USGS - Geographic Names Information System 2015

Appendix D

Interstate River Compacts of the Northeast River Basins

BELLE FOURCHE RIVER COMPACT, 1943

Signatory States: South Dakota and Wyoming

Rivers Controlled: Belle Fourche River and its tributaries arising in Wyoming.

Ratifications: Wyo. Stat. Ann. §4l-12-201 through 215 (2005) [Act of March 3, 1943, 1943 Wyo. Sess. Laws, ch. 117, p. 153]

S.D. Codified Laws §46A-17-l (2005) [Act of March 4, 1943, 1943 S.D. Sess. Laws ch. 283, p. 281]

Summary: This Compact recognizes all existing rights in Wyoming, as of the date of the Compact. It permits Wyoming unlimited use for stock water reservoirs not exceeding 20 acre-feet in capacity, and it allows Wyoming to deplete the unappropriated flow under the conditions existing as of the date of the compact by an additional 10%.

BELLE FOURCHE RIVER COMPACT, 1943

The States of South Dakota and Wyoming, parties signatory to this Compact (hereinafter referred to as South Dakota and Wyoming, respectively, or individually as a State, or collectively as the States) have resolved to conclude a compact as authorized under the Act of Congress of February 26, 1927, Chapter 216, 44 Stat. 1247, and, after negotiations participated in by the following named State Commissioners.

For South Dakota:
M. Q. SHARPE
G. W. MORSMAN
S. G. MORTIMER
W. D. BUCHHOLZ

For Wyoming:
L. C. BISHOP
SAMUEL McKEAN
L. H. ROBINSON
Mrs. E. E. McKEAN

and by Howard R. Stinson, appointed as the Representative of the United States of America, have agreed upon the following articles, to-wit:

ARTICLE I

A. The major purposes of this compact are to provide for the most efficient use of the waters of the Belle Fourche River Basin (hereinafter referred to as the Basin) for multiple purposes; to provide for an equitable division of such waters; to remove all causes, present and future, which might lead to controversies; to promote interstate comity; to recognize that the most efficient utilization of the waters within the basin is required for the full development of the basin; and to promote joint action by the states and the United States in the efficient use of water and the control of floods.

B. The physical and other conditions peculiar to the Basin constitute the basis for this compact; and none of the States hereby, nor the Congress of the United States by its consent, concedes that this compact establishes any general principle or precedent with respect to any other interstate stream.

C. Either State and all others using, claiming or in any manner asserting any right to the use of the waters of the Belle Fourche River under the authority of that State, shall be subject to the terms of this Compact.

ARTICLE II

As used in this Compact:

A. The term “Belle Fourche River” shall mean and include the Belle Fourche River and all its tributaries originating in Wyoming

B. The term “basin” shall mean that area in South Dakota and Wyoming, which is naturally drained by the Belle Fourche River, and all its tributaries

C. The term "beneficial use" is herein defined to be that use by which the water supply of a drainage basin is depleted when usefully employed by the activities of man, and includes water lost by evaporation, and other natural causes from streams, canals, ditches, irrigated areas, and reservoirs;

D. Where the name of the State or the term "State" or "States" is used, these shall be construed to include any person or entity of any nature whatsoever using, claiming, or in any manner asserting any right to the use of the waters of the Belle Fourche River under the authority of that State.

ARTICLE III

It shall be the duty of the two States to administer this Compact through the official in each State who is now or may hereafter be charged with the duty of administering the public water supplies, and to collect and correlate through such officials the data necessary for the proper administration of the provisions of this Compact. Such officials may, by unanimous action, adopt rules and regulations consistent with the provisions of this Compact.

The United States Geological Survey, or whatever federal agency may succeed to the functions and duties of that agency, insofar as this Compact is concerned, shall collaborate with the officials of the States charged with the administration of this Compact in the execution of the duty of such officials in the collection, correlation, and publication of information necessary for the proper administration of this Compact.

ARTICLE IV

Each State shall itself or in conjunction with other responsible agencies cause to be established, maintained, and operated such suitable water gaging stations as it finds necessary to administer this Compact.

ARTICLE V

A. Wyoming and South Dakota agree that the unappropriated waters of the Belle Fourche River as of the date of this Compact shall be allocated to each State as follows:

90% to South Dakota

10% to Wyoming;

Provided, that allocations to Wyoming shall be exclusive of the use of these waters for domestic and stock use, and Wyoming shall be allowed unrestricted use for these purposes, except that no reservoir for such use shall exceed twenty (20) acre-feet in capacity. For storage of its allocated water, Wyoming shall have the privilege of purchasing at cost not to exceed ten percent (10%) of the total storage capacity for any reservoir or reservoirs constructed in Wyoming for irrigation of lands in South Dakota, or may construct reservoirs itself for the purpose of utilizing such water. Either State may temporarily divert, or store for beneficial use, any unused part of the above percentages allotted to the other, but no continuing right shall be established thereby.

B. Rights to the use of the waters of the Belle Fourche River, whether based on direct diversion or storage, are hereby recognized as of the date of this Compact to the extent these rights are valid under the law of the State in which the use is made, and shall remain unimpaired hereby. These rights, together with the additional allocations made under A of this Article, are agreed to be an equitable apportionment between the States of the waters of the Basin.

C. The waters allocated under A of this Article and the rights recognized under B of this Article are hereinafter referred to collectively as the apportioned water. For the purposes of the administration of this Compact and determining the apportioned water at any given date within a given calendar year, there shall be taken the sum of:

(1) The quantity of water in acre-feet that passed the Wyoming-South Dakota state line during the period from January 1 of that year to that given date

(2) The quantity of water in acre-feet in storage on that date in all reservoirs built in Wyoming on the Belle Fourche River subsequent to the date of this Compact.

ARTICLE VI

Any person, entity, or State shall have the right to acquire necessary property rights in another State by purchase or through the exercise of the power of eminent domain for the construction, operation and maintenance of storage reservoirs and of appurtenant works, canals, and conduits required for the enjoyment of the privileges granted by Article V and Article VII A; provided, however, that the grantees of such rights shall pay to the political subdivisions of the State in which such works are located, each and every year during which such rights are enjoyed for such purposes, a sum of money equivalent to the average annual amount of taxes assessed against the lands and improvements thereon during the 10 years preceding the use of such lands in reimbursement for the loss of taxes to said political subdivisions of the State.

ARTICLE VII

A. Either State shall have the right, by compliance with the laws of the other State, to file applications for and receive permits to construct or participate in the construction and use of any dam, storage reservoir, or diversion works in such State for the purpose of conserving and regulating the apportioned water of the other State; provided, that such right is subject to the rights of the other State to control, regulate, and use water apportioned to it.

B. Each claim hereafter initiated for storage or diversion of water in one State for use in another State shall be filed in the Office of the State Engineer of the State in which the water is to be stored or diverted, and a duplicate copy of the application including a map showing the character and location of the proposed facilities and the lands to be irrigated shall be filed in the Office of the State Engineer of the State in which the water is to be used. If a portion or all the lands proposed to be reclaimed are located in a State other than the one in which the water is to be restored or diverted, then, before approval of the application shall be granted, said application shall be checked against the records of the appropriate office of the State in which the water is to be used, and a notation shall be placed thereon by the officer in charge of such records to the effect that the land description does not indicate a conflict with existing water rights. All endorsements shall be placed on both the original and duplicate copies of all such maps filed to the end that the records in both States may be complete and identical.

C. Appropriations may hereafter be adjudicated in the State in which the water is stored or diverted, and where a portion or all the lands irrigated are in the other State, such adjudications shall be confirmed in the latter State by the proper authority. Each adjudication is to conform with the laws of the State where the water is stored or diverted and shall be recorded in the county and State where the water is used.

ARTICLE VIII

In case any reservoir is constructed in, Wyoming to be used principally for irrigation of lands in South Dakota, sufficient water not to exceed 10 cubic feet per second shall be released at all times for stock water use.

ARTICLE IX

No reservoir hereafter built solely to utilize the water allocated to Wyoming shall have a capacity in excess of one thousand (1,000) acre-feet.

ARTICLE X

The provisions of this Compact shall remain in full force and effect until amended by action of the legislature of the States and consented to and approved by the Congress of the United States in the same manner as this Compact is required to be ratified to become effective.

ARTICLE XI

This Compact may be terminated at any time by unanimous consent of the States, and upon such termination, all rights then established hereunder or recognized hereby shall continue to be recognized as valid by the States notwithstanding the termination of the other provisions of the Compact.

ARTICLE XII

Nothing in this Compact shall be construed to limit or prevent either state from instituting maintaining any action or proceeding, legal or equitable, in any federal court or the United States Supreme Court for the protection of any right under this Compact or the enforcement of any of its provisions.

ARTICLE XIII

Nothing in this Compact shall be deemed:

A. To impair or affect any rights or powers of the United States, its agencies, or instrumentalities, in and to the use of the waters of the Belle Fourche River nor its capacity to acquire rights in and to the use of said waters

B. To subject any property of the United States, its agencies, or instrumentalities to taxation by either State or subdivision thereof, or to create an obligation on the part of the United States, its agencies, or instrumentalities, by reason of the acquisition, construction or operation of any property or works of whatsoever kind, to make any payments to any State or political subdivision thereof, State agency, municipality, or entity whatsoever in reimbursement for the loss of taxes;

C. To subject any property of the United States, its agencies, or instrumentalities, to the laws of any State to an extent other than the extent to which these laws would apply without regard to the Compact.

ARTICLE XIV

This Compact shall become operative when approved by the legislature of each of the States, and when consented to by the Congress of the United States by legislation providing, among other things, that:

A. Any beneficial uses hereafter made by the United States, or those acting by or under its authority, within a State, of the waters allocated by this Compact, shall be within the allocations hereinabove made for use in that State and shall be taken into account in determining the extent of use within that State;

B. The United States, or those acting by or under its authority, in the exercise of rights or powers arising from whatever jurisdiction the United States has in, over and to the waters of the Belle Fourche River and all its tributaries, shall recognize, to the extent consistent with the best utilization of the waters for multiple purposes, that beneficial use of the waters within the basin is of paramount importance to development of the Basin, and no exercise of such power or right thereby that would interfere with the full beneficial use of the waters shall be made except upon a determination, giving due consideration to the objectives of this Compact and after consultation with all interested federal agencies and the State officials charged with the administration of this Compact, that such exercise is in the interest of the best utilization of such waters for multiple purposes;

C. The United States, or those acting by or under its authority, will recognize any established use, for domestic and irrigation purposes, of the apportioned waters which may be impaired by the exercise of Federal jurisdiction in, over, and to such waters; provided, that such use is being exercised beneficially, is valid under the laws of the appropriate State and in conformity with this Compact at the time of the impairment thereof, and was validly initiated under State law prior to the initiation or authorization of the federal program or project which causes such impairment.

ARTICLE XV

Should a court of competent jurisdiction hold any part of this Compact to be contrary to the constitution of any State or of the United States, all other severable provisions shall continue in full force and effect.

IN WITNESS WHEREOF, the Commissioners have signed this Compact in triplicate original, one of which shall be filed in the archives of the Department of State of the United States of America and shall be deemed the authoritative original, and of which a duly certified copy shall be forwarded to the Governor of each of the States.

Done at the City of Cheyenne in the State of Wyoming, this 18th day of February, in the year of Our Lord, One Thousand Nine Hundred and Forty-Three.

Commissioners for South Dakota:	M. Q. SHARPE G. W. MORSMAN S. G. MORTIMER W. D. BUCHHOLZ
Commissioners for Wyoming:	L. C. BISHOP SAMUEL McKEAN L. H. ROBINSON Mrs. E. E. McKEAN

I have participated in the negotiation of this Compact and intend to report favorably thereon to the Congress of the United States.

HOWARD R. STINSON

Representative of the United States of America

NOTES

Congressional Consent to Negotiations. --- By the Act of February 26, 1927 (44 Stat. 1247), the Congress gave its consent to the negotiation by the States of South Dakota and Wyoming of compacts "providing for an equitable division and apportionment * * * of the water supply of the Belle Fourche" and other streams common to the two States. This consent was given "upon condition that a representative of the United States from the Department of the Interior, to be appointed by the President, shall participate in the negotiations and shall make report to Congress of the proceedings and of any compact or agreement entered into." It was also provided that no such compact or agreement should become effective until it had been "approved" by the legislatures of the States and by Congress.

Congressional Consent to the Compact. --- Act of February 26, 1944 (58 Stat. 94) from which the text of the Compact above is taken.

Section 2 of this Act reads as follows:

"(a) In order that the conditions stated in Article XIV of the Compact hereby consented to shall be met and that the Compact shall be and continue to be operative, the following provisions are enacted:

"(1) Any beneficial uses hereafter made by the United States, or those acting by or under its authority, within a State, of the waters allocated by such compact, shall be within the allocations made by such compact for use in that State and shall be taken into account in determining the extent of use within that State;

"(2) The United States, or those acting by or under its authority, in the exercise of rights or powers arising from whatever jurisdiction the United States has in, over, and to the waters of the Belle Fourche River and all its tributaries shall recognize, to the extent consistent with the best utilization of the waters for multiple purposes, that beneficial use of the waters within the Basin is of paramount importance to the development of the Basin; and no exercise of such power or right thereby that would interfere with the full beneficial use of the waters within the Basin shall be made except upon a determination, giving due consideration to the objectives of such compact and after consultation with all interested

Federal agencies and the State officials charged with the administration of such compact, that such exercise is in the interest of the best utilization of such waters for multiple purposes;

"(3) The United States, or those acting by or under its authority, will recognize any established use, for domestic and irrigation purposes, of the apportioned water which may be impaired by the exercise of Federal jurisdiction in, over, and to such water; Provided, That such use is being exercised beneficially, is valid under the laws of the appropriate State and in conformity with such compact at the time of the impairment thereof and was validly initiated under State law prior to the initiation or authorization of the Federal program or project which causes such impairment.

"(b) as used in this section, the following terms: 'beneficial use,' 'Basin,' and 'apportioned water,' shall have the same meanings as those ascribed to them in the compact consented to by this Act."

After approving the bill, the President issued the following statement dated February 28, 1944:

"In signing the Belle Fourche River Basin Compact bill, I find it necessary to call attention, as I did last May in the case of the Republican River Compact bill, to the restrictions imposed upon the use of water by the United States. The procedure prescribed by the bill for the exercise of the powers of the Federal Government would not be entirely satisfactory in all circumstances but the prospects in fact for the exercise of such powers in the Belle Fourche basin are not great. For streams where conditions are otherwise and there appears to be a possible need for Federal comprehensive multiple-purpose development or where opportunities for important electric power projects are present, I believe the Belle Fourche River Compact should not serve as a precedent. In such cases the compact and the legislation should more adequately reflect recognition of the responsibilities and prerogatives of the Federal Government."

Legislative History of the Compact. --- See H. R. 2580 and S. 1057, 78th Congress; House Report 788 (Committee on Irrigation and Reclamation) and Senate Report 683 (Committee on Irrigation and Reclamation), 78th Congress; 89 Cong. Rec. 9533-9535 *(1943),* 90 Cong. Rec. 1660 (1944) P. L. 236, 78th Congress. Hearings on H. R. 2580 were printed; for report of Federal representative see pp. 12-15.

YELLOWSTONE RIVER COMPACT, 1950

Signatory States: Montana, North Dakota and Wyoming

Rivers Controlled: Yellowstone River and its tributaries (Clarks Fork, Big Horn, Tongue and Powder), excluding Yellowstone National Park.

Ratifications: Wyo. Stat. Ann. §41-12-601 (2005) [Act of Jan. 27, 1951, 1951 Wyo. Sess. Laws, ch. 10, p. 7]

Mont. Code Ann. §85-20-101 (2003) [Act of Feb. 13, 1951, 1951 Mont. Laws, ch. 39, p. 58]

N.D. Cent. Code §61-23-01 (2003) [Act of March 7, 1951, 1951 N.D. Laws, ch. 339, p. 505]

Summary: The Compact deals with division of the waters of the four tributaries to the Yellowstone River. To all tributaries the following rules apply: 1) existing rights as of January 1, 1950 maintain their status quo; 2) no water may be diverted from the Yellowstone River Basin without consent from all States; 3) existing and future domestic and stock water uses including stock water reservoirs up to a capacity of 20 acre-feet are exempted from provisions of the Compact.

The unappropriated or unused total divertable flow of each tributary after needs for supplemental supply for existing rights are met, is allocated to Wyoming and Montana on a percentage basis.

YELLOWSTONE RIVER COMPACT, 1950

The State of Montana, the State of North Dakota, and the State of Wyoming, being moved by consideration of interstate comity, and desiring to remove all causes of present and future controversy between said States and between persons in one and persons in another with respect to the waters of the Yellowstone River and its tributaries, other than waters within or waters which contribute to the flow of streams within the Yellowstone National Park, and desiring to provide for an equitable division and apportionment of such waters, and to encourage the beneficial development and use thereof, acknowledging that in future projects or programs for the regulation, control and use of water in the Yellowstone River basin the great importance of water for irrigation in the signatory States shall be recognized, have resolved to conclude a Compact as authorized under the Act of Congress of the United States of America, approved June 2, 1949 (Public Law 83, 81st congress, first session), for the attainment of these purposes, and to that end, through their respective governments, have named as their respective Commissioners:

For the State of Montana:

Fred E. Buck
A. W. Bradshaw
H. W. Bunston
John Herzog
John M. Jarussi
Ashton Jones
Chris Josephson
A. Wallace Kingsbury
P. F. Leonard
Walter M. McLaughlin
Dave M. Manning
Joseph Muggli
Chester E. Onstad
Ed F. Parriott
R. R. Renne
Keith W. Trout

For the State of North Dakota:

I. A. Acker
J. J. Walsh
Einar H. Dahl

For the State of Wyoming:

L. C. Bishop
Earl T. Bower
J. Harold Cash
Ben F. Cochrane
Ernest J. Goppert
Richard L. Greene
E. C. Gwillim
E. J. Johnson
Lee E. Keith
N. V. Kurtz
Harry L. Littlefield
R. E. McNally
Will G. Metz
Mark N. Partridge
Alonzo R. Shreve
Charles M. Smith
Leonard F. Thornton
M. B. Walker

who, after negotiations participated in by R. J. Newell, appointed as the representative of the United States of America, have agreed upon the following articles, to-wit:

ARTICLE I

A. Where the name of a State is used in this Compact, as a party thereto, it shall be construed to include the individuals, corporations, partnerships, associations, districts, administrative departments, bureaus, political subdivisions, agencies, persons, permittees, appropriators, and all others using, claiming, or in any manner asserting any right to the use of the waters of the Yellowstone River System under the authority of said State.

B. Any individual, corporation, partnership, association, district, administrative department, bureau, political subdivision, agency, person, permittee, or appropriator authorized by or under the laws of a signatory State, and all others using, claiming, or in any manner asserting any right to the use of the waters of the Yellowstone River System under the authority of said State, shall be subject to the terms of this Compact. Where the singular is used in this article, it shall be construed to include the plural.

ARTICLE II

A. The State of Montana, the State of North Dakota, and the State of Wyoming are hereinafter designated as "Montana", "North Dakota", and "Wyoming", respectively.

B. The terms "Commission" and "Yellowstone River Compact Commission" mean the agency created as provided herein for the administration of this Compact.

C. The term "Yellowstone River Basin" means areas in Wyoming, Montana, and North Dakota drained by the Yellowstone River and its tributaries, and includes the area in Montana known as Lake Basin, but excludes those lands lying within Yellowstone National Park.

D. The term "Yellowstone River System" means the Yellowstone River and all of its tributaries, including springs and swamps, from their sources to the mouth of the Yellowstone River near Buford, North Dakota, except those portions thereof, which are within or contribute to the flow of streams within the Yellowstone National Park.

E. The term "tributary" means any stream, which in a natural state contributes to the flow of the Yellowstone River, including interstate tributaries and tributaries thereof, but excluding those, which are within or contribute to the flow of streams within the Yellowstone National Park.

F. The term "interstate tributaries" means the Clarks Fork, Yellowstone River; the Bighorn River (except Little Bighorn River); the Tongue River; and the Powder River, whose confluences with the Yellowstone River are respectively at or near the city (or town) of Laurel, Big Horn, Miles City, and Terry, all in the State of Montana.

G. The terms "divert" and "diversion" means the taking or removing of water from the Yellowstone River or any tributary thereof when the water so taken or removed is not returned directly into the channel of the Yellowstone River or of the tributary from which it is taken.

H. The term "beneficial use" is herein defined to be that use by which the water supply of a drainage basin is depleted when usefully employed by the activities of man.

I. The term "domestic use" shall mean the use of water by an individual, or by a family unit or household for drinking, cooking, laundering, sanitation and other personal comforts and necessities; and for the irrigation of a family garden or orchard not exceeding one-half acre in area.

J. The term "stock water use" shall mean the use of water for livestock and poultry.

ARTICLE III

A. It is considered that no Commission or administrative body is necessary to administer this Compact or divide the waters of the Yellowstone River Basin as between the states of Montana and North Dakota. The provisions of this Compact, as between the States of Wyoming and Montana, shall be administered by a Commission composed of one representative from the State of Wyoming and one representative from the State of Montana, to be selected by the Governors of said States as such States may choose, and one representative selected by the Director of the United States Geological Survey or whatever Federal agency may succeed to the functions and duties of that agency, to be appointed by him at the request of the States to sit with the Commission and who shall, when present, act as Chairman of the Commission without vote, except as herein provided.

B. The salaries and necessary expenses of each State representative shall be paid by the respective State; all other expenses incident to the administration of this Compact not borne by the United States shall be allocated to and borne one-half by the State of Wyoming and one-half by the State of Montana.

C. In addition to other powers and duties herein conferred upon the Commission and the members thereof, the jurisdiction of the Commission shall include the collection, correlation, and presentation of factual data, the maintenance of records having a bearing upon the administration of this Compact, and recommendations to such States upon matters connected with the administration of this Compact, and the Commission may employ such services and make such expenditures as reasonable and necessary within the limit of funds provided for that purpose by the respective States, and shall compile a report for each year ending September 30 and transmit it to the Governors of the signatory States on or before December 31 of each year.

D. The Secretary of the Army; the Secretary of the Interior; the Secretary of Agriculture; the Chairman, Federal Power Commission; the Secretary of Commerce, or comparable officers of whatever Federal agencies may succeed to the functions and duties of these agencies, and such other federal officers and officers of appropriate agencies of the signatory states having services or data useful or necessary to the Compact Commission, shall cooperate, ex officio, with the Commission in the execution of its duty in the collection, correlation, and publication of records and data necessary for the proper administration of the Compact; and these officers may perform such other services related to the Compact as may be mutually agreed upon with the Commission.

E. The Commission shall have power to formulate rules and regulations and to perform any act which they may find necessary to carry out the provisions of this Compact, and to amend such rules and regulations. All such rules and regulations shall be filed in the office of the State Engineer of each of the signatory States for public inspection.

F. In case of the failure of the representatives of Wyoming and Montana to unanimously agree on any matter necessary to the proper administration of this Compact, then the member selected by the director of the United States Geological Survey shall have the right to vote upon the matters in disagreement and such points of disagreement shall then be decided by a majority vote of the representatives of the States of Wyoming and Montana and said member selected by the Director of the United States Geological Survey, each being entitled to one vote.

G. The Commission herein authorized shall have power to sue and be sued in its official capacity in any Federal Court of the signatory States, and may adopt and use an official seal, which shall be judicially noticed.

ARTICLE IV

The Commission shall itself, or in conjunction with other responsible agencies, cause to be established, maintained, and operated such suitable water gaging and evaporation stations as it finds necessary in connection with its duties.

ARTICLE V

A. Appropriative rights to the beneficial uses of the water of the Yellowstone River system existing in each signatory State as of January 1, 1950, shall continue to be enjoyed in accordance with the laws governing the acquisition and use of water under the doctrine of appropriation.

B. Of the unused and unappropriated waters of the interstate tributaries of the Yellowstone River as of January 1, 1950, there is allocated to each signatory State such quantity of that water as shall be necessary to provide supplemental water supplies for the rights described in paragraph (a) of this Article V, such supplemental rights to be acquired and enjoyed in accordance with the laws governing the acquisition and use of water under the doctrine of appropriation, and the remainder of the unused and unappropriated water is allocated to each State for storage or direct diversions for beneficial use on new lands or for other purposes as follows:

1. Clarks Fork, Yellowstone River

   a) To Wyoming 60%

      To Montana 40%

   b) The point of measurement shall be below the last diversion from Clarks Fork above Rock Creek.

2. Bighorn River (Exclusive of Little Bighorn River)

   a) To Wyoming 80%

      To Montana................ 20%

   b) The point of measurement shall be below the last diversion from the Bighorn River above its junction with the Yellowstone River, and the inflow of the Little Bighorn River shall be excluded from the quantity of water subject to allocation.

3. Tongue River

   a) To Wyoming 40%

      To Montana 60%

   b) The point of measurement shall be below the last diversion from the Tongue River above its junction with the Yellowstone River.

4. Powder River (Including the Little Powder River)

   (a) To Wyoming 42%

      To Montana 58%

   (b) The point of measurement shall be below the last diversion from the Powder River above its junction with the Yellowstone River.

C. The quantity of water subject to the percentage allocations, in Paragraph B 1, 2, 3 and 4 of this Article V, shall be determined on an annual water year basis measured from October 1st of any year through September 30th of the succeeding year. The quantity to which the percentage factors shall be applied through a given date in any water year shall be, in acre-feet, equal to the algebraic sum of:

1. The total diversions, in acre-feet, above the point of measurement, for irrigation, municipal, and industrial uses in Wyoming and Montana developed after January 1, 1950, during the period from October 1st to that given date;

2. The net change in storage, in acre-feet, in all reservoirs in Wyoming and Montana above the point of measurement completed subsequent to January 1, 1950, during the period from October 1st to that given date;

3. The net change in storage, in acre-feet, in existing reservoirs in Wyoming and Montana above the point of measurement, which is used for irrigation, municipal, and industrial purposes developed after January 1, 1950, during the period October 1st to that given date;

4. The quantity of water, in acre-feet, that passed the point of measurement in the stream during the period from October 1st to that given date.

D. All existing rights to the beneficial use of waters of the Yellowstone River in the States of Montana and North Dakota, below Intake, Montana, valid under the laws of these States as of January 1, 1950, are hereby recognized and shall be and remain unimpaired by this Compact. During the period May 1 to September 30, inclusive, of each year, lands within Montana and North Dakota shall be entitled to the beneficial use of the flow of waters of the Yellowstone River below Intake, Montana, on a proportionate basis of acreage irrigated. Waters of tributary streams, having their origin in either Montana or North Dakota, situated entirely in said respective States and flowing into the Yellowstone River below Intake, Montana, are allotted to the respective States in which situated.

E. There are hereby excluded from the provisions of this Compact:

1. Existing and future domestic and stock water uses of water: Provided, that the capacity of any reservoir for stock water so excluded shall not exceed twenty (20) acre-feet;

2. Devices and facilities for the control and regulation of surface waters.

F. From time to time the Commission shall reexamine the allocations herein made and upon unanimous agreement may recommend modifications therein as are fair, just, and equitable, giving consideration among other factors to:

1. Priorities of water rights;

2. Acreage irrigated;

3. Acreage irrigable under existing works; and

4. Potentially irrigable lands.

ARTICLE VI

Nothing contained in this Compact shall be as construed or interpreted as to affect adversely any rights to the use of the waters of Yellowstone River and its tributaries owned by or for Indians, Indian tribes, and their reservations.

ARTICLE VII

A. A lower signatory State shall have the right, by compliance with the laws of an upper signatory State, except as to legislative consent, to file application for and receive permits to appropriate and use any waters in the Yellowstone River System not specifically apportioned to or appropriated by such upper State as provided in Article V; and to construct or participate in the construction and use of any dam, storage reservoir, or diversion works in such upper State for the purpose of conserving and regulating water that may be apportioned to or appropriated by the lower State: provided, that such right is subject to the rights of the upper State to control, regulate, and use the water apportioned to and appropriated by it: and provided further, that should an upper State elect, it may share in the use of any such facilities constructed by a lower State to the extent of its reasonable needs upon assuming or guaranteeing payment of its proportionate share of the cost of the construction, operation, and maintenance. This provision shall apply with equal force and effect to an upper State in the circumstance of the necessity of the acquisition of rights by an upper State in a lower State.

B. Each claim hereafter initiated for an appropriation of water in one signatory State for use in another signatory State shall be filed in the office of the State Engineer of the signatory State in which the water is to be diverted, and a duplicate copy of the application or notice shall be filed in the office of the State Engineer of the signatory State in which the water is to be used.

C. Appropriations may hereafter be adjudicated in the State in which the water is diverted, and where a portion or all of the lands irrigated are in another signatory State, such adjudications shall be confirmed in that State by the proper authority. Each adjudication is to conform to the laws of the State where the water is diverted and shall be recorded in the County and State where the water is used.

D. The use of water allocated under Article V of this Compact for projects constructed after the date of this Compact by the United States of America or any of its agencies or instrumentalities, shall be charged as a use by the State in which the use is made: Provided, that such use incident to the diversion, impounding, or conveyance of water in one State for use in another shall be charged to such latter State.

ARTICLE VIII

A lower signatory State shall have the right to acquire in an upper State by purchase, or through exercise of the power of eminent domain, such lands, easements, and rights-of-way for the construction, operation, and maintenance of pumping plants, storage reservoirs, canals, conduits, and appurtenant works as may be required for the enjoyment of the privileges granted herein to such lower State. This provision shall apply with equal force and effect to an upper State in the circumstance of the necessity of the acquisition of rights by an upper State in a lower State.

ARTICLE IX

Should any facilities be constructed by a lower signatory State in an upper signatory State under the provisions of Article VII, the construction, operation, repairs, and replacements of such facilities shall be subject to the laws of the upper State. This provision shall apply with equal force and effect to an upper State in the circumstance of the necessity of the acquisition of rights by an upper State in a lower State.

ARTICLE X

No water shall be diverted from the Yellowstone River Basin without the unanimous consent of all the signatory States. In the event water from another river basin shall be imported into the Yellowstone River Basin or transferred from one tributary basin to another by the United States of America, Montana, North Dakota, or Wyoming, or any of them jointly, the state having the right to the use of such water shall be given proper credit therefore in determining its share of the water apportioned in accordance with Article V herein.

ARTICLE XI

The provisions of this Compact shall remain in full force and effect until amended in the same manner as it is required to be ratified to become operative as provided in Article XV.

ARTICLE XII

This Compact may be terminated at any time by unanimous consent of the signatory States, and upon such termination all rights then established hereunder shall continue unimpaired.

ARTICLE XIII

Nothing in this Compact shall be construed to limit or prevent any State from instituting or maintaining any action or proceeding, legal or equitable, in any Federal Court or the United States Supreme Court, for the protection of any right under this Compact or the enforcement of any of its provisions.

ARTICLE XIV

The physical and other conditions characteristic of the Yellowstone River and peculiar to the territory drained and served thereby and to the development thereof, have actuated the signatory States in the consummation of this Compact, and none of them, nor the United States of America by its consent and approval, concedes thereby the establishment of any general principle or precedent with respect to other interstate streams.

ARTICLE XV

This Compact shall become operative when approved by the Legislature of each of the signatory States and consented to and approved by the Congress of the United States.

ARTICLE XVI

Nothing in this Compact shall be deemed:

(a) To impair or affect the sovereignty or jurisdiction of the United States of America in or over the area of waters affected by such compact, any rights or powers of the United States of America, its agencies, or instrumentalities, in and to the use of the waters of the Yellowstone River Basin nor its capacity to acquire rights in and to the use of said waters;

(b) To subject any property of the United States of America, its agencies, or instrumentalities to taxation by any State or subdivision thereof, nor to create an obligation on the part of the United States of America, its agencies, or instrumentalities, by reason of the acquisition, construction, or operation of any property or works of whatsoever kind, to make any payments to any State or political subdivision thereof, State agency, municipality, or entity whatsoever in reimbursement for the loss of taxes;

(c) To subject any property of the United States of America, its agencies, or instrumentalities, to the laws of any State to an extent other than the extent to which these laws would apply without regard to the Compact.

ARTICLE XVII

Should a Court of competent jurisdiction hold any part of this Compact to be contrary to the Constitution of any signatory State or of the United States of America, all other severable provisions of this Compact shall continue in full force and effect.

ARTICLE XVIII

No sentence, phrase, or clause in this Compact or in any provision thereof, shall be construed or interpreted to divest any signatory State or any of the agencies or officers of such States of the jurisdiction of the water of each State as apportioned in this Compact.

IN WITNESS WHEREOF the Commissioners have signed this Compact in quadruplicate original, one (1) of which shall be filed in the archives of the Department of State of the United States of America and shall be deemed the authoritative original, and of which a duly certified copy shall be forwarded to the Governor of each signatory State.

Done at the city of Billings in the state of Montana, this 8th day of December, in the year of our Lord, One Thousand Nine Hundred and Fifty.

Commissioners for the State of Montana:

Fred E. Buck
A. W. Bradshaw
H. W. Bunston
John Herzog
John M. Jarussi
Ashton Jones
Chris Josephson
A. Wallace Kingsbury
P. F. Leonard
Walter M. McLaughlin
Dave M. Manning
Joseph Muggli
Chester E. Onstad
Ed F. Parriott
R. R. Renne
Keith W. Trout

Commissioners for the State of North Dakota:

I. A. Acker
J. J. Walsh
Einar H. Dahl

Commissioners for the State of Wyoming

L. C. Bishop
Earl T. Bower
J. Harold Cash
Ben F. Cochrane
Ernest J. Goppert
Richard L. Greene
E. C. Gwillim
E. J. Johnson
Lee E. Keith
N. V. Kurtz
Harry L. Littlefield
R. E. McNally
Will G. Metz
Mark N. Partridge
Alonzo R. Shreve
Charles M. Smith
Leonard F. Thornton
M. B. Walker

I have participated in the negotiation of this Compact and intend to report favorably thereon to the Congress of the United States.

R. J. Newell

Representative of the United States of America.

NOTES

Congressional Consent to Negotiations. --- By the Act of June 2, 1949 (63 Stat. 152), the Congress gave its consent to the negotiation by the States of Montana, North Dakota and Wyoming of a Yellowstone River Compact or agreement not later than June 1, 1952. The consent was upon condition "one suitable person, who shall be appointed by the President of the United States shall participate in said negotiations as the Representative of the United States and shall make a report to Congress of proceedings and of any compact or agreement entered into." The Act further provided that the compact or agreement should not be effective until "approved" by the legislatures of the States and by the Congress and that "nothing in this Act shall apply to any waters within or tributary to the Yellowstone National Park or shall establish any right or interest in or to any lands within the boundaries thereof."

In a letter to Robert Newell, the Federal Representative on the Yellowstone River Compact negotiating team, the President expressed his views on certain possible compact provisions by reference to the recently approved Snake River Compact. The text of the letter and an attached memorandum from the Director of the Bureau of the Budget follow:

“May 3, 1950

“MY DEAR MR. NEWELL: The purpose of this letter is to call your attention to a problem of growing concern and, in the solution of which, the Federal Representatives assigned to interstate water compact commissions are in a position to perform a valuable public service. I refer to the somewhat recent tendency to incorporate in interstate water compacts questionable or conflicting provisions imposing restrictions on use of waters by the United States, such as appear in the Snake River Compact enactment, which I approved on March 21, 1950 (Public Law 464, 8lst Congress, 2nd Session).

“In this particular case, the possibility of misinterpretation of certain apparently conflicting provisions was not considered to be serious enough to warrant withholding approval of the enrolled enactment of the Congress (S. 3159). Such provisions however, if followed as precedent for general application, may jeopardize the prospect of consent and approval of compacts by the Federal Government because of the far reaching effects such provisions might have upon the interests of the United States. This matter is further discussed in a memorandum to me from the Director of the Bureau of the Budget, a copy of which is enclosed for your information and guidance.

“I fully realize how difficult it is to resolve the numerous Complex jurisdictional and other problems encountered in reaching agreement upon the allocation of waters of an interstate stream. At the same time, I am impressed with the importance of insuring that compact provisions reflect as clearly as possible a recognition of the respective responsibilities and prerogatives of the United States and the affected States. I can assure you that any efforts made by you and the other compact commissioners with whom you have occasion to collaborate in eliminating or correcting this area of possible conflict, will be appreciated.

“Sincerely yours,

“Harry S. Truman”

“April 21, 1950

“Memorandum for the President:

“Analysis of the enrolled enactment granting the consent and approval of the Congress to the Snake River Compact, prior to your approval on March 21,1950, (Public Law 464, 8lst Congress, 2nd Session), revealed the possibility of misinterpretation of certain apparently conflicting provisions, which did not appear to be serious enough in this particular case to provide a sound basis for recommending disapproval of the bill, but which, if followed as precedent for general application, might have far reaching effects upon the interests of the United States. The conflicts arise primarily between specific provisions imposing restrictions upon uses of water by the United States for power and other purposes, and the general savings clause in Article XIV. This article provides that nothing in the compact shall be deemed to impair or affect any rights or powers of the United States in and to the use of the waters of the Snake River nor its capacity to acquire rights in and to the use of said waters. By reason of such conflicts, doubts may rise as to the extent of the control which the States concerned may exercise over the rights, interests and structures owned or built by the United States on the river. The resulting possibility of confusion thus tends to defeat one of the basic purposes of the compact, of settling the respective rights and interests of the Federal and State Governments in, over and to the river.

“The Committee on Public Lands of the House of Representatives, in its report on the bill (S. 3159) recorded its interpretation of the term “beneficial uses” appearing in Article XIV-B, as not regarded by the Committee as including the use and control of water by the United States by reason of its power with respect to navigable waters under the commerce clause of the Constitution (H. R. Report No. 1743, 8lst Congress, 2nd Session). It is also significant that the Congress saw fit to include in the enactment a provision (Section 2) expressly preserving to the United States the right to alter, amend, and repeal the Act at any time.

“Somewhat similar provisions appear in the proposed Cheyenne River Compact now pending before Congress (H. R. 3336 and S. 1211) and in the Republican River Compact approved May 26, 1943, and the Belle Fourche River Basin Compact approved February 26, 1944. In approving each of these latter enactments, President Roosevelt issued a statement emphasizing that the procedure prescribed by the bill for exercise of the powers of the Federal Government, would not be entirely satisfactory in all circumstances and that these compacts should not serve as precedents, particularly for streams where there appears to be a possible need for Federal comprehensive multiple purpose development or where opportunities for important electric power projects are present. Likewise the Snake River Compact should not serve as a precedent.

“In its report in S. 3159 the Public Lands Committee of the Senate expressed the view that the compact method is the logical and proper manner to settle interstate water controversies. With this view I am in accord but I am also mindful that compact provisions, which are subject to misinterpretation or leave in doubt the respective rights and interests of the United States and the affected States, serve to impair these rights. It is obvious therefore, that the compact method places upon the compact commissioners the important responsibility of drawing compacts in specific and unequivocal language, devoid of all possible ambiguity, and which do not attempt to define, limit or otherwise determine the extent of the powers to be exercised by the United States which is a matter for determination by the Congress through Federal legislation as required.

“The importance of insuring that future compacts more adequately reflect a clear recognition of the respective responsibilities and prerogatives of the United States and the affected States, I believe is readily apparent. In formulating provisions of interstate water compacts, which impose restrictions upon use by the United States of waters in the streams concerned, the responsibility for protecting the rights and interests of the United States rests in the first instance upon those appointed to represent the Federal Government in negotiations with the State compact commissions. The Federal Representatives also are in a position to assist the compact commission in avoiding further use of questionable or conflicting provisions similar to the aforementioned, in order to minimize the possibility of disapproval of the compact by the State legislatures or the Federal Government, or the later possibility of prolonged and costly litigation.

“F.J. Lawton”

“Director”

Congressional Consent to and Legislative History of the Compact. --- Act of October 30, 1951 (65 Stat. 663) from which the text of the Compact set out above is taken. Section 2 of this Act read as follows:

“The right to alter, amend or repeal Section 1 of this Act is expressly reserved. This reservation shall not be construed to prevent the vesting of rights to the use of water pursuant to applicable law and no alteration, amendment or repeal of Section 1 of this Act shall be held to affect rights so vested.”

For legislative history, see S. 1311 and H.R. 3544, 82nd Congress; Senate Report 883 (Committee on Interior and Insular Affairs) and House Report 1118 (Committee on Interior and Insular Affairs), 82nd Congress; 97 Cong. Rec. 12954-12956, 13478-13480 (1951); P.L. 231, 82nd Congress

UPPER NIOBRARA RIVER COMPACT, 1962

Signatory States: Nebraska and Wyoming

Rivers Controlled: The Niobrara River and its tributaries in Nebraska and Wyoming west of Range 55 West of the 6th Principal Meridian.

Ratifications: Wyo. Stat. §41-512.5 (Supp. 1969) [Act of Feb. 16, 1963, Wyo. Sess. Laws, ch. 105]

Neb. Rev. Stat. vol. 2A, app. §1-112 (1995) [Act of Oct. 26, 1962, 1963 Neb. Laws, ch. 332]

Summary: The Compact provides for only limited restrictions on Wyoming's use of the Niobrara River. Basically, these restrictions relate to: 1) priority dates and storage rights in Wyoming reservoirs and 2) priority dates and direct flow reights in the Niobrara, its tributaries and ditches. The Compact also lays the foundation for future apportionment of the ground water in the Niobrara River Basin.

UPPER NIOBRARA RIVER COMPACT, 1962

The State of Wyoming, and the State of Nebraska, parties signatory to this Compact (hereinafter referred to as Wyoming and Nebraska, respectively, or individually as a "State" or collectively as "States"), having resolved to conclude a compact with respect to the use of waters of the Niobrara River Basin, and being duly authorized by Act of Congress of the United States of America, approved August 5, 1953 (Public Law 191, 83rd Congress, 1st Session, Chapter 324, 67 Stat. 365) and the Act of May 29, 1958 (Public Law 85-427, 85th Congress, S. 2557, 72 Stat. 147) and the Act of August 30, 1961 (Public Law 87-181, 87th Congress, S. 2245, 75 Stat. 412) and pursuant to the Acts of their respective Legislatures have, through their respective Governors, appointed as their commissioners: for Wyoming, Earl Lloyd, Andrew McMaster, Richard Pfister, John Christian, Eugene P. Willson, H. T. Person, Norman B. Gray, E. J. Van Camp; For Nebraska, Dan S. Jones, Jr., who after negotiations participated in by W. E. Blomgren appointed by the President of the United States of America, have agreed upon the following articles:

ARTICLE I

A. The major purposes of this Compact are to provide for an equitable division or apportionment of the available surface waters supply of the Upper Niobrara River Basin between the states; to provide for obtaining information or groundwater and underground water flow necessary for apportioning the underground flow by supplement to this Compact; to remove all causes, present and future which might lead to controversies; and to promote interstate comity.

B. The physical and other conditions peculiar to the upper Niobrara River Basin constitute the basis for this Compact, and neither of the States hereby concedes that this Compact establishes any general principle or precedent with respect to any other interstate stream.

C. Either State and all others using, claiming or in any other manner asserting any right to the use of the waters of the Niobrara River Basin under the authority of that State, shall be subject to the terms of this Compact.

ARTICLE II

A. The term "Upper Niobrara River" shall mean and include the Niobrara River and its tributaries in Nebraska and Wyoming west of Range 55 West of the 6th P. M.

B. The term "Upper Niobrara River Basin" or the term "Basin" shall mean that area in Wyoming and Nebraska, which is naturally drained by the Niobrara River west of Range 55 West of the 6th P. M.

C. Where the name of a State or the term "State" or "States" is used, they shall be construed to include any person or entity of any nature whatsoever using, claiming, or in any manner asserting any right to the use of the waters of the Niobrara River under the authority of that State.

ARTICLE III

It shall be the duty of the two (2) States to administer this Compact through the official in each State who is now or may hereafter be charged with the duty of administering the public water supplies, and to collect and correlate through such officials the data necessary for the proper administration of the provisions of this Compact. Such officials may, by unanimous action, adopt rules and regulations consistent with the provisions of this Compact.

The States agree that the United States Geological Survey, or whatever federal agency may succeed to the functions and duties of that agency, insofar as this Compact is concerned, may collaborate with the officials of the States charged with the administration of this Compact in the execution of the duty of such officials in the collection, correlation, and publication of information necessary for the proper administration of this Compact.

ARTICLE IV

Each State shall itself or in conjunction with other responsible agencies cause to be established, maintained, and operated such suitable water gaging stations as are found necessary to administer this Compact.

ARTICLE V

A. Wyoming and Nebraska agree that the division of surface waters of the Upper Niobrara River shall be in accordance with the following provisions:

1. There shall be no restrictions on the use of the surface waters of the Upper Niobrara River by Wyoming except as would be imposed under Wyoming law and the following limitations:

(a) No reservoir constructed after August 1, 1957, and used solely for domestic and stock water purposes shall exceed twenty (20) acre-feet in capacity.

(b) Storage reservoirs with priority dates after August 1, 1957, and storing water from the main stem of the Niobrara River east of Range 62 West of the 6th P. M. and from the main stem of Van Tassel Creek south of Section 27, Township 32 North, Range 60 West of the 6th P. M. shall not store in any water year (October 1 of one (1) year to September 30 of the next year) more than a total of 500 acre-feet of water.

(c) Storage in reservoirs with priority dates prior to August 1, 1957, and storing water from the main stem of the Niobrara River East of Range 62 West and from the main stem of Van Tassel Creek south of Section 27, Township 32 North, shall be made only during the period October 1 of one (1) year to June 1 of the next year and at such times during the period June 1 to September 30 that the water is not required to meet the legal requirements by direct flow appropriations in Wyoming and Nebraska west of Range 55 West. Where water is pumped from such storage reservoirs, the quantity of storage water pumped or otherwise diverted for irrigation purposes or other beneficial purposes from any such reservoir in any water year shall be limited to the capacity of such reservoir as shown by the records of the Wyoming State Engineer's Office, unless additional storage water becomes available during the period June 1 to September 30 after meeting the legal diversion requirements by direct flow appropriations in Wyoming and Nebraska west of Range 55 West.

(d) Storage in reservoirs with priority dates after August 1, 1957 and storing water from the main stem of the Niobrara River east of Range 62 West and the main stem of Van Tassel Creek south of Section 27, Township 32 North, shall be made only during the period October 1 of one (1) year to May 1 of the next year and at such times during the period May 1 and September 30 that the water is not required for direct diversion by ditches in Wyoming and in Nebraska west of Range 55 West.

(e) Direct flow rights with priority dates after August 1, 1957, on the main stem of the Niobrara River east of Range 62 West and Van Tassel Creek south of Section 27, Township 32 North, shall be regulated on a priority basis with Nebraska rights west of Range 55 West, provided that any direct flow rights for maximum of 143 acres which may be granted by the Wyoming State Engineer with a priority date not later than July 1, 1961 for lands which had territorial rights under the Van Tassel No. 4 Ditch with a priority date of April 8, 1882, and the Van Tassel No. 5 Ditch with a priority date of April 18, 1882, shall be exempt from the provisions of this subsection (e).

(f) All direct flow diversions from the main stem of the Niobrara River east of Range 62 West and from Van Tassel Creek south of Section 27, Township 32 North shall at all times be limited to their diversion rates as specified by Wyoming law, and provided that Wyoming laws relating to diversion of "surplus water" (W.S. 41-4-317 through 41-4-324) shall apply only when the water flowing in the main channel of the Niobrara River west of Range 55 West is in excess of the legal diversion requirements of Nebraska ditches having priority dates before August 1, 1957.

ARTICLE VI

A. Nebraska and Wyoming recognize that the future use of ground water for irrigation in the Niobrara River basin may be a factor in the depletion of the surface flows of the Niobrara River, and since the data now available are inadequate to make a determination in regard to this matter, any apportionment of the ground water of the Niobrara River Basin should be delayed until such time as adequate data on ground water of the basin are available.

B. To obtain data on ground water, Nebraska and Wyoming, with the cooperation and advice of the United States Geological Survey, Groundwater Branch, shall undertake ground water investigations in the Niobrara River basin in the area of the Wyoming-Nebraska State line. The investigations shall be such as are agreed to by the State Engineer of Wyoming and the Director of Water Resources of Nebraska, and may include such observation wells as the said two officials agree are essential for the investigations. Costs of the investigations may be financed under the cooperative ground water programs between the United States Geological Survey and the States, and the States' share of the costs shall be borne equally by the two States.

C. The ground water investigations shall begin within one year after the effective date of this Compact. Upon collection of not more than twelve months of ground water data Nebraska and Wyoming with the cooperation of the United States Geological Survey shall make, or cause to be made an analysis of such data to determine the desirability or necessity of apportioning the ground water by supplement to this Compact. If, upon completion of the initial analysis, it is determined that apportionment of the ground water is not then desirable or necessary, re-analysis shall be made at not to exceed two-year intervals, using all data collected until such apportionment is made.

D. When the results of the ground water investigations indicate that apportionment of ground water of the Niobrara River Basin is desirable, the two States shall proceed to negotiate a supplement to this Compact apportioning the ground water of the Basin.

E. Any proposed supplement to this Compact apportioning the ground water shall not become effective until ratified by the legislatures of the two States and approved by the Congress of the United States.

ARTICLE VII

The provisions of this Compact shall remain in full force and effect until amended by action of the Legislatures of the signatory States and until such amendment is consented to and approved by the Congress of the United States in the same manner as this Compact is required to be ratified and consented to in order to become effective.

ARTICLE VIII

Nothing in this Compact shall be construed to limit or prevent either State from instituting or maintaining any action or proceeding, legal or equitable, in any court of competent jurisdiction for the protection of any right under this Compact or the enforcement of any of its provisions.

ARTICLE IX

Nothing in this Compact shall be deemed:

A. To impair or affect any rights or powers of the United States, its agencies, or instrumentalities, in and to the use of the waters of the Upper Niobrara River Basin nor its capacity to acquire rights in and to the use of said waters; provided that any beneficial uses of the waters allocated by this Compact hereafter made within a State by the United States, or those acting by or under its authority, shall be taken into account in determining the extent of use within that State.

B. To subject any property of the United States, its agencies, or instrumentalities to taxation by either State or subdivision thereof, nor to create an obligation on the part of the United States, its agencies, or instrumentalities, by reason of the acquisition, construction or operation of any property or works of whatsoever kind, to make any payment to any State or political subdivision thereof, State agency, municipality, or equity whatsoever in reimbursement for the loss of taxes.

C. To subject any property of the United States, its agencies, or instrumentalities, to the laws of any State to an extent other than the extent to which these laws apply without regard to the Compact.

D. To affect the obligations of the United States of America to Indians or Indian tribes, or any right owned or held by or for Indians or Indian tribes, which is subject to the jurisdiction of the United States.

ARTICLE X

Should a court of competent jurisdiction hold any part of this Compact contrary to the Constitution of any State or of the United States, all other severable provisions shall continue in full force and effect.

ARTICLE XI

This Compact shall become effective when ratified by the Legislatures of each of the signatory States and by the Congress of the United States.

IN WITNESS WHEREOF, the commissioners have signed this Compact in triplicate original, one of which shall be filed in the archives of the United States of America and shall be deemed the authoritative original, and one copy of which shall be forwarded to the Governor of each of the signatory States.

Done at the city of Cheyenne, in the state of Wyoming, this 26th day of October, in the year of our Lord, One Thousand Nine Hundred Sixty-Two, 1962.

Commissioners for the State of Nebraska

Dan S. Jones, Jr.

Commissioners for the State of Wyoming

Earl Lloyd
Andrew McMaster
Richard Pfister
John Christian
Eugene P. Wilson
H. T. Person
Norman B. Gray
E. J. Van Camp

I have participated in the negotiation of this Compact and intend to report favorably thereon to the Congress of the United States.

W. E. Blomgren

Representative of the United States of America.

NOTES

Congressional Consent to Negotiation. --- By the Act of August 5, 1953 (67 Stat. 365) the Congress gave its consent to negotiations between the States of Wyoming and Nebraska. The time for negotiation was extended by the Act of May 29, 1958 (72 Stat. 147) and again by the Act of August 30, 1961 (75 Stat. 412)

Congressional Consent to Compact. --- Act of August 4, 1969 (83 Stat. 86) from which the text of the Compact set out above is taken. Sections 2 and 3 of this Act read as follows:

> Section 2: The right to alter, amend or repeal this Act is reserved.
>
> Section 3. Nothing in this Act shall be deemed to impair or affect any rights or powers of the United States, its agencies, instrumentalities, permittees or licensees in, over, and to the use of the waters of the Upper Niobrara River Basin; nor to impair or affect their capacity to acquire rights in and to the use of said waters.

Legislative History of the Compact. --- For legislative history, see House Report No. 91-359 (Committee on Interior and Insular Affairs); Senate Report No 91-265 (Committee on Interior and Insular Affairs); Cong. Rec. vol. 115 (1969); and Public Law 91-52.

Appendix E-1

Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the NERB excluding Wind River structural basin, Wyoming

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Quaternary alluvial aquifers	Dissolved oxygen	25	0.20	0.30	0.80	5.6	9.1
	pH (standard units)	65	6.9	7.1	7.4	7.6	8.7
	Specific conductance (µS/cm)	65	174	1,040	1,640	2,730	6,000
	Hardness (as $CaCO_3$)	65	77.0	331	570	1,160	2,600
	Calcium	65	19.0	70.0	116	273	540
	Magnesium	65	5.2	33.3	63.0	120	370
	Potassium	61	1.0	3.0	6.7	13.0	30.0
	Sodium	65	5.7	35.0	149	306	970
	Sodium adsorption ratio (unitless)	65	0.19	0.75	2.0	5.4	30.0
	Alkalinity (as $CaCO_3$)	65	72.0	308	373	502	720
	Chloride	64	0.08	5.6	9.7	67.5	290
	Fluoride	64	0.10	0.23	0.40	0.60	1.2
	Silica	64	2.5	11.0	13.3	17.0	35.0
	Sulfate	65	7.1	150	450	1,220	2,700
	Total dissolved solids	65	106	649	1,140	2,110	4,880
	Ammonia (as N)	51	--	0.001	0.005	0.05	2.1
	Ammonia plus organic nitrogen (as N)	8	0.08	0.11	0.14	0.16	0.17
	Ammonia plus organic nitrogen, unfiltered (as N)	5	1.1	1.3	1.9	2.3	3.8
	Ammonia, unfiltered (as N)	17	--	0.003	0.01	0.09	1.9
	Dissolved organic carbon	25	0.64	1.7	2.4	3.0	4.6
	Nitrate (as N)	71	0.02	0.06	0.20	1.4	30.0
	Nitrate plus nitrite (as N)	52	0.03	0.08	0.27	2.8	21.0
	Nitrate, unfiltered (as N)	12	0.11	0.11	0.75	2.7	5.5
	Nitrate+nitrite, unfiltered (as N)	5	0.05	0.08	0.11	0.12	0.45
	Nitrite (as N)	51	--	0.001	0.002	0.005	0.16
	Nitrite, unfiltered (as N)	12	--	0.0005	0.002	0.02	0.11
	Organic nitrogen	8	--	--	--	--	<0.17
	Organic nitrogen, unfiltered	20	0.01	0.02	0.07	0.33	2.1
	Orthophosphate (as P)	51	--	0.005	0.01	0.02	0.31
	Phosphorus	8	0.004	0.006	0.008	0.01	0.01
	Phosphorus, unfiltered	9	0.13	0.13	0.26	0.41	2.5
	Total nitrogen	8	--	0.19	0.32	0.56	1.5
	Total nitrogen, unfiltered	5	1.2	1.7	2.0	2.3	3.9
	Total nitrogen, unfiltered, analytically determined	17	0.15	0.20	0.72	2.7	5.1
	Aluminum	30	--	0.40	1.4	4.6	30.0
	Antimony	30	0.04	0.05	0.11	0.25	2.0
	Arsenic	32	0.20	0.27	0.48	0.85	4.1

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Quaternary alluvial aquifers —Continued	Barium	27	8.4	30.0	51.9	89.6	170
	Beryllium	30	<0.06	--	--	--	10.0
	Boron	56	40.0	100	165	290	950
	Cadmium	32	--	--	--	--	<5.0
	Chromium	30	--	0.25	0.57	1.3	20.0
	Cobalt	25	0.12	0.17	0.24	0.33	0.53
	Copper	29	--	0.94	1.8	3.4	27.0
	Iron	30	--	0.15	2.2	31.0	4,300
	Iron, unfiltered	48	10.0	54.8	255	3,050	110,000
	Lead	32	--	0.01	0.06	0.27	4.0
	Lithium	13	8.0	18.1	23.5	120	170
	Manganese	30	0.09	1.3	37.0	190	13,000
	Manganese, unfiltered	22	--	2.4	53.0	780	13,000
	Mercury	5	--	--	--	--	<0.5
	Molybdenum	30	0.32	1.3	8.9	15.0	22.0
	Nickel	30	0.20	0.50	1.0	2.0	14.0
	Selenium	32	--	0.33	0.94	2.7	22.0
	Strontium	25	140	460	577	1,100	8,100
	Vanadium	29	0.40	0.56	0.96	1.7	3.6
	Zinc	30	--	0.16	0.83	4.3	230
	Radon-222, in pCi/L	9	500	680	850	1,190	1,440
	Tritium, unfiltered, in pCi/L	4	37.1	42.9	50.7	62.7	72.6
	Uranium	20	1.4	4.0	8.8	13.5	83.0
Quaternary terrace-deposit aquifers	Dissolved oxygen	2	1.4	--	--	--	6.5
	pH (standard units)	2	7.2	--	--	--	7.4
	Specific conductance (µS/cm)	2	923	--	--	--	1,320
	Hardness (as $CaCO_3$)	2	281	--	--	--	429
	Calcium	2	68.0	--	--	--	77.0
	Magnesium	2	27.0	--	--	--	57.0
	Potassium	2	2.4	--	--	--	6.0
	Sodium	2	36.0	--	--	--	210
	Sodium adsorption ratio (unitless)	2	0.75	--	--	--	5.4
	Alkalinity (as $CaCO_3$)	2	388	--	--	--	424
	Chloride	2	14.0	--	--	--	36.0
	Fluoride	2	0.40	--	--	--	0.50
	Silica	2	15.0	--	--	--	19.0
	Sulfate	2	75.0	--	--	--	290
	Total dissolved solids	2	536	--	--	--	861

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Quaternary terrace-deposit aquifers—Continued	Ammonia (as N)	2	<0.025	--	--	--	1.3
	Ammonia, unfiltered (as N)	1	<0.03	--	--	--	--
	Dissolved organic carbon	2	1.9	--	--	--	1.9
	Nitrate (as N)	2	<0.05	--	--	--	1.8
	Nitrate plus nitrite (as N)	1	<0.05	--	--	--	--
	Nitrate, unfiltered (as N)	1	1.2	--	--	--	--
	Nitrite (as N)	2	--	--	--	--	<0.01
	Nitrite, unfiltered (as N)	1	0.005	--	--	--	--
	Organic nitrogen, unfiltered	1	<1.7	--	--	--	--
	Orthophosphate (as P)	2	<0.01	--	--	--	0.08
	Total nitrogen, unfiltered, analytically determined	2	1.2	--	--	--	1.7
	Aluminum	2	--	--	--	--	<100
	Antimony	2	--	--	--	--	<1.0
	Arsenic	2	--	--	--	--	<4.0
	Barium	2	15.0	--	--	--	150
	Beryllium	2	--	--	--	--	<1.0
	Boron	2	100	--	--	--	110
	Cadmium	2	--	--	--	--	<0.2
	Chromium	2	--	--	--	--	<5.0
	Cobalt	2	--	--	--	--	<2.0
	Copper	2	--	--	--	--	<5.0
	Iron	2	--	--	--	--	<100
	Iron, unfiltered	2	--	--	--	--	<100
	Lead	2	--	--	--	--	<1.0
	Manganese	2	<2.0	--	--	--	11.0
	Manganese, unfiltered	2	<2.0	--	--	--	14.0
	Molybdenum	2	10.0	--	--	--	12.0
	Nickel	2	--	--	--	--	<4.0
	Selenium	2	1.4	--	--	--	2.0
	Strontium	2	690	--	--	--	840
	Vanadium	2	--	--	--	--	<10.0
	Zinc	2	--	--	--	--	<50.0
	Radon-222, in pCi/L	1	1,270	--	--	--	--
	Uranium	1	10.0	--	--	--	--
Quaternary dune sand (eolian) deposits	pH (standard units)	2	8.3	--	--	--	8.4
	Specific conductance (µS/cm)	2	2,030	--	--	--	2,750
	Hardness (as $CaCO_3$)	2	243	--	--	--	634
	Calcium	2	64.0	--	--	--	165

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Quaternary dune sand (eolian) deposits —Continued	Magnesium	2	20.2	--	--	--	54.0
	Potassium	2	6.5	--	--	--	8.5
	Sodium	2	356	--	--	--	410
	Sodium adsorption ratio (unitless)	2	7.1	--	--	--	9.9
	Alkalinity (as $CaCO_3$)	2	225	--	--	--	295
	Chloride	2	99.0	--	--	--	151
	Fluoride	1	0.80	--	--	--	--
	Silica	1	12.0	--	--	--	--
	Sulfate	2	472	--	--	--	1,100
	Total dissolved solids	2	1,340	--	--	--	2,110
	Nitrate plus nitrite (as N)	1	9.4	--	--	--	--
	Boron	1	290	--	--	--	--
	Iron, unfiltered	2	<30.0	--	--	--	30.0
Quaternary landslide deposits	pH (standard units)	1	8.1	--	--	--	--
	Specific conductance (µS/cm)	1	166	--	--	--	--
	Calcium	1	29.0	--	--	--	--
	Magnesium	1	9.0	--	--	--	--
	Potassium	1	2.0	--	--	--	--
	Sodium	1	3.0	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.12	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	94.3	--	--	--	--
	Chloride	1	1.0	--	--	--	--
	Fluoride	1	0.10	--	--	--	--
	Silica	1	21.0	--	--	--	--
	Sulfate	1	17.0	--	--	--	--
	Total dissolved solids	1	124	--	--	--	--
Quaternary glacial deposits	pH (standard units)	1	6.7	--	--	--	--
	Specific conductance (µS/cm)	1	99.0	--	--	--	--
	Hardness (as $CaCO_3$)	1	38.0	--	--	--	--
	Calcium	1	10.0	--	--	--	--
	Magnesium	1	3.2	--	--	--	--
	Potassium	1	1.0	--	--	--	--
	Sodium	1	4.7	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.30	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	48.0	--	--	--	--
	Chloride	1	0.10	--	--	--	--

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Quaternary glacial deposits —Continued	Fluoride	1	0.10	--	--	--	--
	Silica	1	21.0	--	--	--	--
	Sulfate	1	3.3	--	--	--	--
	Total dissolved solids	1	82.0	--	--	--	--
	Nitrate (as N)	1	0.02	--	--	--	--
	Boron	1	10.0	--	--	--	--
	Iron, unfiltered	1	220	--	--	--	--
Tertiary intrusive igneous rocks	pH (standard units)	1	6.6	--	--	--	--
	Specific conductance (µS/cm)	1	105	--	--	--	--
	Hardness (as $CaCO_3$)	1	40.0	--	--	--	--
	Calcium	1	13.0	--	--	--	--
	Magnesium	1	1.8	--	--	--	--
	Potassium	1	1.3	--	--	--	--
	Sodium	1	3.5	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.20	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	38.0	--	--	--	--
	Chloride	1	0.70	--	--	--	--
	Fluoride	1	0.30	--	--	--	--
	Silica	1	18.0	--	--	--	--
	Sulfate	1	8.2	--	--	--	--
	Total dissolved solids	1	80.0	--	--	--	--
	Nitrate (as N)	1	0.54	--	--	--	--
	Boron	1	10.0	--	--	--	--
	Iron, unfiltered	1	30.0	--	--	--	--
	Tritium, unfiltered, in pCi/L	1	41.9	--	--	--	--
Arikaree aquifer	Dissolved oxygen	27	0.80	5.3	7.2	8.3	11.9
	pH (standard units)	52	7.0	7.5	7.6	7.9	8.6
	Specific conductance (µS/cm)	56	199	366	402	539	1,530
	Hardness (as $CaCO_3$)	42	106	160	180	240	544
	Calcium	57	31.0	49.0	56.0	68.0	192
	Magnesium	57	5.4	10.0	13.0	18.0	50.0
	Potassium	57	2.6	6.2	7.5	9.0	29.0
	Sodium	57	5.4	9.0	12.0	19.0	83.0
	Sodium adsorption ratio (unitless)	57	0.19	0.30	0.36	0.60	1.6
	Alkalinity (as $CaCO_3$)	57	110	170	187	223	449
	Chloride	57	1.0	3.5	7.0	14.0	141
	Fluoride	45	0.10	0.20	0.30	0.40	0.60

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Arikaree aquifer —Continued	Silica	53	23.0	53.9	56.0	58.0	74.0
	Sulfate	57	1.1	8.1	15.0	27.0	293
	Total dissolved solids	56	198	263	285	373	1,150
	Ammonia (as N)	25	--	--	--	--	<0.25
	Dissolved organic carbon	22	0.43	0.82	0.99	2.3	16.3
	Nitrate (as N)	31	0.16	2.0	2.8	5.6	23.0
	Nitrate plus nitrite (as N)	17	0.16	1.9	2.7	3.4	25.0
	Nitrite (as N)	27	--	0.001	0.002	0.003	0.01
	Organic nitrogen	1	<0.08	--	--	--	--
	Organic nitrogen, unfiltered	21	--	--	--	--	<19
	Orthophosphate (as P)	23	0.06	0.10	0.13	0.15	124
	Phosphorus, unfiltered	5	<0.03	--	--	--	0.07
	Total nitrogen, unfiltered, analytically determined	21	0.81	2.1	2.8	5.2	40.0
	Aluminum	22	--	--	--	--	<100
	Antimony	24	--	--	--	--	<1.0
	Arsenic	24	--	2.3	3.2	4.5	10.0
	Barium	24	81.0	101	130	156	250
	Beryllium	24	--	--	--	--	<1.0
	Boron	32	10.0	26.8	41.0	62.6	180
	Cadmium	24	--	--	--	--	<0.5
	Chromium	24	--	--	--	--	<50.0
	Cobalt	22	--	--	--	--	<2.0
	Copper	24	--	--	--	--	<10.0
	Iron	25	--	--	--	--	<100
	Iron, unfiltered	32	--	5.9	23.6	94.1	4,860
	Lead	24	<1.0	--	--	--	2.0
	Lithium	1	16.9	--	--	--	--
	Manganese	23	<0.4	--	--	--	50.0
	Manganese, unfiltered	26	--	0.01	0.11	0.93	107
	Mercury	1	<0.2	--	--	--	--
	Molybdenum	22	1.8	5.3	7.4	8.9	16.0
	Nickel	24	--	--	--	--	<20.0
	Selenium	24	0.70	0.87	1.4	2.3	11.0
	Strontium	22	200	270	290	640	1,900
	Vanadium	22	--	6.2	7.7	9.7	15.4
	Zinc	23	--	--	--	--	<50.0
	Gross alpha radioactivity, in pCi/L	11	9.4	14.1	21.0	26.0	31.6
	Gross beta radioactivity, in pCi/L	5	5.3	12.9	15.4	16.0	16.6

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Arikaree aquifer —Continued	Radium-226, in pCi/L	11	--	--	--	--	<1.0
	Radium-228, in pCi/L	11	0.08	0.13	0.23	0.38	0.70
	Radon-222, in pCi/L	4	430	501	703	895	955
	Uranium	5	11.0	13.0	23.2	36.9	41.7
White River hydrogeologic unit	pH (standard units)	5	7.4	7.7	7.7	8.0	8.0
	Specific conductance (µS/cm)	5	536	553	670	720	746
	Hardness (as $CaCO_3$)	5	8.0	17.0	22.0	80.0	190
	Calcium	5	3.2	6.5	8.5	26.0	73.0
	Magnesium	4	0.20	0.20	1.6	3.3	3.6
	Potassium	5	3.4	9.6	10.0	11.0	26.0
	Sodium	5	62.0	121	124	131	167
	Sodium adsorption ratio (unitless)	5	1.9	6.0	11.0	18.0	20.0
	Alkalinity (as $CaCO_3$)	5	220	252	261	295	317
	Chloride	5	9.8	11.0	12.0	33.0	57.0
	Fluoride	5	0.40	0.60	1.2	1.9	5.0
	Silica	5	9.2	31.0	49.0	54.0	60.0
	Sulfate	5	2.0	25.0	25.0	40.0	44.0
	Total dissolved solids	5	320	387	428	479	495
	Nitrate (as N)	5	0.02	0.09	0.88	2.3	5.0
	Boron	5	60.0	80.0	120	280	370
	Iron, unfiltered	5	10.0	60.0	110	3,300	5,700
Wasatch aquifer (lower Tertiary aquifer system in Powder River structural basin)	Dissolved oxygen	19	0.01	0.10	0.40	1.0	1.5
	pH (standard units)	215	5.6	7.3	7.6	8.1	9.6
	Specific conductance (µS/cm)	214	248	990	1,635	2,210	7,660
	Hardness (as $CaCO_3$)	216	4.0	130	350	715	4,800
	Calcium	221	1.1	34.0	96.0	190	830
	Magnesium	220	0.33	9.7	26.0	55.0	919
	Potassium	219	0.90	2.9	6.8	11.0	120
	Sodium	221	2.3	110	220	330	1,140
	Sodium adsorption ratio (unitless)	221	0.09	2.3	6.6	9.9	99.4
	Alkalinity (as $CaCO_3$)	221	14.0	180	300	599	1,750
	Chloride	220	0.30	5.2	9.7	16.0	550
	Fluoride	203	0.10	0.20	0.30	0.70	7.6
	Silica	209	1.0	8.6	11.0	17.3	43.0

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Wasatch aquifer (lower Tertiary aquifer system in Powder River structural basin)—Continued	Sulfate	220	0.50	110	420	883	5,940
	Total dissolved solids	220	160	624	1,125	1,700	8,620
	Ammonia (as N)	85	0.04	0.54	1.0	2.6	130
	Ammonia plus organic nitrogen (as N)	14	0.11	0.71	1.3	7.4	30.0
	Ammonia plus organic nitrogen, unfiltered (as N)	6	0.13	0.23	0.42	0.73	1.1
	Ammonia, unfiltered (as N)	20	0.02	0.20	1.1	1.8	9.1
	Dissolved organic carbon	80	0.80	2.2	7.5	33.0	280
	Nitrate (as N)	107	0.01	0.02	0.08	0.38	19.4
	Nitrate plus nitrite (as N)	81	0.01	0.01	0.04	0.12	28.0
	Nitrate, unfiltered (as N)	14	--	--	--	--	<0.005
	Nitrate+nitrite, unfiltered (as N)	6	--	0.04	0.07	0.10	0.30
	Nitrite (as N)	37	--	0.005	0.01	0.02	0.11
	Nitrite, unfiltered (as N)	15	--	--	--	--	<0.01
	Organic nitrogen	12	0.09	0.16	0.48	1.1	4.0
	Organic nitrogen, unfiltered	21	--	0.006	0.02	0.07	1.1
	Orthophosphate (as P)	21	0.01	0.02	0.02	0.03	0.06
	Phosphorus	16	0.003	0.01	0.03	0.04	6.0
	Phosphorus, unfiltered	6	0.01	0.02	0.04	0.51	1.8
	Total nitrogen	14	0.38	0.53	1.6	7.5	30.0
	Total nitrogen, unfiltered	6	0.18	0.23	0.45	0.73	1.4
	Total nitrogen, unfiltered, analytically determined	18	0.25	0.68	1.5	2.0	9.1
	Aluminum	55	10.0	10.3	20.7	41.8	2,000
	Antimony	31	--	0.29	0.40	0.53	1.0
	Arsenic	85	--	0.56	1.2	2.4	36.0
	Barium	63	6.7	25.8	64.7	200	1,400
	Beryllium	40	<1.0	--	--	--	20.0
	Boron	181	10.0	38.5	84.1	184	4,400
	Cadmium	51	--	0.005	0.03	0.18	9.0
	Chromium	47	--	2.6	4.8	8.8	20.0
	Cobalt	20	--	--	--	--	<100
	Copper	37	0.30	0.58	1.2	2.7	28.0
	Iron	112	1.0	101	555	2,050	110,000
	Iron, unfiltered	139	10.0	90.0	380	2,200	46,000
	Lead	47	--	0.10	0.43	1.9	22.0
	Lithium	48	10.6	80.0	100	135	700

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Wasatch aquifer (lower Tertiary aquifer system in Powder River structural basin)—Continued	Manganese	79	4.0	30.0	120	320	4,800
	Manganese, unfiltered	24	5.8	19.7	60.4	139	4,700
	Mercury	31	--	0.03	0.06	0.11	0.40
	Molybdenum	32	--	1.6	3.4	7.2	44.0
	Nickel	42	0.44	0.56	1.9	6.5	300
	Selenium	54	--	0.04	0.23	1.4	330
	Strontium	26	8.1	143	805	3,450	13,000
	Vanadium	21	0.30	0.48	1.1	2.7	15.0
	Zinc	69	--	2.7	10.3	38.6	17,000
	Gross alpha radioactivity, in pCi/L	14	1.1	1.8	5.4	15.4	55.0
	Gross beta radioactivity, in pCi/L	21	2.1	3.1	5.3	9.0	29.0
	Radium-226, in pCi/L	15	0.10	0.26	0.50	0.94	9.9
	Radium-228, in pCi/L	2	<1.0	--	--	--	2.0
	Radon-222, in pCi/L	6	490	540	570	730	1,390
	Tritium, unfiltered, in pCi/L	8	--	1.0	1.6	7.6	179
	Uranium	39	--	0.03	0.30	7.2	84.0
Wasatch Formation coal aquifers (lower Tertiary aquifer system in Powder River structural basin)	pH (standard units)	6	7.9	8.0	8.0	8.1	8.2
	Specific conductance (µS/cm)	2	1,480	1,480	1,600	1,720	1,720
	Calcium	8	15.0	20.7	34.0	131	448
	Magnesium	8	3.2	4.8	7.4	45.0	292
	Potassium	6	3.1	4.2	4.9	6.0	8.0
	Sodium	8	142	225	312	396	560
	Sodium adsorption ratio (unitless)	8	2.3	5.5	12.8	16.9	21.9
	Alkalinity (as $CaCO_3$)	2	550	550	560	570	570
	Bicarbonate	6	317	378	678	1,060	1,250
	Fluoride	2	0.40	--	--	--	1.0
	Chloride	8	2.0	5.4	9.0	12.8	44.0
	Silica	2	8.2	8.2	9.6	11.0	11.0
	Sulfate	6	5.4	20.7	339	720	3,040
	Total dissolved solids	8	805	881	1,095	1,237	4,582
	Boron	1	70.0	--	--	--	--
	Barium	1	500	--	--	--	--
	Iron	3	300	--	400	--	10,300
	Zinc	1	30.0	--	--	--	--
	Radium-226, in pCi/L	1	2.2	--	--	--	--

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Fort Union aquifer (lower Tertiary aquifer system in the Powder River structural basin)	Dissolved oxygen	18	0.02	0.10	0.25	5.2	11.8
	pH (standard units)	233	6.4	7.4	7.9	8.3	8.9
	Specific conductance (µS/cm)	196	217	768	1,380	1,995	6,000
	Hardness (as $CaCO_3$)	227	6.0	32.0	140	480	2,740
	Calcium	238	1.8	8.9	31.0	100	600
	Magnesium	238	0.10	2.8	11.5	47.0	346
	Potassium	222	0.20	3.6	6.4	11.0	150
	Sodium	238	2.7	140	274	385	890
	Sodium adsorption ratio (unitless)	238	0.10	5.2	8.5	20.9	57.0
	Alkalinity (as $CaCO_3$)	237	77.0	283	445	670	1,943
	Chloride	238	1.0	5.8	8.1	15.8	140
	Fluoride	191	0.10	0.50	0.87	1.6	8.1
	Silica	216	1.2	8.0	9.3	13.0	86.6
	Sulfate	236	0.20	8.6	142	690	3,560
	Total dissolved solids	236	113	537	1,015	1,550	5,480
	Ammonia (as N)	17	0.01	0.67	1.3	2.5	43.0
	Ammonia plus organic nitrogen (as N)	10	0.37	0.97	1.6	2.6	37.0
	Ammonia plus organic nitrogen, unfiltered (as N)	32	0.05	0.28	0.91	3.2	130
	Ammonia, unfiltered (as N)	40	0.01	0.49	1.0	1.7	4.6
	Dissolved organic carbon	13	1.0	1.5	2.0	2.3	128
	Nitrate (as N)	86	--	0.009	0.04	0.27	2.3
	Nitrate plus nitrite (as N)	55	--	0.01	0.04	0.13	13.0
	Nitrate, unfiltered (as N)	7	<0.005	--	--	--	0.12
	Nitrate+nitrite, unfiltered (as N)	34	0.01	0.02	0.07	0.52	13.0
	Nitrite (as N)	20	--	0.001	0.003	0.007	0.03
	Nitrite, unfiltered (as N)	7	<0.005	--	--	--	0.03
	Organic nitrogen	5	0.39	0.40	0.43	3.0	6.0
	Organic nitrogen, unfiltered	37	0.02	0.05	0.23	0.84	130
	Orthophosphate (as P)	14	0.01	0.01	0.03	0.04	0.08
	Phosphorus	4	--	0.009	0.01	0.02	0.03
	Phosphorus, unfiltered	35	0.01	0.01	0.04	0.10	6.3
	Total nitrogen	10	0.39	0.79	2.1	2.7	37.0
	Total nitrogen, unfiltered	32	0.05	0.71	1.3	4.1	130
	Total nitrogen, unfiltered, analytically determined	12	0.59	1.0	1.5	2.0	2.8

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Fort Union aquifer (lower Tertiary aquifer system in the Powder River structural basin)—Continued	Aluminum	50	10.0	15.5	28.1	51.1	280
	Antimony	55	--	0.26	0.44	0.72	2.0
	Arsenic	80	--	0.16	0.48	1.5	150
	Barium	43	6.1	30.3	100	200	550
	Beryllium	63	--	0.005	0.05	0.56	20.0
	Boron	153	10.0	46.4	92.7	140	5,400
	Cadmium	76	--	0.01	0.06	0.32	20.0
	Chromium	57	--	--	--	--	<50.0
	Cobalt	13	--	--	--	--	<100
	Copper	62	--	0.53	1.6	4.7	230
	Iron	120	0.02	58.5	170	645	120,000
	Iron, unfiltered	140	1.0	105	308	855	900,000
	Lead	86	--	0.31	1.1	3.6	100
	Lithium	35	20.0	20.0	60.0	130	900
	Manganese	72	2.0	14.4	30.0	69.0	1,400
	Manganese, unfiltered	44	4.6	30.0	68.7	475	15,000
	Mercury	64	--	--	--	--	<1.0
	Molybdenum	65	--	0.46	1.2	3.2	26.0
	Nickel	52	2.0	2.1	2.9	4.2	12.0
	Selenium	80	--	0.06	0.20	0.66	20.0
	Strontium	19	18.0	180	498	2,500	9,100
	Vanadium	27	0.10	0.33	0.88	2.3	64.0
	Zinc	56	2.0	3.3	11.4	39.2	1,800
	Gross alpha radioactivity, in pCi/L	21	--	0.98	1.5	2.3	5.2
	Gross beta radioactivity, in pCi/L	19	--	2.2	4.8	11.0	24.0
	Radium-226, in pCi/L	14	0.12	0.30	0.57	0.60	4.8
	Radium-228, in pCi/L	8	--	1.0	1.5	5.5	6.7
	Radon-222, in pCi/L	2	180	--	--	--	340
	Tritium, unfiltered, in pCi/L	2	<1.0	--	--	--	76.2
	Uranium	29	0.02	0.03	0.13	0.53	19.0

Appendix E-1. Summary statistics for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituents	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Fort Union Formation coal aquifers (lower Tertiary aquifer system in the Powder River structural basin)	pH (standard units)	217	6.8	7.3	7.7	8.0	9.2
	Specific conductance (µS/cm)	62	470	990	1,205	1,700	4,180
	Calcium	447	1.7	16.0	26.0	38.0	160
	Magnesium	448	0.02	7.2	12.1	19.0	67.0
	Potassium	222	2.2	7.0	10.0	15.3	50.4
	Sodium	449	12.0	201	314	528	1,500
	Sodium adsorption ratio (unitless)	449	0.24	6.9	10.8	22.2	133
	Alkalinity (as $CaCO_3$)	318	67.5	514	819	1,240	3,419
	Bicarbonate	136	329	928	1,300	1,630	4,270
	Carbonate	26	1.0	1.0	9.9	16.8	349
	Chloride	438	2.0	8.9	11.8	18.0	583
	Fluoride	132	0.10	0.80	1.1	1.5	4.6
	Silica	83	0.20	4.2	4.8	6.5	22.0
	Sulfate	245	0.01	0.50	2.0	5.0	986
	Total dissolved solids	442	96.9	734	1,090	1,569	4,589
	Arsenic	51	--	0.06	0.27	0.63	510
	Boron	44	--	56.5	75.1	100	300
	Barium	121	10.0	330	550	800	600,000
	Cobalt	41	--	0.07	0.09	0.10	0.24
	Chromium	51	--	0.002	0.03	0.64	2,000
	Copper	45	1.0	2.8	3.8	6.1	28.6
	Iron	154	9.5	150	420	810	120,000
	Lithium	52	18.0	35.5	49.5	68.5	208
	Manganese	45	5.3	14.0	30.0	47.0	130
	Nickel	45	0.77	2.6	4.6	8.1	35.4
	Strontium	116	25.5	187	436	743	1,900
	Zinc	58	--	0.98	3.1	10.0	554
	Radium-226, in pCi/L	33	0.30	0.40	0.68	1.5	2.7

Appendix E-2

Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the NERB excluding Wind River structural basin, Wyoming

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Lance aquifer (Upper Cretaceous aquifer system in Powder River structural basin)	Dissolved oxygen	8	0.10	0.10	0.55	0.90	4.5
	pH (standard units)	46	7.0	7.6	8.0	8.4	8.9
	Specific conductance (µS/cm)	48	412	1,020	1,435	2,065	3,940
	Hardness (as $CaCO_3$)	47	5.0	20.0	71.5	360	1,700
	Calcium	48	1.0	5.7	13.0	88.0	481
	Magnesium	48	0.20	1.6	7.1	30.5	134
	Potassium	47	0.80	2.0	3.1	4.8	12.0
	Sodium	48	8.5	190	291	431	922
	Sodium adsorption ratio (unitless)	48	0.26	3.4	16.0	35.5	94.0
	Alkalinity (as $CaCO_3$)	48	131	355	448	522	1,123
	Chloride	48	1.6	4.4	8.6	19.0	110
	Fluoride	47	0.01	0.20	0.50	1.4	9.4
	Silica	46	2.1	8.2	10.0	13.0	29.0
	Sulfate	48	0.30	140	273	582	1,780
	Total dissolved solids	47	244	662	946	1,370	3,060
	Ammonia (as N)	7	--	0.04	0.38	0.56	0.95
	Ammonia, unfiltered (as N)	1	<0.03	--	--	--	--
	Dissolved organic carbon	8	0.72	1.1	1.6	2.7	3.3
	Nitrate (as N)	23	--	0.008	0.04	0.14	3.6
	Nitrate plus nitrite (as N)	11	0.01	0.05	0.14	1.2	2.9
	Nitrate, unfiltered (as N)	1	0.71	--	--	--	--
	Nitrite (as N)	7	<0.005	--	--	--	0.006
	Nitrite, unfiltered (as N)	1	0.006	--	--	--	--
	Organic nitrogen, unfiltered	7	--	--	--	--	<0.39
	Orthophosphate (as P)	7	0.03	0.05	0.05	0.06	0.06
	Phosphorus	1	0.03	--	--	--	--
	Phosphorus, unfiltered	1	<0.03	--	--	--	--
	Total nitrogen, unfiltered, analytically determined	8	0.15	0.52	0.74	1.1	2.8
	Aluminum	10	--	--	--	--	<100
	Antimony	8	--	--	--	--	<1.0
	Arsenic	12	--	0.42	0.85	1.7	7.5
	Barium	10	10.0	14.7	22.2	33.3	68.0
	Beryllium	10	--	--	--	--	<10.0
	Boron	44	40.0	120	160	220	3,700
	Cadmium	11	--	--	--	--	<10.0
	Chromium	11	--	--	--	--	<50.0
	Cobalt	8	--	--	--	--	<2.0
	Copper	10	--	--	--	--	<10.0
	Iron	14	0.007	0.43	5.5	120	1,400

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Lance aquifer (Upper Cretaceous aquifer system in Powder River structural basin)—Continued	Iron, unfiltered	38	10.0	47.5	110	330	8,600
	Lead	11	--	--	--	--	<50.0
	Lithium	1	7.0	--	--	--	--
	Manganese	11	5.4	5.7	12.0	50.0	270
	Manganese, unfiltered	9	4.3	11.6	23.0	120	290
	Mercury	4	<1.0	--	--	--	1.5
	Molybdenum	9	5.4	5.7	7.2	9.0	13.0
	Nickel	10	--	--	--	--	<100
	Selenium	10	--	0.68	1.4	2.9	8.2
	Strontium	8	98.0	130	630	2,900	4,800
	Vanadium	9	<10.0	--	--	--	10.0
	Zinc	11	10.0	14.4	22.5	35.1	60.0
	Gross alpha radioactivity, in pCi/L	1	9.5	--	--	--	--
	Gross beta radioactivity, in pCi/L	1	<7.1	--	--	--	--
	Radium-226, in pCi/L	1	0.15	--	--	--	--
	Uranium	6	--	0.12	0.84	44.0	47.0
Fox Hills aquifer (Upper Cretaceous aquifer system in Powder River structural basin)	Dissolved oxygen	1	0.01	--	--	--	--
	pH (standard units)	21	7.2	7.7	8.2	8.5	9.3
	Specific conductance (µS/cm)	21	875	1,450	1,730	2,780	4,690
	Hardness (as $CaCO_3$)	18	5.0	12.0	51.0	164	320
	Calcium	21	1.8	5.0	20.0	46.0	69.0
	Magnesium	21	0.10	1.1	6.4	16.0	37.0
	Potassium	21	0.11	1.3	3.3	4.2	10.0
	Sodium	21	82.0	315	391	625	1,100
	Sodium adsorption ratio (unitless)	21	0.10	8.2	24.0	39.0	66.0
	Alkalinity (as $CaCO_3$)	21	251	311	401	520	816
	Chloride	21	2.1	11.0	13.0	29.0	89.0
	Fluoride	21	0.10	0.28	0.40	0.80	7.0
	Silica	18	3.2	8.6	10.5	12.0	15.0
	Sulfate	21	3.3	210	460	840	2,400
	Total dissolved solids	21	28.0	904	1,170	2,000	3,520
	Ammonia (as N)	1	0.83	--	--	--	--
	Dissolved organic carbon	1	1.2	--	--	--	--
	Nitrate (as N)	7	--	0.01	0.04	0.11	0.98
	Nitrate plus nitrite (as N)	5	0.20	0.33	0.90	1.3	3.4
	Nitrite (as N)	2	0.02	--	--	--	0.03
	Orthophosphate (as P)	1	0.04	--	--	--	--
	Phosphorus, unfiltered	2	<0.03	--	--	--	0.05

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Fox Hills aquifer (Upper Cretaceous aquifer system in Powder River structural basin)—Continued	Total nitrogen, unfiltered, analytically determined	1	1.8	--	--	--	--
	Aluminum	1	<100	--	--	--	--
	Antimony	2	--	--	--	--	<1.0
	Arsenic	5	--	--	--	--	<10.0
	Barium	5	--	--	--	--	<100
	Beryllium	2	--	--	--	--	<1.0
	Boron	16	0.03	115	315	480	1,300
	Cadmium	5	--	--	--	--	<10.0
	Chromium	5	--	--	--	--	<50.0
	Cobalt	1	<2.0	--	--	--	--
	Copper	2	--	--	--	--	<5.0
	Iron	3	<100	--	--	--	940
	Iron, unfiltered	12	30.0	65.5	162	291	4,900
	Lead	5	--	--	--	--	<50.0
	Manganese	2	30.0	--	--	--	41.0
	Manganese, unfiltered	1	44.0	--	--	--	--
	Mercury	4	--	--	--	--	<1.0
	Molybdenum	1	<5.0	--	--	--	--
	Nickel	2	--	--	--	--	<20.0
	Selenium	7	--	1.1	2.6	6.4	20.0
	Strontium	1	1,500	--	--	--	--
	Vanadium	1	20.0	--	--	--	--
	Zinc	2	--	--	--	--	<50.0
	Gross alpha radioactivity, in pCi/L	1	3.4	--	--	--	--
	Gross beta radioactivity, in pCi/L	1	4.1	--	--	--	--
	Radium-226, in pCi/L	1	<0.2	--	--	--	--
	Radium-228, in pCi/L	1	2.7	--	--	--	--
	Uranium	5	--	0.45	3.0	20.0	21.0
Lewis confining unit	pH (standard units)	1	7.9	--	--	--	--
	Specific conductance (µS/cm)	1	1,110	--	--	--	--
	Hardness (as $CaCO_3$)	1	52.0	--	--	--	--
	Calcium	1	16.0	--	--	--	--
	Magnesium	1	2.9	--	--	--	--
	Potassium	1	0.10	--	--	--	--
	Sodium	1	236	--	--	--	--
	Sodium adsorption ratio (unitless)	1	14.3	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	276	--	--	--	--

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Lewis confining unit —Continued	Chloride	1	30.0	--	--	--	--
	Fluoride	1	0.20	--	--	--	--
	Silica	1	38.0	--	--	--	--
	Sulfate	1	233	--	--	--	--
	Total dissolved solids	1	739	--	--	--	--
	Boron	1	60.0	--	--	--	--
	Iron, unfiltered	1	440	--	--	--	--
Pierre confining unit	pH (standard units)	4	7.4	7.5	7.8	8.2	8.4
	Specific conductance (µS/cm)	4	490	678	908	1,575	2,200
	Hardness (as $CaCO_3$)	4	16.0	88.0	190	290	360
	Calcium	4	3.9	19.5	48.0	71.0	81.0
	Magnesium	4	1.5	9.8	18.0	28.0	38.0
	Potassium	4	2.6	3.2	5.6	9.2	11.0
	Sodium	4	41.0	46.5	87.5	342	560
	Sodium adsorption ratio (unitless)	4	1.2	1.3	2.5	32.3	61.0
	Alkalinity (as $CaCO_3$)	4	188	235	286	532	773
	Chloride	4	1.7	1.8	3.9	10.5	15.0
	Fluoride	4	0.20	0.30	0.45	0.60	0.70
	Silica	4	6.9	11.0	15.5	22.5	29.0
	Sulfate	4	65.0	124	193	332	460
	Total dissolved solids	4	276	407	591	1,077	1,510
	Nitrate (as N)	2	0.09	--	--	--	0.16
	Nitrate plus nitrite (as N)	1	0.51	--	--	--	--
	Boron	3	20.0	--	30.0	--	140
	Iron, unfiltered	4	10.0	25.0	95.0	250	350
Mesaverde aquifer	pH (standard units)	7	6.7	7.5	7.8	8.3	8.9
	Specific conductance (µS/cm)	7	625	823	1,950	3,120	5,000
	Hardness (as $CaCO_3$)	7	10.0	44.0	210	410	550
	Calcium	7	0.20	15.0	62.0	97.0	146
	Magnesium	7	1.2	2.3	14.0	46.0	48.0
	Potassium	7	0.80	2.0	2.3	7.4	9.2
	Sodium	7	29.0	141	366	712	1,100
	Sodium adsorption ratio (unitless)	7	0.63	6.7	19.0	22.8	48.0
	Alkalinity (as $CaCO_3$)	7	33.0	180	270	349	543
	Chloride	7	1.6	3.7	12.0	36.0	73.0
	Fluoride	7	0.20	0.30	0.30	0.90	2.5
	Silica	7	1.8	7.1	10.0	13.0	22.0

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Mesaverde aquifer —Continued	Sulfate	7	89.0	186	995	1,430	2,040
	Total dissolved solids	7	370	550	1,490	2,340	4,430
	Nitrate (as N)	4	0.02	0.02	0.29	0.77	0.97
	Nitrate plus nitrite (as N)	2	0.10	--	--	--	153
	Boron	7	80.0	80.0	150	420	480
	Iron, unfiltered	7	110	220	1,300	12,000	20,000
Cody confining unit	pH (standard units)	1	8.0	--	--	--	--
	Specific conductance (µS/cm)	2	1,130	--	--	--	13,000
	Hardness (as $CaCO_3$)	2	600	--	--	--	3,100
	Calcium	2	77.0	--	--	--	298
	Magnesium	2	99.0	--	--	--	573
	Potassium	1	17.0	--	--	--	--
	Sodium	2	30.0	--	--	--	2,350
	Sodium adsorption ratio (unitless)	2	0.53	--	--	--	18.4
	Alkalinity (as $CaCO_3$)	2	167	--	--	--	410
	Chloride	2	8.0	--	--	--	227
	Sulfate	2	465	--	--	--	7,830
	Total dissolved solids	2	780	--	--	--	12,600
	Nitrate (as N)	2	0.23	--	--	--	0.36
	Boron	1	2,000	--	--	--	--
Frontier aquifer	pH (standard units)	11	7.1	7.8	8.7	8.9	8.9
	Specific conductance (µS/cm)	13	556	1,180	1,550	2,350	3,230
	Hardness (as $CaCO_3$)	12	3.0	10.0	205	430	730
	Calcium	13	0.10	1.4	47.0	110	177
	Magnesium	12	0.10	1.2	19.0	32.0	70.0
	Potassium	9	0.60	1.2	1.7	4.7	6.2
	Sodium	14	12.0	120	326	550	766
	Sodium adsorption ratio (unitless)	13	0.07	2.4	4.0	63.7	100
	Alkalinity (as $CaCO_3$)	14	143	230	322	570	1,170
	Chloride	14	1.7	4.6	9.1	21.0	190
	Fluoride	11	0.30	0.70	0.90	1.5	5.5
	Silica	9	7.4	9.8	11.0	15.0	29.0
	Sulfate	14	4.3	104	328	528	1,280
	Total dissolved solids	12	348	887	1,120	1,725	2,270
	Nitrate (as N)	4	--	0.02	0.03	0.07	0.09
	Nitrate plus nitrite (as N)	6	--	0.10	0.40	1.2	3.3
	Phosphorus, unfiltered	1	<0.03	--	--	--	--

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Frontier aquifer —Continued	Boron	7	270	370	580	1,500	1,800
	Iron, unfiltered	9	20.0	57.0	210	380	2,900
Mowry confining unit	pH (standard units)	1	7.3	--	--	--	--
	Specific conductance (µS/cm)	1	1,140	--	--	--	--
	Hardness (as $CaCO_3$)	1	130	--	--	--	--
	Calcium	1	36.0	--	--	--	--
	Magnesium	1	9.7	--	--	--	--
	Potassium	1	1.7	--	--	--	--
	Sodium	1	196	--	--	--	--
	Sodium adsorption ratio (unitless)	1	7.5	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	116	--	--	--	--
	Chloride	1	1.9	--	--	--	--
	Fluoride	1	1.3	--	--	--	--
	Silica	1	22.0	--	--	--	--
	Sulfate	1	424	--	--	--	--
	Total dissolved solids	1	765	--	--	--	--
	Ammonia (as N)	2	0.23	--	--	--	0.83
	Nitrate (as N)	2	0.04	--	--	--	0.07
	Nitrate plus nitrite (as N)	3	0.04	--	0.07	--	0.50
	Nitrite (as N)	2	--	--	--	--	<0.008
	Orthophosphate (as P)	2	<0.02	--	--	--	0.12
	Boron	1	370	--	--	--	--
	Iron, unfiltered	1	620	--	--	--	--
Muddy aquifer	pH (standard units)	1	8.5	--	--	--	--
	Specific conductance (µS/cm)	1	3,640	--	--	--	--
	Hardness (as $CaCO_3$)	1	16.0	--	--	--	--
	Calcium	1	0.40	--	--	--	--
	Magnesium	1	3.5	--	--	--	--
	Potassium	1	9.5	--	--	--	--
	Sodium	1	1,000	--	--	--	--
	Sodium adsorption ratio (unitless)	1	110	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	1,607	--	--	--	--
	Chloride	1	270	--	--	--	--
	Fluoride	1	4.3	--	--	--	--
	Silica	1	12.0	--	--	--	--
	Total dissolved solids	1	2,380	--	--	--	--
	Boron	1	1,200	--	--	--	--

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Newcastle aquifer	pH (standard units)	1	7.7	--	--	--	--
	Hardness (as $CaCO_3$)	1	214	--	--	--	--
	Calcium	1	51.0	--	--	--	--
	Magnesium	1	21.0	--	--	--	--
	Sodium	1	3,410	--	--	--	--
	Sodium adsorption ratio (unitless)	1	102	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	1,451	--	--	--	--
	Chloride	1	4,380	--	--	--	--
	Sulfate	1	5.0	--	--	--	--
	Total dissolved solids	1	8,740	--	--	--	--
	Boron	1	5,100	--	--	--	--
Skull Creek confining unit	Ammonia (as N)	1	5.6	--	--	--	--
	Nitrate (as N)	1	<0.06	--	--	--	--
	Nitrate plus nitrite (as N)	1	<0.06	--	--	--	--
	Nitrite (as N)	1	<0.008	--	--	--	--
	Orthophosphate (as P)	1	<0.02	--	--	--	--
Cloverly aquifer	pH (standard units)	5	8.0	8.2	8.2	8.5	9.1
	Specific conductance (µS/cm)	5	1,620	1,910	2,490	4,510	4,850
	Hardness (as $CaCO_3$)	5	6.5	12.0	21.0	30.0	40.0
	Calcium	5	1.0	1.7	3.4	5.6	12.0
	Magnesium	5	1.0	1.9	2.2	3.0	4.0
	Potassium	5	1.0	2.0	3.9	5.4	12.0
	Sodium	5	340	435	615	1,180	1,260
	Sodium adsorption ratio (unitless)	5	24.0	73.6	77.0	93.1	120
	Alkalinity (as $CaCO_3$)	5	210	536	700	1,041	2,008
	Chloride	5	21.0	117	203	278	1,080
	Fluoride	4	0.60	1.4	2.5	3.0	3.2
	Silica	4	12.0	12.0	12.0	12.0	12.0
	Sulfate	4	1.0	171	451	563	565
	Total dissolved solids	5	1,080	1,120	1,670	2,790	2,970
	Nitrate (as N)	4	--	--	--	--	<0.09
	Nitrate plus nitrite (as N)	1	<0.1	--	--	--	--
	Boron	4	60.0	420	2,190	3,700	3,800
	Iron, unfiltered	4	20.0	21.8	28.3	70.0	110

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; CaCO$_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Inyan Kara aquifer	Dissolved oxygen	1	0.17	--	--	--	--
	pH (standard units)	50	4.2	7.5	7.7	8.2	9.0
	Specific conductance (µS/cm)	49	309	696	1,350	1,780	4,000
	Hardness (as CaCO$_3$)	41	3.0	57.0	200	480	2,100
	Calcium	52	0.04	7.8	40.5	84.0	603
	Magnesium	49	0.02	2.8	16.0	32.0	240
	Potassium	49	0.04	2.4	6.0	11.0	36.0
	Sodium	59	2.6	61.0	232	365	810
	Sodium adsorption ratio (unitless)	49	0.10	1.2	2.3	16.0	190
	Alkalinity (as CaCO$_3$)	59	1.0	141	170	223	387
	Chloride	59	1.7	5.0	12.0	19.0	840
	Fluoride	46	0.03	0.20	0.40	0.60	2.8
	Silica	42	4.0	8.2	10.0	13.0	39.0
	Sulfate	59	1.0	220	454	830	2,100
	Total dissolved solids	58	180	634	912	1,480	3,340
	Ammonia (as N)	1	<0.025	--	--	--	--
	Nitrate (as N)	14	--	0.008	0.03	0.10	4.5
	Nitrate plus nitrite (as N)	15	0.01	0.02	0.08	0.39	1.6
	Nitrite (as N)	2	--	--	--	--	<0.1
	Organic nitrogen, unfiltered	1	<0.2	--	--	--	--
	Orthophosphate (as P)	1	0.09	--	--	--	--
	Phosphorus, unfiltered	1	<0.03	--	--	--	--
	Total nitrogen, unfiltered, analytically determined	1	0.20	--	--	--	--
	Aluminum	1	<100	--	--	--	--
	Antimony	1	<0.5	--	--	--	--
	Arsenic	8	<1.0	--	--	--	33.0
	Barium	7	<50.0	--	--	--	300
	Beryllium	1	<1.0	--	--	--	--
	Boron	37	10.0	60.0	70.0	210	1,200
	Cadmium	7	--	--	--	--	<10.0
	Chromium	7	--	--	--	--	<50.0
	Cobalt	1	<2.0	--	--	--	--
	Copper	2	--	--	--	--	<10.0
	Iron	9	20.0	140	840	6,000	18,000
	Iron, unfiltered	29	10.0	180	530	2,000	46,000
	Lead	7	--	--	--	--	<50.0
	Manganese	2	30.0	--	--	--	180
	Manganese, unfiltered	2	<10.0	--	--	--	180
	Mercury	6	--	--	--	--	<1.0
	Molybdenum	1	6.3	--	--	--	--

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Inyan Kara aquifer —Continued	Nickel	1	<4.0	--	--	--	--
	Selenium	7	<1.0	--	--	--	20.0
	Strontium	1	1,400	--	--	--	--
	Vanadium	1	<10.0	--	--	--	--
	Zinc	1	<50.0	--	--	--	--
	Gross alpha radioactivity, in pCi/L	6	0.80	1.1	2.4	6.2	7.6
	Gross beta radioactivity, in pCi/L	2	3.7	--	--	--	7.2
	Radium-226, in pCi/L	5	0.75	1.2	1.3	2.8	6.9
	Radium-228, in pCi/L	5	0.22	0.50	0.60	1.3	2.1
	Uranium	9	--	0.39	6.0	15.0	23.0
Morrison confining unit	pH (standard units)	1	8.2	--	--	--	--
	Specific conductance (µS/cm)	1	1,400	--	--	--	--
	Hardness (as $CaCO_3$)	1	99.0	--	--	--	--
	Calcium	1	23.0	--	--	--	--
	Magnesium	1	10.0	--	--	--	--
	Potassium	1	8.7	--	--	--	--
	Sodium	1	276	--	--	--	--
	Sodium adsorption ratio (unitless)	1	12.0	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	205	--	--	--	--
	Chloride	1	6.0	--	--	--	--
	Fluoride	1	0.80	--	--	--	--
	Silica	1	9.2	--	--	--	--
	Sulfate	1	460	--	--	--	--
	Total dissolved solids	1	922	--	--	--	--
	Nitrate (as N)	1	0.18	--	--	--	--
	Boron	1	1,800	--	--	--	--
	Iron, unfiltered	1	320	--	--	--	--
Sundance aquifer	Dissolved oxygen	4	0.10	1.1	2.2	5.7	9.0
	pH (standard units)	15	5.6	7.2	7.5	7.7	8.1
	Specific conductance (µS/cm)	15	425	779	1,200	2,040	4,970
	Hardness (as $CaCO_3$)	12	140	320	501	788	1,300
	Calcium	15	35.0	56.0	105	140	393
	Magnesium	15	14.0	20.0	52.0	87.0	112
	Potassium	14	2.5	6.0	8.3	12.0	18.0
	Sodium	15	5.0	9.0	24.0	110	1,150
	Sodium adsorption ratio (unitless)	15	0.10	0.19	0.40	2.2	26.7

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Sundance aquifer —Continued	Alkalinity (as $CaCO_3$)	15	6.6	194	290	339	407
	Chloride	15	1.3	3.9	6.8	9.6	19.0
	Fluoride	13	0.02	0.20	0.20	0.30	1.4
	Silica	12	1.7	9.3	12.5	14.0	16.0
	Sulfate	15	35.0	156	420	927	2,750
	Total dissolved solids	15	243	492	847	1,690	4,100
	Ammonia (as N)	4	--	--	--	--	<0.25
	Dissolved organic carbon	3	0.33	--	1.2	--	1.4
	Nitrate (as N)	6	0.03	0.09	1.7	2.7	2.8
	Nitrate plus nitrite (as N)	3	0.04	--	0.33	--	8.9
	Nitrite (as N)	4	--	--	--	--	<0.005
	Organic nitrogen, unfiltered	4	--	--	--	--	<2.9
	Orthophosphate (as P)	4	0.03	0.03	0.04	0.06	0.06
	Total nitrogen, unfiltered, analytically determined	4	--	0.81	1.6	2.4	2.9
	Aluminum	4	--	--	--	--	<100
	Antimony	4	--	--	--	--	<1.0
	Arsenic	5	--	--	--	--	<4.0
	Barium	4	8.7	13.9	19.0	32.0	45.0
	Beryllium	4	--	--	--	--	<1.0
	Boron	10	60.0	110	170	260	350
	Cadmium	4	--	--	--	--	<0.2
	Chromium	4	--	--	--	--	<5.0
	Cobalt	4	--	--	--	--	<2.0
	Copper	4	<5.0	--	--	--	10.0
	Iron	7	--	26.8	84.3	350	1,060
	Iron, unfiltered	10	--	48.0	221	1,200	5,000
	Lead	4	--	--	--	--	<1.0
	Manganese	4	<2.0	--	--	--	16.0
	Manganese, unfiltered	5	--	1.2	2.4	16.0	160
	Mercury	1	1.1	--	--	--	--
	Molybdenum	4	11.0	12.0	13.0	13.5	14.0
	Nickel	4	--	--	--	--	<4.0
	Selenium	5	1.0	3.0	3.0	9.0	15.0
	Strontium	4	1,800	1,850	2,350	2,950	3,100
	Vanadium	4	--	--	--	--	<10.0
	Zinc	4	--	--	--	--	<50.0
	Gross beta radioactivity, in pCi/L	1	<10.0	--	--	--	--
	Radium-226, in pCi/L	1	0.10	--	--	--	--
	Uranium	1	3.3	--	--	--	--

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Chugwater confining unit	pH (standard units)	2	7.8	--	--	--	7.9
	Specific conductance (µS/cm)	2	1,570	--	--	--	2,380
	Hardness (as $CaCO_3$)	2	750	--	--	--	1,600
	Calcium	2	188	--	--	--	508
	Magnesium	2	67.0	--	--	--	93.0
	Potassium	2	2.5	--	--	--	4.3
	Sodium	2	15.0	--	--	--	108
	Sodium adsorption ratio (unitless)	2	0.16	--	--	--	1.7
	Alkalinity (as $CaCO_3$)	2	139	--	--	--	172
	Chloride	2	5.7	--	--	--	7.7
	Fluoride	2	0.30	--	--	--	0.60
	Silica	2	11.0	--	--	--	26.0
	Sulfate	2	789	--	--	--	1,460
	Total dissolved solids	2	1,300	--	--	--	2,410
	Nitrate (as N)	1	0.84	--	--	--	--
	Nitrate plus nitrite (as N)	1	4.2	--	--	--	--
	Boron	2	170	--	--	--	210
	Iron, unfiltered	2	10.0	--	--	--	60.0
Spearfish aquifer	Dissolved oxygen	4	0.20	0.25	2.1	6.3	8.8
	pH (standard units)	13	6.7	7.0	7.2	7.5	8.1
	Specific conductance (µS/cm)	12	674	2,045	2,620	3,160	41,800
	Hardness (as $CaCO_3$)	12	340	1,555	1,700	1,875	3,000
	Calcium	12	66.0	470	500	542	910
	Magnesium	12	43.0	78.5	103	150	168
	Potassium	11	2.1	5.8	8.5	11.0	24.0
	Sodium	12	13.0	34.5	79.5	125	10,100
	Sodium adsorption ratio (unitless)	12	0.20	0.39	0.80	1.4	81.0
	Alkalinity (as $CaCO_3$)	13	154	192	230	256	336
	Chloride	13	2.5	9.0	13.0	22.0	15,600
	Fluoride	10	0.09	0.10	0.25	0.60	1.0
	Silica	11	10.0	12.0	14.0	17.0	36.0
	Sulfate	13	84.0	1,400	1,600	2,000	3,190
	Total dissolved solids	11	459	2,390	2,650	3,280	30,100
	Ammonia (as N)	5	--	--	--	--	<0.04
	Ammonia plus organic nitrogen, unfiltered (as N)	1	0.16	--	--	--	--
	Ammonia, unfiltered (as N)	1	<0.01	--	--	--	--
	Dissolved organic carbon	2	1.5	--	--	--	2.2

Appendix E-2. Summary statistics for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter; E, estimated value]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Spearfish aquifer —Continued	Nitrate (as N)	10	0.16	0.37	1.8	3.0	4.0
	Nitrate plus nitrite (as N)	2	2.3	--	--	--	9.8
	Nitrate+nitrite, unfiltered (as N)	1	0.90	--	--	--	--
	Nitrite (as N)	5	--	--	--	--	<0.008
	Organic nitrogen, unfiltered	5	--	--	--	--	<3.8
	Orthophosphate (as P)	5	E0.01	0.04	0.06	0.06	0.07
	Phosphorus, unfiltered	1	<0.01	--	--	--	--
	Total nitrogen, unfiltered	1	1.1	--	--	--	--
	Total nitrogen, unfiltered, analytically determined	4	0.43	1.4	2.6	3.4	3.8
	Aluminum	4	--	--	--	--	<100
	Antimony	4	--	--	--	--	<1.0
	Arsenic	4	1.1	1.7	2.2	3.6	4.7
	Barium	4	7.3	7.6	7.9	10.0	12.0
	Beryllium	4	--	--	--	--	<1.0
	Boron	12	100	380	435	800	2,000
	Cadmium	4	--	--	--	--	<0.2
	Chromium	4	--	--	--	--	<5.0
	Cobalt	4	--	--	--	--	<2.0
	Copper	4	<5.0	--	--	--	11.0
	Iron	5	<100	--	--	--	340
	Iron, unfiltered	10	--	18.9	60.4	184	1,900
	Lead	4	--	--	--	--	<1.0
	Manganese	4	<2.0	--	--	--	8.5
	Manganese, unfiltered	5	--	1.5	2.1	8.9	20.0
	Molybdenum	4	14.0	15.0	16.0	24.0	32.0
	Nickel	4	--	--	--	--	<4.0
	Selenium	4	3.0	14.5	31.5	103	169
	Strontium	4	7,200	7,800	9,150	9,950	10,000
	Vanadium	4	<10.0	--	--	--	19.0
	Zinc	4	<50.0	--	--	--	95.0

Appendix E-3

Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the NERB excluding Wind River structural basin, Wyoming

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Minnekahta aquifer	pH (standard units)	7	7.5	7.6	7.7	7.8	8.0
	Specific conductance (µS/cm)	7	400	904	1,860	2,190	2,380
	Hardness (as $CaCO_3$)	7	230	520	1,300	1,500	1,700
	Calcium	7	59.0	148	420	472	532
	Magnesium	7	21.0	37.0	51.0	78.0	83.0
	Potassium	7	1.3	1.6	1.9	2.6	2.6
	Sodium	7	3.2	3.4	3.8	5.4	5.5
	Sodium adsorption ratio (unitless)	7	0.04	0.04	0.10	0.10	0.10
	Alkalinity (as $CaCO_3$)	7	156	185	191	210	242
	Chloride	7	1.0	1.4	1.6	4.0	5.0
	Fluoride	7	0.20	0.20	0.30	0.40	0.40
	Silica	7	8.3	11.0	13.0	14.0	16.0
	Sulfate	7	24.0	261	1,000	1,260	1,420
	Total dissolved solids	7	245	648	1,620	1,970	2,200
	Ammonia plus organic nitrogen, unfiltered (as N)	1	0.21	--	--	--	--
	Ammonia, unfiltered (as N)	1	<0.01	--	--	--	--
	Nitrate (as N)	1	1.7	--	--	--	--
	Nitrate plus nitrite (as N)	5	0.34	0.38	1.4	3.2	4.7
	Nitrate+nitrite, unfiltered (as N)	1	4.6	--	--	--	--
	Organic nitrogen, unfiltered	1	0.21	--	--	--	--
	Orthophosphate (as P)	2	0.01	--	--	--	0.01
	Phosphorus	1	0.01	--	--	--	--
	Phosphorus, unfiltered	2	<0.01	--	--	--	0.02
	Total nitrogen, unfiltered	1	4.8	--	--	--	--
	Aluminum	2	--	--	--	--	<100
	Antimony	1	<1.0	--	--	--	--
	Arsenic	2	2.0	--	--	--	3.0
	Barium	1	<100	--	--	--	--
	Beryllium	2	<10.0	--	--	--	10.0
	Boron	7	50.0	50.0	50.0	110	210
	Cadmium	1	<2.0	--	--	--	--
	Chromium	2	--	--	--	--	<20.0
	Copper	2	<2.0	--	--	--	180
	Iron	2	--	--	--	--	<10.0
	Iron, unfiltered	3	<10.0	--	30.0	--	40.0
	Lead	2	<2.0	--	--	--	9.0
	Lithium	2	<10.0	--	--	--	20.0
	Manganese	2	--	--	--	--	<10.0
	Manganese, unfiltered	1	<10.0	--	--	--	--

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Minnekahta aquifer —Continued	Mercury	1	<0.5	--	--	--	--
	Molybdenum	2	2.0	--	--	--	6.0
	Nickel	1	2.0	--	--	--	--
	Selenium	2	<1.0	--	--	--	2.0
	Strontium	1	3,600	--	--	--	--
	Vanadium	2	2.0	--	--	--	3.4
	Zinc	2	50.0	--	--	--	200
Opeche confining unit	pH (standard units)	1	7.8	--	--	--	--
	Specific conductance (µS/cm)	1	855	--	--	--	--
	Hardness (as $CaCO_3$)	1	480	--	--	--	--
	Calcium	1	136	--	--	--	--
	Magnesium	1	35.0	--	--	--	--
	Potassium	1	2.0	--	--	--	--
	Sodium	1	4.9	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.10	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	243	--	--	--	--
	Chloride	1	2.2	--	--	--	--
	Fluoride	1	0.40	--	--	--	--
	Silica	1	17.0	--	--	--	--
	Sulfate	1	235	--	--	--	--
	Total dissolved solids	1	602	--	--	--	--
	Nitrate (as N)	1	0.68	--	--	--	--
	Boron	1	120	--	--	--	--
	Iron, unfiltered	1	30.0	--	--	--	--
Tensleep aquifer	pH (standard units)	18	7.2	7.7	8.0	8.1	8.4
	Specific conductance (µS/cm)	12	407	413	444	489	809
	Hardness (as $CaCO_3$)	13	210	220	250	270	410
	Calcium	19	35.0	43.0	52.0	210	370
	Magnesium	19	24.0	26.0	31.0	49.0	100
	Potassium	15	0.80	1.2	1.5	2.4	36.0
	Sodium	19	1.1	3.0	4.6	380	1,400
	Sodium adsorption ratio (unitless)	19	0.03	0.08	0.10	6.0	17.9
	Alkalinity (as $CaCO_3$)	19	100	192	225	258	560
	Chloride	19	0.20	1.3	6.0	550	1,400
	Fluoride	13	0.10	0.10	0.20	0.40	0.60
	Silica	13	7.8	8.9	9.8	11.0	14.0
	Sulfate	19	1.6	13.0	43.0	450	1,700

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Tensleep aquifer —Continued	Total dissolved solids	20	192	236	312	1,825	5,320
	Ammonia plus organic nitrogen, unfiltered (as N)	1	<0.1	--	--	--	--
	Nitrate (as N)	8	--	0.15	0.49	0.66	1.5
	Nitrate plus nitrite (as N)	2	0.90	--	--	--	1.6
	Phosphorus	1	<0.01	--	--	--	--
	Aluminum	1	30.0	--	--	--	--
	Arsenic	1	<1.0	--	--	--	--
	Barium	1	<100	--	--	--	--
	Boron	12	9.0	10.0	20.0	35.0	100
	Copper	1	<2.0	--	--	--	--
	Iron	1	<10.0	--	--	--	--
	Iron, unfiltered	12	20.0	25.0	40.0	50.0	140
	Lead	1	<2.0	--	--	--	--
	Lithium	1	<10.0	--	--	--	--
	Manganese	1	20.0	--	--	--	--
	Mercury	1	<0.5	--	--	--	--
	Molybdenum	1	1.0	--	--	--	--
	Selenium	1	1.0	--	--	--	--
	Strontium	1	550	--	--	--	--
	Vanadium	1	18.0	--	--	--	--
	Zinc	1	<20.0	--	--	--	--
Minnelusa aquifer	Dissolved oxygen	2	7.2	--	--	--	7.5
	pH (standard units)	31	6.5	7.4	7.7	7.9	8.5
	Specific conductance (µS/cm)	27	358	495	794	1,820	3,010
	Hardness (as $CaCO_3$)	33	39.0	260	435	1,000	2,200
	Calcium	33	11.0	76.0	118	240	615
	Magnesium	33	2.8	23.0	36.0	68.0	161
	Potassium	24	0.05	1.5	2.2	4.0	15.0
	Sodium	33	0.08	2.8	5.1	23.0	739
	Sodium adsorption ratio (unitless)	33	0.002	0.10	0.10	0.50	29.0
	Alkalinity (as $CaCO_3$)	33	77.0	182	230	253	652
	Chloride	33	0.10	1.4	4.0	11.0	760
	Fluoride	29	0.01	0.20	0.30	0.90	2.9
	Silica	27	2.3	8.5	10.0	11.0	14.0
	Sulfate	33	5.8	15.0	212	820	1,980
	Total dissolved solids	33	218	331	551	1,410	3,220
	Ammonia (as N)	2	--	--	--	--	<0.025

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Minnelusa aquifer —Continued	Ammonia plus organic nitrogen, unfiltered (as N)	3	0.03	--	0.03	--	0.16
	Ammonia, unfiltered (as N)	3	--	--	--	--	<0.01
	Nitrate (as N)	21	0.02	0.04	0.11	0.36	3.6
	Nitrate plus nitrite (as N)	2	0.03	--	--	--	0.13
	Nitrate+nitrite, unfiltered (as N)	3	0.20	--	0.20	--	0.72
	Nitrite (as N)	3	0.005	--	0.005	--	0.10
	Organic nitrogen, unfiltered	5	0.03	0.04	0.05	0.07	0.16
	Orthophosphate (as P)	2	0.03	--	--	--	0.04
	Phosphorus, unfiltered	3	--	--	--	--	<0.01
	Total nitrogen, unfiltered	3	0.23	--	0.23	--	0.88
	Total nitrogen, unfiltered, analytically determined	2	0.28	--	--	--	1.9
	Aluminum	5	--	--	--	--	<100
	Antimony	5	<0.5	--	--	--	1.0
	Arsenic	5	1.0	1.0	1.6	1.6	2.0
	Barium	2	60.0	--	--	--	330
	Beryllium	5	<1.0	--	--	--	20.0
	Boron	18	20.0	29.6	50.8	100	200
	Cadmium	2	--	--	--	--	<0.2
	Chromium	2	--	--	--	--	<5.0
	Cobalt	2	--	--	--	--	<2.0
	Copper	5	<2.0	--	--	--	6.0
	Iron	9	0.06	0.21	2.5	100	13,000
	Iron, unfiltered	24	20.0	28.6	96.0	490	14,000
	Lead	4	<0.5	--	--	--	2.0
	Lithium	3	--	--	--	--	<10.0
	Manganese	7	--	0.91	6.3	70.0	1,000
	Manganese, unfiltered	5	<2.0	--	--	--	16.0
	Mercury	3	--	--	--	--	<0.5
	Molybdenum	5	1.0	2.0	6.3	14.0	140
	Nickel	5	2.0	2.6	3.1	4.0	5.0
	Selenium	5	1.0	1.0	1.0	2.0	4.0
	Strontium	2	340	--	--	--	690
	Vanadium	5	1.6	2.8	3.6	4.7	6.6
	Zinc	5	<20.0	--	--	--	300
	Gross alpha radioactivity, in pCi/L	1	5.3	--	--	--	--
	Radium-226, in pCi/L	1	0.40	--	--	--	--
	Radium-228, in pCi/L	1	2.6	--	--	--	--
	Tritium, unfiltered, in pCi/L	3	<2.5	--	14.1	--	27.0

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Hartville aquifer (Hartville Uplift area)	pH (standard units)	2	8.0	--	--	--	8.4
	Specific conductance (µS/cm)	2	433	--	--	--	478
	Calcium	2	36.0	--	--	--	48.0
	Magnesium	2	17.0	--	--	--	18.0
	Potassium	2	6.0	--	--	--	9.0
	Sodium	2	25.0	--	--	--	27.0
	Sodium adsorption ratio (unitless)	2	0.79	--	--	--	0.92
	Alkalinity (as $CaCO_3$)	2	164	--	--	--	166
	Chloride	2	9.0	--	--	--	24.0
	Fluoride	2	0.60	--	--	--	2.3
	Silica	1	25.8	--	--	--	--
	Sulfate	2	43.0	--	--	--	44.0
	Total dissolved solids	2	256	--	--	--	305
	Nitrate plus nitrite (as N)	2	1.5	--	--	--	1.5
	Iron, unfiltered	2	430	--	--	--	2,550
	Manganese, unfiltered	1	31.0	--	--	--	--
	Gross alpha radioactivity, in pCi/L	2	11.3	--	--	--	15.5
	Radium-226, in pCi/L	2	0.14	--	--	--	0.63
	Radium-228, in pCi/L	2	0.51	--	--	--	0.68
	Uranium	1	10.9	--	--	--	--
Madison aquifer	Dissolved oxygen	2	2.0	--	--	--	3.8
	pH (standard units)	65	6.4	7.1	7.3	7.7	8.5
	Specific conductance (µS/cm)	57	99.0	480	707	925	4,280
	Hardness (as $CaCO_3$)	66	45.0	270	360	474	1,100
	Calcium	69	11.0	62.0	79.0	135	366
	Magnesium	69	4.1	27.0	32.0	41.0	104
	Potassium	66	0.20	1.3	2.0	5.2	69.0
	Sodium	69	0.60	2.2	3.7	32.0	760
	Sodium adsorption ratio (unitless)	69	0.02	0.08	0.10	0.71	11.0
	Alkalinity (as $CaCO_3$)	69	43.0	167	209	235	270
	Chloride	67	0.10	1.3	2.0	23.0	1,200
	Fluoride	65	0.10	0.30	0.50	2.0	5.5
	Silica	61	3.1	11.0	12.0	21.1	74.0
	Sulfate	69	1.0	28.0	148	270	1,130
	Total dissolved solids	69	65.0	281	454	668	3,490
	Ammonia (as N)	12	--	0.009	0.01	0.02	0.06
	Ammonia plus organic nitrogen (as N)	13	0.01	0.01	0.02	0.07	0.34

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Madison aquifer —Continued	Ammonia plus organic nitrogen, unfiltered (as N)	26	0.01	0.04	0.12	0.17	0.75
	Ammonia, unfiltered (as N)	15	--	0.005	0.01	0.01	0.07
	Dissolved organic carbon	3	0.40	--	0.60	--	5.1
	Nitrate (as N)	23	0.01	0.04	0.09	0.20	0.52
	Nitrate plus nitrite (as N)	23	0.10	0.16	0.19	0.26	1.1
	Nitrate, unfiltered (as N)	9	0.10	0.17	0.19	0.20	1.0
	Nitrate+nitrite, unfiltered (as N)	16	0.02	0.13	0.19	0.19	0.21
	Nitrite (as N)	14	--	--	--	--	<0.1
	Nitrite, unfiltered (as N)	9	--	--	--	--	<0.01
	Organic nitrogen	7	0.01	0.01	0.01	0.07	0.31
	Organic nitrogen, unfiltered	16	0.01	0.02	0.07	0.13	0.51
	Orthophosphate (as P)	10	0.01	0.01	0.01	0.01	0.02
	Phosphorus	20	--	0.007	0.009	0.01	0.02
	Phosphorus, unfiltered	16	--	0.009	0.01	0.01	0.02
	Total nitrogen	13	0.17	0.18	0.20	0.22	0.53
	Total nitrogen, unfiltered	18	0.06	0.18	0.24	0.30	0.73
	Aluminum	28	--	8.6	12.7	18.7	40.0
	Antimony	10	--	--	--	--	<10.0
	Arsenic	37	--	0.96	1.7	2.9	12.0
	Barium	31	--	--	--	--	<500
	Beryllium	20	--	--	--	--	<10.0
	Boron	56	2.0	8.9	28.0	88.3	890
	Cadmium	15	--	--	--	--	<10.0
	Chromium	16	<1.0	--	--	--	90.0
	Cobalt	2	--	--	--	--	<2.0
	Copper	30	--	0.49	1.9	7.4	180
	Iron	38	--	7.2	60.0	490	6,900
	Iron, unfiltered	14	40.0	70.0	215	420	580
	Lead	26	--	0.29	0.72	1.8	20.0
	Lithium	27	--	0.43	3.6	30.0	870
	Manganese	40	--	2.7	11.0	70.0	300
	Manganese, unfiltered	18	--	4.0	9.5	20.0	280
	Mercury	38	--	--	--	--	<1.0
	Molybdenum	29	1.0	2.1	4.2	8.3	50.0
	Nickel	11	1.0	1.4	1.9	2.6	3.0
	Selenium	36	--	0.72	1.4	2.8	11.0
	Strontium	27	70.0	250	520	3,000	6,000
	Vanadium	31	0.50	1.4	2.3	5.6	14.0
	Zinc	28	4.0	6.2	17.6	45.0	370

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Madison aquifer —Continued	Gross alpha radioactivity, in pCi/L	12	1.5	1.6	3.2	5.0	12.0
	Gross beta radioactivity, in pCi/L	23	--	1.0	3.4	12.0	93.0
	Radium-226, in pCi/L	14	0.10	0.19	0.90	1.4	8.3
	Radium-228, in pCi/L	13	0.10	0.22	0.52	1.4	8.7
	Radon-222, in pCi/L	2	168	--	--	--	190
	Tritium, unfiltered, in pCi/L	8	--	0.22	1.3	26.0	78.0
	Uranium	8	2.2	2.2	6.5	8.7	9.1
Whitewood aquifer	Hardness (as $CaCO_3$)	1	370	--	--	--	--
	Calcium	1	84.0	--	--	--	--
	Magnesium	1	39.0	--	--	--	--
	Potassium	1	2.4	--	--	--	--
	Sodium	1	4.7	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.10	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	180	--	--	--	--
	Chloride	1	2.8	--	--	--	--
	Fluoride	1	0.90	--	--	--	--
	Silica	1	22.0	--	--	--	--
	Sulfate	1	190	--	--	--	--
	Total dissolved solids	1	465	--	--	--	--
	Ammonia (as N)	1	0.03	--	--	--	--
	Ammonia plus organic nitrogen (as N)	1	0.21	--	--	--	--
	Ammonia plus organic nitrogen, unfiltered (as N)	1	0.16	--	--	--	--
	Dissolved organic carbon	1	0.20	--	--	--	--
	Nitrate plus nitrite (as N)	1	0.21	--	--	--	--
	Organic nitrogen	1	0.18	--	--	--	--
	Organic nitrogen, unfiltered	1	0.13	--	--	--	--
	Phosphorus	1	0.01	--	--	--	--
	Total nitrogen	1	0.42	--	--	--	--
	Total nitrogen, unfiltered	1	0.37	--	--	--	--
	Aluminum	1	<100	--	--	--	--
	Arsenic	1	<1.0	--	--	--	--
	Barium	1	200	--	--	--	--
	Boron	1	30.0	--	--	--	--
	Iron	1	1,900	--	--	--	--
	Lithium	1	9.0	--	--	--	--
	Manganese	1	170	--	--	--	--

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Whitewood aquifer —Continued	Mercury	1	<0.5	--	--	--	--
	Molybdenum	1	24.0	--	--	--	--
	Selenium	1	4.0	--	--	--	--
	Strontium	1	1,700	--	--	--	--
	Gross beta radioactivity, in pCi/L	1	4.4	--	--	--	--
Flathead aquifer	pH (standard units)	2	6.9	--	--	--	7.2
	Specific conductance (µS/cm)	2	160	--	--	--	1,320
	Hardness (as $CaCO_3$)	2	100	--	--	--	240
	Calcium	2	29.0	--	--	--	70.0
	Magnesium	2	7.0	--	--	--	15.0
	Potassium	2	1.7	--	--	--	23.0
	Sodium	2	2.4	--	--	--	180
	Sodium adsorption ratio (unitless)	2	0.10	--	--	--	5.1
	Alkalinity (as $CaCO_3$)	2	91.0	--	--	--	184
	Chloride	2	1.0	--	--	--	290
	Fluoride	2	0.20	--	--	--	4.5
	Silica	2	6.5	--	--	--	31.0
	Sulfate	2	9.4	--	--	--	74.0
	Total dissolved solids	2	112	--	--	--	793
	Ammonia plus organic nitrogen, unfiltered (as N)	2	0.16	--	--	--	1.1
	Ammonia, unfiltered (as N)	1	<0.01	--	--	--	--
	Nitrate+nitrite, unfiltered (as N)	1	0.62	--	--	--	--
	Organic nitrogen, unfiltered	1	0.16	--	--	--	--
	Phosphorus	1	<0.01	--	--	--	--
	Phosphorus, unfiltered	1	<0.01	--	--	--	--
	Total nitrogen, unfiltered	1	0.78	--	--	--	--
	Aluminum	2	--	--	--	--	<100
	Antimony	1	<1.0	--	--	--	--
	Arsenic	2	<1.0	--	--	--	7.0
	Barium	1	200	--	--	--	--
	Beryllium	1	<10.0	--	--	--	--
	Boron	2	<20.0	--	--	--	340
	Chromium	1	<20.0	--	--	--	--
	Copper	2	--	--	--	--	<2.0
	Iron	2	<10.0	--	--	--	80.0
	Iron, unfiltered	1	340	--	--	--	--
	Lithium	2	<10.0	--	--	--	400

Appendix E-3. Summary statistics for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; pCi/L, picocuries per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Flathead aquifer —Continued	Manganese	2	20.0	--	--	--	50.0
	Manganese, unfiltered	1	20.0	--	--	--	--
	Mercury	2	--	--	--	--	<0.5
	Molybdenum	2	<1.0	--	--	--	1.0
	Nickel	1	6.0	--	--	--	--
	Selenium	2	<1.0	--	--	--	1.0
	Strontium	1	2,400	--	--	--	--
	Vanadium	2	0.60	--	--	--	1.5
	Zinc	2	<20.0	--	--	--	90.0
	Gross beta radioactivity, in pCi/L	1	19.0	--	--	--	--
	Radium-226, in pCi/L	1	14.0	--	--	--	--
Precambrian basal confining unit	pH (standard units)	1	7.0	--	--	--	--
	Specific conductance (µS/cm)	1	92.0	--	--	--	--
	Hardness (as $CaCO_3$)	1	34.0	--	--	--	--
	Calcium	1	9.6	--	--	--	--
	Magnesium	1	2.4	--	--	--	--
	Potassium	1	1.2	--	--	--	--
	Sodium	1	3.6	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.30	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	39.0	--	--	--	--
	Chloride	1	0.10	--	--	--	--
	Fluoride	1	0.10	--	--	--	--
	Silica	1	17.0	--	--	--	--
	Sulfate	1	5.3	--	--	--	--
	Total dissolved solids	1	63.0	--	--	--	--
	Nitrate (as N)	1	0.16	--	--	--	--
	Boron	1	10.0	--	--	--	--
	Iron, unfiltered	1	50.0	--	--	--	--

Appendix F

Summary statistics for environmental water samples from the Wind River structural basin within the NERB, Wyoming

Appendix F. Summary statistics for environmental water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen;]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Cenozoic hydrogeologic units							
Fort Union aquifer	pH (standard units)	5	6.6	6.6	7.2	7.2	8.6
	Specific conductance (µS/cm)	2	1,200	--	--	--	2,210
	Hardness (as $CaCO_3$)	5	24.0	400	517	809	980
	Calcium	5	8.0	56.0	118	184	236
	Magnesium	5	1.0	39.0	54.0	85.0	95.0
	Potassium	3	1.0	--	10.0	--	15.0
	Sodium	5	5.0	12.0	37.0	175	317
	Sodium adsorption ratio (unitless)	5	0.10	0.30	0.60	2.4	28.1
	Alkalinity (as $CaCO_3$)	5	50.0	95.1	110	160	436
	Chloride	5	8.0	8.0	10.0	12.0	78.0
	Fluoride	2	0.90	--	--	--	5.8
	Silica	1	7.2	--	--	--	--
	Sulfate	4	255	323	545	960	1,220
	Total dissolved solids	5	400	641	767	1,120	1,940
	Boron	1	250	--	--	--	--
	Iron, unfiltered	4	2,700	11,100	25,750	45,000	58,000
	Gross beta radioactivity, in pCi/L	1	5.0	--	--	--	--
	Radium-226, in pCi/L	1	0.10	--	--	--	--
Mesozoic hydrogeologic units							
Mesaverde aquifer	pH (standard units)	1	8.6	--	--	--	--
	Specific conductance (µS/cm)	1	3,450	--	--	--	--
	Hardness (as $CaCO_3$)	1	83.0	--	--	--	--
	Calcium	1	20.0	--	--	--	--
	Magnesium	1	8.0	--	--	--	--
	Potassium	1	4.0	--	--	--	--
	Sodium	1	830	--	--	--	--
	Sodium adsorption ratio (unitless)	1	39.7	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	783	--	--	--	--
	Chloride	1	164	--	--	--	--
	Fluoride	1	0.86	--	--	--	--
	Sulfate	1	920	--	--	--	--
	Total dissolved solids	1	2,646	--	--	--	--
	Gross beta radioactivity, in pCi/L	1	10.0	--	--	--	--
	Radium-226, in pCi/L	1	0.10	--	--	--	--

Appendix F. Summary statistics for environmental water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen;]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Mesozoic hydrogeologic units—Continued							
Muddy aquifer	pH (standard units)	1	8.4	--	--	--	--
	Calcium	1	10.0	--	--	--	--
	Magnesium	1	3.0	--	--	--	--
	Sodium	1	693	--	--	--	--
	Sodium adsorption ratio (unitless)	1	49.0	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	1,148	--	--	--	--
	Chloride	1	25.0	--	--	--	--
	Sulfate	1	56.0	--	--	--	--
	Total dissolved solids	1	1,690	--	--	--	--
Paleozoic hydrogeologic units							
Tensleep aquifer	pH (standard units)	1	7.6	--	--	--	--
	Specific conductance (µS/cm)	1	450	--	--	--	--
	Hardness (as $CaCO_3$)	1	210	--	--	--	--
	Calcium	1	55.0	--	--	--	--
	Magnesium	1	17.0	--	--	--	--
	Potassium	1	2.2	--	--	--	--
	Sodium	1	2.5	--	--	--	--
	Sodium adsorption ratio (unitless)	1	0.10	--	--	--	--
	Alkalinity (as $CaCO_3$)	1	136	--	--	--	--
	Chloride	1	4.0	--	--	--	--
	Fluoride	1	2.2	--	--	--	--
	Silica	1	9.4	--	--	--	--
	Sulfate	1	73.0	--	--	--	--
	Total dissolved solids	1	248	--	--	--	--
	Ammonia plus organic nitrogen, unfiltered (as N)	1	0.47	--	--	--	--
	Ammonia, unfiltered (as N)	1	<0.01	--	--	--	--
	Nitrate+nitrite, unfiltered (as N)	1	0.05	--	--	--	--
	Organic nitrogen, unfiltered	1	0.47	--	--	--	--
	Phosphorus, unfiltered	1	0.01	--	--	--	--
	Total nitrogen, unfiltered	1	0.52	--	--	--	--
	Aluminum	1	20.0	--	--	--	--
	Antimony	1	1.0	--	--	--	--
	Arsenic	1	5.0	--	--	--	--
	Beryllium	1	<10.0	--	--	--	--
	Boron	1	90.0	--	--	--	--
	Copper	1	<2.0	--	--	--	--
	Iron	1	550	--	--	--	--

Appendix F. Summary statistics for environmental water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; <, less than; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25°Celsius; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen;]

Hydrogeologic unit	Characteristic and constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Paleozoic hydrogeologic units—Continued							
Tensleep aquifer —Continued	Iron, unfiltered	1	24,000	--	--	--	--
	Lead	1	2.0	--	--	--	--
	Lithium	1	<10.0	--	--	--	--
	Manganese	1	30.0	--	--	--	--
	Manganese, unfiltered	1	40.0	--	--	--	--
	Mercury	1	<0.5	--	--	--	--
	Molybdenum	1	1.0	--	--	--	--
	Nickel	1	4.0	--	--	--	--
	Selenium	1	2.0	--	--	--	--
	Vanadium	1	0.50	--	--	--	--

Appendix G-1

Summary statistics for produced-water samples from Cenozoic-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming

Appendix G-1. Summary statistics for produced-water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Wasatch aquifer (lower Tertiary aquifer system in Powder River structural basin)	pH (standard units)	21	6.1	6.7	6.8	7.3	7.8
	Calcium	21	155	254	378	515	578
	Magnesium	21	75.0	125	153	195	280
	Potassium	20	6.0	8.0	10.0	16.0	21.0
	Sodium	20	9.0	27.0	55.5	112	207
	Sodium adsorption ratio (unitless)	20	0.13	0.32	0.53	1.1	1.9
	Bicarbonate	21	317	451	476	549	634
	Chloride	21	4.0	10.0	13.0	20.0	51.0
	Sulfate	21	112	860	1,400	1,829	2,173
	Total dissolved solids	20	1,105	1,612	2,315	2,880	3,376
	Iron	1	--	--	--	--	2,000
Fort Union aquifer (lower Tertiary aquifer system in Powder River structural basin)	pH (standard units)	32	6.7	7.6	8.0	8.4	9.4
	Calcium	32	3.0	6.5	16.4	41.0	1,835
	Magnesium	31	1.0	2.0	8.0	21.0	205
	Potassium	22	0.99	3.0	7.5	20.0	170
	Sodium	34	10.0	256	377	925	63,210
	Sodium adsorption ratio (unitless)	32	0.10	13.0	28.7	45.6	379
	Bicarbonate	34	199	482	690	1,020	5,197
	Carbonate	11	2.0	10.0	24.0	48.1	301
	Chloride	32	1.0	9.5	37.5	435	101,000
	Sulfate	26	1.0	24.0	133	528	1,265
	Total dissolved solids	34	225	706	1,137	2,350	167,200
	Iron	11	150	420	2,500	8,100	190,000

Appendix G-2

Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the NERB excluding Wind River structural basin, Wyoming

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; CaCO$_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Lance aquifer (Upper Cretaceous aquifer system in the Powder River structural basin)	pH (standard units)	56	3.6	8.1	8.2	8.4	8.9
	Calcium	56	1.0	7.0	13.8	32.5	1,511
	Magnesium	46	1.0	2.9	5.0	24.0	446
	Potassium	27	2.0	10.0	13.0	16.0	43.0
	Sodium	57	387	664	1,164	1,480	16,780
	Sodium adsorption ratio (unitless)	56	8.7	35.4	60.1	105	403
	Bicarbonate	56	288	988	1,513	2,510	4,230
	Carbonate	25	24.0	36.0	60.0	96.0	512
	Chloride	57	46.0	210	430	676	25,000
	Sulfate	49	0.79	19.8	77.0	265	4,271
	Total dissolved solids	57	1,002	1,625	3,280	5,300	47,910
	Iron	16	50.0	150	1,040	4,920	72,000
Fox Hills aquifer (Upper Cretaceous aquifer system in the Powder River structural basin)	pH (standard units)	68	6.7	7.8	8.2	8.5	9.3
	Calcium	72	1.0	2.5	5.0	20.0	1,001
	Magnesium	57	0.40	1.0	2.0	7.0	563
	Potassium	58	--	3.0	5.5	11.0	168
	Sodium	78	125	338	419	669	1,408
	Sodium adsorption ratio (unitless)	74	2.9	30.8	47.8	71.7	122
	Bicarbonate	78	80.0	538	763	1,070	2,355
	Carbonate	34	6.6	19.0	36.0	60.0	252
	Chloride	78	7.0	25.0	56.0	210	3,003
	Fluoride	1	--	--	--	--	7.0
	Sulfate	73	2.5	81.0	167	276	2,600
	Total dissolved solids	78	325	920	1,234	1,998	6,758
	Iron	23	100	300	1,200	1,940	50,000
Lewis confining unit	pH (standard units)	2	8.2	--	--	--	8.6
	Calcium	3	4.0	--	29.0	--	31.0
	Magnesium	3	2.0	--	4.0	--	36.0
	Potassium	3	11.0	--	57.0	--	74.0
	Sodium	3	268	--	500	--	895
	Sodium adsorption ratio (unitless)	3	7.9	--	42.1	--	42.3
	Bicarbonate	3	451	--	634	--	1,098
	Carbonate	1	--	--	--	--	48.0
	Chloride	3	72.0	--	122	--	955
	Sulfate	3	120	--	245	--	250
	Total dissolved solids	3	1,027	--	1,252	--	2,519

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Pierre confining unit	pH (standard units)	28	7.1	7.9	8.3	8.5	8.8
	Calcium	38	1.0	7.0	18.0	36.0	304
	Magnesium	38	1.0	3.0	6.8	16.0	85.0
	Potassium	20	16.0	34.1	46.5	171	940
	Sodium	39	1,420	2,915	3,922	4,775	14,490
	Sodium adsorption ratio (unitless)	39	55.8	108	160	332	871
	Bicarbonate	38	740	1,842	2,190	2,548	5,417
	Carbonate	16	24.0	42.0	90.0	204	1,440
	Chloride	39	500	3,261	4,976	5,728	17,730
	Sulfate	35	0.99	2.0	7.0	120	1,248
	Total dissolved solids	39	3,399	7,825	10,480	12,450	37,370
	Iron	3	60.0	--	990	--	1,550
Mesaverde aquifer	pH (standard units)	391	5.1	7.5	7.9	8.2	9.4
	Calcium	466	1.5	27.0	56.0	99.0	4,316
	Magnesium	447	1.0	8.0	13.0	22.0	899
	Potassium	300	2.1	29.0	46.0	92.0	6,000
	Sodium	466	69.0	4,102	5,266	6,174	17,010
	Sodium adsorption ratio (unitless)	466	2.4	98.1	154	198	497
	Bicarbonate	462	117	1,244	1,688	2,120	3,927
	Carbonate	96	1.2	48.0	72.0	108	606
	Chloride	466	6.0	5,000	7,375	8,800	29,010
	Fluoride	3	5.3	--	5.6	--	5.7
	Sulfate	341	1.0	8.0	30.0	194	4,967
	Total dissolved solids	463	399	10,480	14,170	16,280	48,670
	Boron	7	4,030	8,800	12,400	13,130	17,190
	Iron	155	51.0	2,300	6,900	15,100	848,000
Cody confining unit	pH (standard units)	380	4.6	7.5	8.0	8.2	9.4
	Calcium	413	1.0	13.0	35.0	149	1,678
	Magnesium	394	1.0	5.0	11.0	35.5	564
	Potassium	344	2.0	23.0	48.0	197	28,590
	Sodium	413	344	3,017	5,250	9,100	25,270
	Sodium adsorption ratio (unitless)	414	3.0	132	181	264	596
	Bicarbonate	409	8.0	736	1,476	1,880	8,800
	Carbonate	74	8.0	48.0	84.0	204	1,262
	Chloride	415	8.0	3,347	7,340	14,000	39,130
	Sulfate	290	0.99	9.0	17.5	59.0	5,879

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Cody confining unit —Continued	Total dissolved solids	415	97.2	7,854	13,400	23,900	76,100
	Boron	2	2,020	--	--	--	10,070
	Iron	103	430	10,160	31,550	80,930	856,000
Steele confining unit	pH (standard units)	33	7.7	8.0	8.3	8.4	8.9
	Calcium	33	2.0	17.0	23.0	42.0	95.0
	Magnesium	31	1.0	4.0	7.0	12.1	27.0
	Potassium	1	--	--	--	--	20.0
	Sodium	33	568	2,720	3,216	3,949	4,320
	Sodium adsorption ratio (unitless)	33	42.8	108	135	156	585
	Bicarbonate	33	683	1,159	2,000	2,165	2,490
	Carbonate	19	24.0	59.0	84.0	144	192
	Chloride	33	156	3,100	3,740	5,400	6,100
	Sulfate	26	5.0	15.0	22.0	30.0	676
	Total dissolved solids	33	1,989	6,832	8,087	10,070	10,960
Niobrara confining unit	pH (standard units)	8	5.9	6.5	7.5	8.2	8.5
	Calcium	32	12.0	254	557	828	4,565
	Magnesium	32	10.0	25.0	65.5	99.0	201
	Potassium	28	16.0	85.0	129	240	376
	Sodium	32	678	3,979	9,005	10,900	16,540
	Sodium adsorption ratio (unitless)	32	17.5	59.6	87.7	109	249
	Bicarbonate	32	254	541	867	1,135	5,490
	Carbonate	5	0.00	24.0	84.0	240	240
	Chloride	32	240	5,983	14,850	19,760	29,420
	Sulfate	29	11.0	21.0	29.0	50.0	2,202
	Total dissolved solids	32	1,984	12,150	25,220	32,230	47,800
	Iron	4	1,870	1,870	6,935	72,300	132,600
Carlile confining unit	pH (standard units)	16	6.5	6.9	7.3	8.0	9.1
	Calcium	69	3.0	472	642	929	5,693
	Magnesium	68	0.99	66.0	94.5	117	484
	Potassium	69	4.0	161	913	1,376	2,854
	Sodium	70	530	11,340	13,700	16,500	30,460
	Sodium adsorption ratio (unitless)	70	37.5	125	140	151	671
	Bicarbonate	70	307	476	549	649	2,745
	Carbonate	4	5.0	20.5	180	414	504
	Chloride	70	63.0	20,860	23,916	28,300	50,970

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Carlile confining unit —Continued	Fluoride	1	--	--	--	--	4.6
	Sulfate	63	3.0	12.0	24.0	41.0	1,321
	Total dissolved solids	70	86.2	34,970	40,350	47,300	84,100
	Boron	1	--	--	--	--	11,400
	Iron	9	130	2,000	38,780	81,900	1,088,000
Frontier aquifer	pH (standard units)	265	4.4	7.9	8.2	8.4	11.8
	Specific conductance (uS/cm)	1	--	--	--	--	3,530
	Calcium	315	1.0	14.0	27.2	73.0	13,540
	Magnesium	301	1.0	4.0	9.0	22.3	4,275
	Potassium	196	1.0	11.0	20.5	51.0	33,300
	Sodium	318	61.0	1,467	2,534	4,526	39,630
	Sodium adsorption ratio (unitless)	316	1.3	63.5	105	169	345
	Alkalinity (as CaCO3)	1	--	--	--	--	1,820
	Bicarbonate	317	12.0	855	1,610	2,754	6,921
	Carbonate	149	12.0	60.0	132	243	1,443
	Chloride	321	8.0	775	2,020	5,150	98,000
	Fluoride	1	--	--	--	--	13.0
	Sulfate	284	1.0	31.0	153	550	10,520
	Total dissolved solids	320	227	3,848	7,019	11,840	156,600
	Boron	3	1,800	--	10,090	--	11,120
	Iron	12	200	1,295	12,270	31,900	54,000
Greenhorn confining unit	Calcium	2	53.0	--	--	--	62.0
	Magnesium	2	41.0	--	--	--	54.0
	Sodium	2	7,021	--	--	--	7,902
	Sodium adsorption ratio (unitless)	2	162	--	--	--	191
	Bicarbonate	2	420	--	--	--	560
	Chloride	2	10,740	--	--	--	12,050
	Sulfate	2	53.0	--	--	--	134
	Total dissolved solids	2	18,420	--	--	--	20,670
Mowry confining unit	pH (standard units)	5	7.2	7.2	7.5	7.6	8.5
	Calcium	9	4.0	80.0	271	698	2,590
	Magnesium	9	1.0	43.0	69.0	110	336
	Potassium	6	5.0	48.0	59.0	76.0	368
	Sodium	9	678	4,144	9,650	12,200	13,900

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Mowry confining unit —Continued	Sodium adsorption ratio (unitless)	9	55.7	78.6	94.6	142	220
	Bicarbonate	9	337	658	1,110	1,601	2,165
	Carbonate	1	--	--	--	--	86.0
	Chloride	9	20.0	2,500	17,200	20,300	23,400
	Fluoride	2	0.90	--	--	--	13.5
	Sulfate	9	3.0	14.0	28.0	51.0	7,942
	Total dissolved solids	9	1,608	13,440	27,500	35,200	38,600
	Boron	2	9,600	--	--	--	9,800
	Selenium	1	--	--	--	--	240
Muddy aquifer	pH (standard units)	277	3.6	7.5	7.9	8.2	9.8
	Calcium	293	1.2	22.1	45.0	98.0	2,294
	Magnesium	290	0.20	7.0	16.0	31.0	990
	Potassium	236	1.3	18.1	37.1	57.0	8,100
	Sodium	300	2.0	2,292	4,777	7,343	23,050
	Sodium adsorption ratio (unitless)	295	0.28	93.4	152	199	499
	Bicarbonate	299	7.3	1,074	1,730	2,208	5,520
	Carbonate	85	0.00	36.0	48.0	96.0	2,244
	Chloride	301	2.0	2,620	6,294	10,350	38,500
	Fluoride	9	0.40	0.60	1.9	5.2	8.8
	Sulfate	257	0.80	11.0	35.0	99.0	6,000
	Total dissolved solids	300	37.0	5,867	12,630	18,870	64,780
	Boron	16	900	6,400	10,150	12,250	19,000
	Iron	21	600	6,890	17,000	29,000	278,000
	Selenium	9	30.0	80.0	90.0	130	300
Newcastle aquifer	pH (standard units)	151	6.1	7.7	8.0	8.3	9.8
	Calcium	160	2.0	23.5	42.5	76.5	910
	Magnesium	156	1.0	10.5	20.0	35.5	176
	Potassium	72	2.0	14.0	22.0	46.0	14,540
	Sodium	163	141	1,624	3,650	4,803	11,370
	Sodium adsorption ratio (unitless)	161	5.5	57.8	102	154	587
	Bicarbonate	163	177	904	1,720	2,823	9,050
	Carbonate	65	--	54.0	119	300	1,930
	Chloride	163	6.0	1,040	3,749	6,300	18,570
	Sulfate	145	1.0	15.0	50.0	337	6,700
	Total dissolved solids	163	707	4,357	9,531	12,400	31,500
	Boron	3	2,200	--	5,100	--	13,700

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Newcastle aquifer —Continued	Iron	5	740	950	3,600	6,300	64,550
	Selenium	1	--	--	--	--	40.0
Skull Creek confining unit	pH (standard units)	2	8.5	--	--	--	9.8
	Calcium	2	24.2	--	--	--	368
	Magnesium	1	--	--	--	--	24.2
	Potassium	1	--	--	--	--	68.0
	Sodium	2	4,341	--	--	--	4,643
	Sodium adsorption ratio (unitless)	2	66.7	--	--	--	149
	Bicarbonate	2	695	--	--	--	2,228
	Carbonate	2	66.5	--	--	--	264
	Chloride	2	5,433	--	--	--	7,100
	Sulfate	2	2.0	--	--	--	81.0
	Total dissolved solids	2	12,120	--	--	--	12,870
Cloverly aquifer	pH (standard units)	93	5.4	7.7	8.0	8.3	9.3
	Calcium	110	3.0	20.0	52.5	109	1,216
	Magnesium	98	1.0	8.0	15.0	29.0	401
	Potassium	50	4.0	14.0	24.5	45.0	18,180
	Sodium	107	573	1,681	4,093	6,641	18,420
	Sodium adsorption ratio (unitless)	110	10.3	78.0	131	165	362
	Bicarbonate	110	224	975	1,321	1,574	6,564
	Carbonate	35	12.0	36.0	72.0	134	1,104
	Chloride	110	40.0	1,710	5,300	9,300	28,940
	Sulfate	101	8.0	248	615	1,036	3,280
	Total dissolved solids	110	1,484	5,037	11,120	17,920	50,760
	Boron	1	--	--	--	--	19,270
	Iron	1	--	--	--	--	170
Inyan Kara aquifer	pH (standard units)	293	5.7	7.9	8.2	8.6	10.7
	Calcium	296	0.11	7.5	13.0	29.5	1,623
	Magnesium	273	1.0	2.0	4.0	9.0	158
	Potassium	147	1.0	5.0	9.0	16.0	360
	Sodium	304	12.0	660	947	1,884	24,140
	Sodium adsorption ratio (unitless)	299	0.86	46.8	67.3	101	306
	Bicarbonate	305	61.0	732	1,208	1,756	5,671
	Carbonate	157	4.0	52.0	96.0	168	1,022
	Chloride	306	4.0	76.0	271	1,140	36,000

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Inyan Kara aquifer —Continued	Fluoride	1	--	--	--	--	2.7
	Sulfate	294	1.0	160	390	802	7,500
	Total dissolved solids	305	188	1,780	2,615	4,947	67,260
	Boron	5	900	1,300	1,600	9,030	30,600
	Iron	30	100	2,000	8,895	17,780	59,150
	Selenium	1	--	--	--	--	130
Morrison confining unit	pH (standard units)	15	6.9	7.6	7.9	8.2	8.6
	Calcium	19	7.0	40.0	251	348	629
	Magnesium	17	1.0	19.0	43.0	53.0	104
	Potassium	4	26.0	45.0	71.5	585	1,090
	Sodium	20	14.0	1,947	3,123	3,862	18,440
	Sodium adsorption ratio (unitless)	19	0.16	37.2	56.9	137	187
	Bicarbonate	19	85.0	370	450	1,171	2,600
	Carbonate	7	22.0	37.0	72.0	96.0	168
	Chloride	20	44.1	249	352	3,713	27,600
	Sulfate	19	20.0	1,182	3,856	6,568	8,200
	Total dissolved solids	20	1,952	6,283	10,230	12,580	51,760
	Iron	2	1,980	--	--	--	3,050
Sundance aquifer	pH (standard units)	82	4.9	7.5	8.0	8.3	9.9
	Calcium	107	8.0	70.0	141	264	2,667
	Magnesium	104	4.0	18.5	33.0	56.1	945
	Potassium	35	6.0	11.0	25.0	49.0	160
	Sodium	107	199	1,848	2,909	3,697	12,210
	Sodium adsorption ratio (unitless)	107	2.3	38.4	54.8	74.9	159
	Bicarbonate	107	68.0	495	701	983	2,452
	Carbonate	25	5.0	36.0	60.0	97.0	300
	Chloride	107	16.0	430	1,790	3,440	17,330
	Sulfate	106	2.0	1,832	2,902	3,958	8,562
	Total dissolved solids	106	1,233	5,804	8,560	11,240	33,660
	Iron	3	90.0	--	240	--	18,410
Chugwater confining unit	pH (standard units)	32	5.3	7.7	8.3	8.5	9.4
	Calcium	32	3.0	15.5	21.0	46.0	532
	Magnesium	32	1.0	5.0	12.0	21.5	218
	Potassium	20	3.0	4.5	5.5	10.0	38.0
	Sodium	32	367	488	708	897	10,500

Appendix G-2. Summary statistics for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; values in blue are in micrograms per liter. --, not applicable; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Chugwater confining unit —Continued	Sodium adsorption ratio (unitless)	32	7.4	24.0	28.2	38.6	121
	Bicarbonate	32	110	604	1,049	1,745	3,660
	Carbonate	17	12.0	36.0	78.0	108	300
	Chloride	31	32.0	56.0	112	248	14,100
	Sulfate	31	40.0	230	380	635	4,880
	Total dissolved solids	32	1,049	1,544	2,174	3,465	30,500
	Iron	1	--	--	--	--	920
Spearfish aquifer	pH (standard units)	1	--	--	--	--	7.7
	Calcium	1	--	--	--	--	500
	Magnesium	1	--	--	--	--	117
	Potassium	1	--	--	--	--	124
	Sodium	1	--	--	--	--	3,759
	Sodium adsorption ratio (unitless)	1	--	--	--	--	39.3
	Bicarbonate	1	--	--	--	--	827
	Chloride	1	--	--	--	--	3,940
	Sulfate	1	--	--	--	--	3,950
	Total dissolved solids	1	--	--	--	--	10,320
Goose Egg confining unit	pH (standard units)	7	7.8	8.1	8.2	8.2	8.5
	Calcium	7	251	306	322	474	474
	Magnesium	7	24.0	41.0	52.0	65.0	97.0
	Potassium	2	30.0	--	--	--	50.0
	Sodium	7	334	429	1,276	2,981	3,243
	Sodium adsorption ratio (unitless)	7	3.9	6.6	16.6	38.0	43.1
	Bicarbonate	7	78.0	108	537	1,150	1,340
	Carbonate	2	10.0	--	--	--	14.0
	Chloride	7	160	228	680	700	812
	Sulfate	7	282	1,716	2,565	5,522	5,806
	Total dissolved solids	7	2,028	2,802	5,186	10,150	10,800

Appendix G-3

Summary statistics for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the NERB excluding Wind River structural basin, Wyoming

Appendix G-3. Summary statistics for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Minnekahta aquifer	pH (standard units)	12	6.1	7.1	7.5	7.9	9.0
	Calcium	13	294	522	589	1,708	27,730
	Magnesium	12	34.0	110	172	327	10,020
	Potassium	5	13.0	26.0	42.0	48.0	450
	Sodium	13	132	407	2,284	30,810	72,650
	Sodium adsorption ratio (unitless)	13	1.2	4.8	28.8	132	348
	Bicarbonate	13	83.0	207	256	390	695
	Carbonate	2	36.0	--	--	--	120
	Chloride	13	21.0	46.1	420	50,000	125,000
	Sulfate	13	688	2,483	3,850	4,650	5,954
	Total dissolved solids	13	2,910	4,066	8,678	88,730	195,900
	Iron	1	--	--	--	--	40,000
Tensleep aquifer	pH (standard units)	156	6.2	7.1	7.6	8.0	11.4
	Calcium	173	6.0	219	299	403	2,205
	Magnesium	172	2.0	37.0	54.0	79.0	439
	Potassium	61	3.0	38.0	90.0	142	990
	Sodium	168	61.7	429	562	1,111	13,850
	Sodium adsorption ratio (unitless)	173	0.36	5.9	8.1	14.2	174
	Bicarbonate	171	73.0	171	244	407	2,795
	Carbonate	22	6.0	24.0	36.5	79.0	1,780
	Chloride	173	8.0	310	600	845	18,500
	Sulfate	173	7.0	821	1,080	1,576	10,320
	Total dissolved solids	173	1,138	2,349	2,962	4,553	41,000
	Iron	8	100	185	625	4,400	56,000
Amsden hydrogeologic unit	pH (standard units)	4	6.4	6.8	7.2	8.4	9.6
	Calcium	7	23.0	80.0	292	332	415
	Magnesium	6	8.0	12.0	41.0	63.0	114
	Potassium	1	--	--	--	--	175
	Sodium	7	468	474	548	868	1,223
	Sodium adsorption ratio (unitless)	7	6.6	7.0	8.3	14.3	56.0
	Bicarbonate	6	8.0	123	279	425	925
	Carbonate	3	14.0	--	34.0	--	483
	Chloride	7	12.0	420	612	742	940
	Sulfate	7	484	573	1,025	1,154	1,597
	Total dissolved solids	7	1,964	2,069	2,538	3,186	3,921
Minnelusa aquifer	pH (standard units)	861	3.9	6.8	7.3	7.8	10.8
	Calcium	929	1.0	432	607	976	16,000
	Magnesium	916	1.0	81.5	139	320	9,200

Appendix G-3. Summary statistics for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Minnelusa aquifer —Continued	Potassium	548	2.0	89.0	217	806	21,240
	Sodium	928	2.0	825	4,675	22,200	115,100
	Sodium adsorption ratio (unitless)	929	0.02	10.3	46.0	168	1,159
	Bicarbonate	903	2.1	268	458	708	13,680
	Carbonate	69	2.4	36.0	60.0	120	4,805
	Chloride	927	3.0	520	5,736	36,000	185,800
	Fluoride	2	0.20	--	--	--	2.0
	Sulfate	927	4.0	1,730	2,728	4,100	150,000
	Total dissolved solids	928	91.9	4,438	15,250	64,620	307,700
	Boron	11	1,200	4,800	17,500	45,600	101,940
	Iron	131	40.0	500	2,000	19,000	1,500,000
	Selenium	7	20.0	120	200	800	1,300
Madison aquifer	pH (standard units)	48	4.3	7.0	7.5	7.8	9.6
	Specific conductance (uS/cm)	1	--	--	--	--	550
	Calcium	54	2.0	156	275	334	1,746
	Magnesium	53	1.0	31.0	51.0	61.0	392
	Potassium	22	2.0	9.0	25.0	45.0	196
	Sodium	54	3.0	315	468	702	18,290
	Sodium adsorption ratio (unitless)	54	0.07	4.2	6.4	11.6	223
	Bicarbonate	53	12.0	131	178	299	1,269
	Carbonate	6	7.0	12.0	19.5	24.0	227
	Chloride	54	2.0	86.0	555	693	29,600
	Fluoride	2	1.4	--	--	--	3.0
	Sulfate	54	25.0	707	996	1,142	3,864
	Total dissolved solids	53	282	1,900	2,550	3,070	53,900
	Boron	2	40.0	--	--	--	360
	Iron	8	400	935	1,100	35,950	90,000
	Selenium	2	1.0	--	--	--	1.0
Bighorn aquifer	pH (standard units)	5	7.1	7.4	7.5	7.8	10.8
	Calcium	5	210	254	351	500	735
	Magnesium	4	15.0	41.0	71.0	99.5	124
	Sodium	4	132	358	671	1,036	1,313
	Sodium adsorption ratio (unitless)	5	2.2	6.8	7.4	14.6	53.8
	Bicarbonate	5	120	270	360	370	410
	Carbonate	1	--	--	--	--	426
	Chloride	5	18.0	110	140	180	200
	Sulfate	5	826	1,876	3,326	3,675	5,308
	Total dissolved solids	5	1,304	3,219	5,286	5,917	9,061

Appendix G-3. Summary statistics for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area excluding Wind River structural basin, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter; µS/cm, microsiemens per centimeter at 25° Celsius; $CaCO_3$, calcium carbonate]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Gallatin hydrogeologic unit	Calcium	2	318	--	--	--	332
	Sodium	2	550	--	--	--	609
	Sodium adsorption ratio (unitless)	2	8.5	--	--	--	9.2
	Bicarbonate	1	--	--	--	--	43.0
	Chloride	2	760	--	--	--	825
	Sulfate	2	881	--	--	--	918
	Total dissolved solids	2	2,509	--	--	--	2,705
Precambrian basal confining unit	pH (standard units)	1	--	--	--	--	9.6
	Calcium	1	--	--	--	--	36.0
	Magnesium	1	--	--	--	--	4.9
	Potassium	1	--	--	--	--	19.0
	Sodium	1	--	--	--	--	1,197
	Sodium adsorption ratio (unitless)	1	--	--	--	--	49.7
	Bicarbonate	1	--	--	--	--	248
	Carbonate	1	--	--	--	--	37.5
	Chloride	1	--	--	--	--	568
	Sulfate	1	--	--	--	--	1,608
	Total dissolved solids	1	--	--	--	--	3,718

Appendix H

Summary statistics for produced-water samples from hydrogeologic units in the Wind River structural basin within the NERB, Wyoming

Appendix H. Summary statistics for produced-water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Wind River aquifer	pH (standard units)	4	7.2	7.8	8.5	8.6	8.6
	Calcium	4	11.0	11.5	14.5	19.5	22.0
	Magnesium	4	2.0	2.5	4.0	7.0	9.0
	Potassium	3	9.0	--	12.0	--	20.0
	Sodium	4	440	507	614	834	1,013
	Sodium adsorption ratio (unitless)	4	31.0	32.9	35.4	42.7	49.4
	Bicarbonate	4	708	714	751	1,074	1,366
	Carbonate	3	72.0	--	96.0	--	132
	Chloride	4	136	185	267	520	740
	Sulfate	4	60.0	99.0	178	259	300
	Total dissolved solids	4	1,117	1,301	1,638	2,197	2,603
Fort Union aquifer	pH (standard units)	31	6.4	7.6	7.9	8.4	8.9
	Calcium	31	3.0	9.0	16.0	24.0	1,242
	Magnesium	28	0.70	3.0	5.0	7.0	152
	Potassium	23	5.3	15.0	33.0	132	3,560
	Sodium	31	49.9	1,024	1,327	2,290	4,920
	Sodium adsorption ratio (unitless)	31	4.7	55.9	75.5	142	221
	Bicarbonate	31	114	1,513	2,294	3,001	3,855
	Carbonate	10	24.0	32.0	120	216	408
	Chloride	31	56.0	486	900	1,994	6,087
	Sulfate	29	3.0	20.0	70.0	257	1,249
	Total dissolved solids	31	270	2,459	3,720	6,087	15,900
	Iron	6	490	3,540	11,580	51,600	643,000
Lance aquifer	pH (standard units)	33	6.8	8.0	8.3	8.5	9.2
	Calcium	33	3.7	12.0	23.0	56.0	627
	Magnesium	31	1.0	3.7	10.0	21.0	111
	Potassium	19	9.3	18.2	72.0	126	425
	Sodium	33	803	1,440	2,055	2,870	7,197
	Sodium adsorption ratio (unitless)	33	38.0	70.3	90.2	113	289
	Bicarbonate	33	708	1,952	2,700	3,387	5,490
	Carbonate	13	34.0	60.9	70.0	128	252
	Chloride	33	90.0	504	1,090	2,260	10,000
	Sulfate	30	1.0	14.8	133	559	5,119
	Total dissolved solids	33	2,236	3,830	5,750	8,670	21,520
	Iron	14	50.0	82.0	337	810	21,000

Appendix H. Summary statistics for produced-water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Meeteetse confining unit	pH (standard units)	1	--	--	--	--	8.3
	Calcium	1	--	--	--	--	121
	Magnesium	1	--	--	--	--	48.0
	Potassium	1	--	--	--	--	23.0
	Sodium	1	--	--	--	--	970
	Sodium adsorption ratio (unitless)	1	--	--	--	--	18.9
	Bicarbonate	1	--	--	--	--	1,964
	Carbonate	1	--	--	--	--	84.0
	Chloride	1	--	--	--	--	422
	Sulfate	1	--	--	--	--	350
	Total dissolved solids	1	--	--	--	--	3,983
Mesaverde aquifer	pH (standard units)	1	--	--	--	--	9.5
	Calcium	1	--	--	--	--	11.0
	Magnesium	2	3.0	--	--	--	7.0
	Sodium	1	--	--	--	--	538
	Sodium adsorption ratio (unitless)	2	23.7	--	--	--	66.6
	Bicarbonate	2	224	--	--	--	1,304
	Carbonate	1	--	--	--	--	165
	Chloride	2	27.0	--	--	--	81.0
	Sulfate	1	--	--	--	--	431
	Total dissolved solids	2	1,132	--	--	--	1,263
Cody confining unit	Calcium	2	37.0	--	--	--	253
	Magnesium	2	218	--	--	--	325
	Sodium	2	467	--	--	--	1,666
	Sodium adsorption ratio (unitless)	2	4.6	--	--	--	23.0
	Bicarbonate	2	905	--	--	--	1,600
	Carbonate	1	--	--	--	--	79.0
	Chloride	2	42.0	--	--	--	302
	Sulfate	2	2,093	--	--	--	2,626
	Total dissolved solids	2	3,625	--	--	--	5,715
Frontier aquifer	pH (standard units)	3	6.4	--	8.2	--	8.6
	Calcium	11	6.0	14.0	30.0	76.0	268
	Magnesium	10	1.0	8.0	14.0	18.0	31.0
	Potassium	1	--	--	--	--	122
	Sodium	10	1,149	1,562	4,421	5,910	8,567

Appendix H. Summary statistics for produced-water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Frontier aquifer —Continued	Sodium adsorption ratio (unitless)	11	22.6	48.4	136	198	229
	Bicarbonate	11	251	1,700	2,174	2,754	4,730
	Carbonate	5	73.0	119	180	240	378
	Chloride	11	44.0	940	4,340	8,024	11,700
	Sulfate	7	10.0	13.0	40.0	96.0	761
	Total dissolved solids	11	1,161	3,808	9,734	16,310	22,700
	Iron	1	--	--	--	--	57,400
Mowry confining unit	Calcium	1	--	--	--	--	11.0
	Magnesium	1	--	--	--	--	2.0
	Sodium adsorption ratio (unitless)	1	--	--	--	--	30.7
	Bicarbonate	1	--	--	--	--	809
	Carbonate	1	--	--	--	--	35.0
	Chloride	1	--	--	--	--	26.0
	Sulfate	1	--	--	--	--	186
	Total dissolved solids	1	--	--	--	--	1,490
Muddy aquifer	pH (standard units)	14	6.8	8.1	8.3	8.5	9.3
	Calcium	14	8.0	14.0	25.5	135	800
	Magnesium	13	3.0	4.0	10.0	14.1	240
	Potassium	5	19.0	20.0	37.0	50.0	204
	Sodium	14	705	1,202	2,412	4,338	16,170
	Sodium adsorption ratio (unitless)	14	36.6	65.9	95.1	139	187
	Bicarbonate	14	363	1,220	2,056	2,489	4,510
	Carbonate	10	36.0	84.0	186	228	243
	Chloride	14	21.0	450	2,928	5,800	26,150
	Sulfate	12	20.0	22.5	58.0	152	588
	Total dissolved solids	14	1,688	3,029	6,783	12,170	43,790
	Iron	1	--	--	--	--	154,000
Cloverly aquifer	pH (standard units)	7	7.0	7.5	8.2	8.5	8.5
	Calcium	7	8.0	9.0	277	290	818
	Magnesium	7	2.0	3.0	64.0	107	222
	Sodium	7	902	993	1,778	3,041	16,320
	Sodium adsorption ratio (unitless)	7	19.6	24.6	43.1	81.4	131
	Bicarbonate	7	561	604	663	1,818	1,830
	Carbonate	3	24.1	--	144	--	156
	Chloride	7	128	132	402	3,528	26,830
	Sulfate	7	67.0	152	1,842	3,606	3,606
	Total dissolved solids	7	2,158	2,429	6,460	9,151	44,620

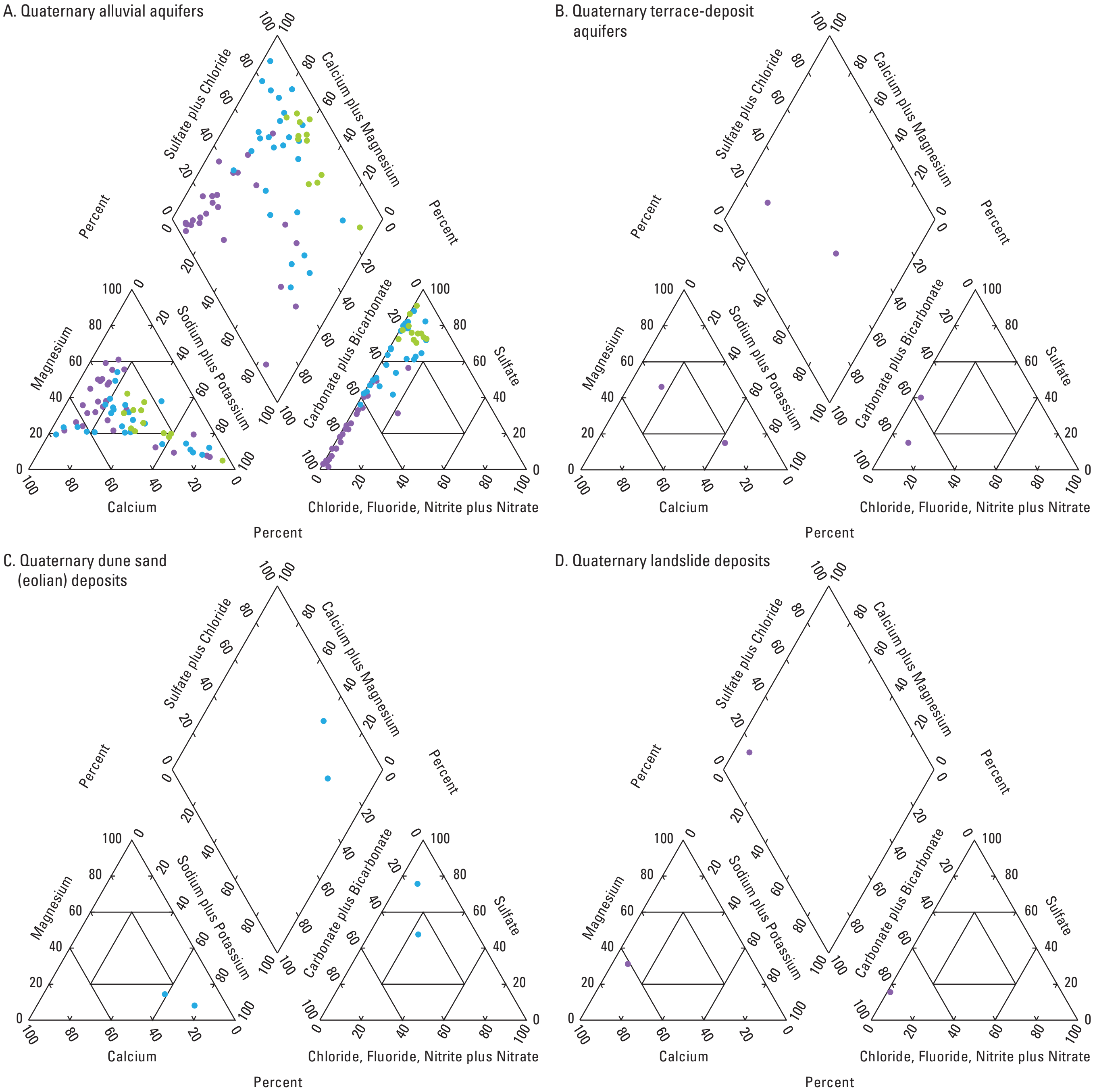
Appendix H. Summary statistics for produced-water samples from Cenozoic-, Mesozoic-, and Paleozoic-age hydrogeologic units in the Wind River structural basin, Northeastern River Basins study area, Wyoming.—Continued

[Values in black are in milligrams per liter unless otherwise noted; --, not applicable; values in blue are in micrograms per liter]

Hydrogeologic unit	Characteristic or constituent	Sample size	Minimum	25th percentile	Median	75th percentile	Maximum
Tensleep aquifer	pH (standard units)	1	--	--	--	--	7.7
	Calcium	1	--	--	--	--	382
	Magnesium	1	--	--	--	--	18.0
	Potassium	1	--	--	--	--	115
	Sodium	1	--	--	--	--	487
	Sodium adsorption ratio (unitless)	1	--	--	--	--	6.6
	Bicarbonate	1	--	--	--	--	464
	Chloride	1	--	--	--	--	340
	Sulfate	1	--	--	--	--	1,320
	Total dissolved solids	1	--	--	--	--	2,891

Appendix I-1

Trilinear diagrams for environmental samples from Cenozoic-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming

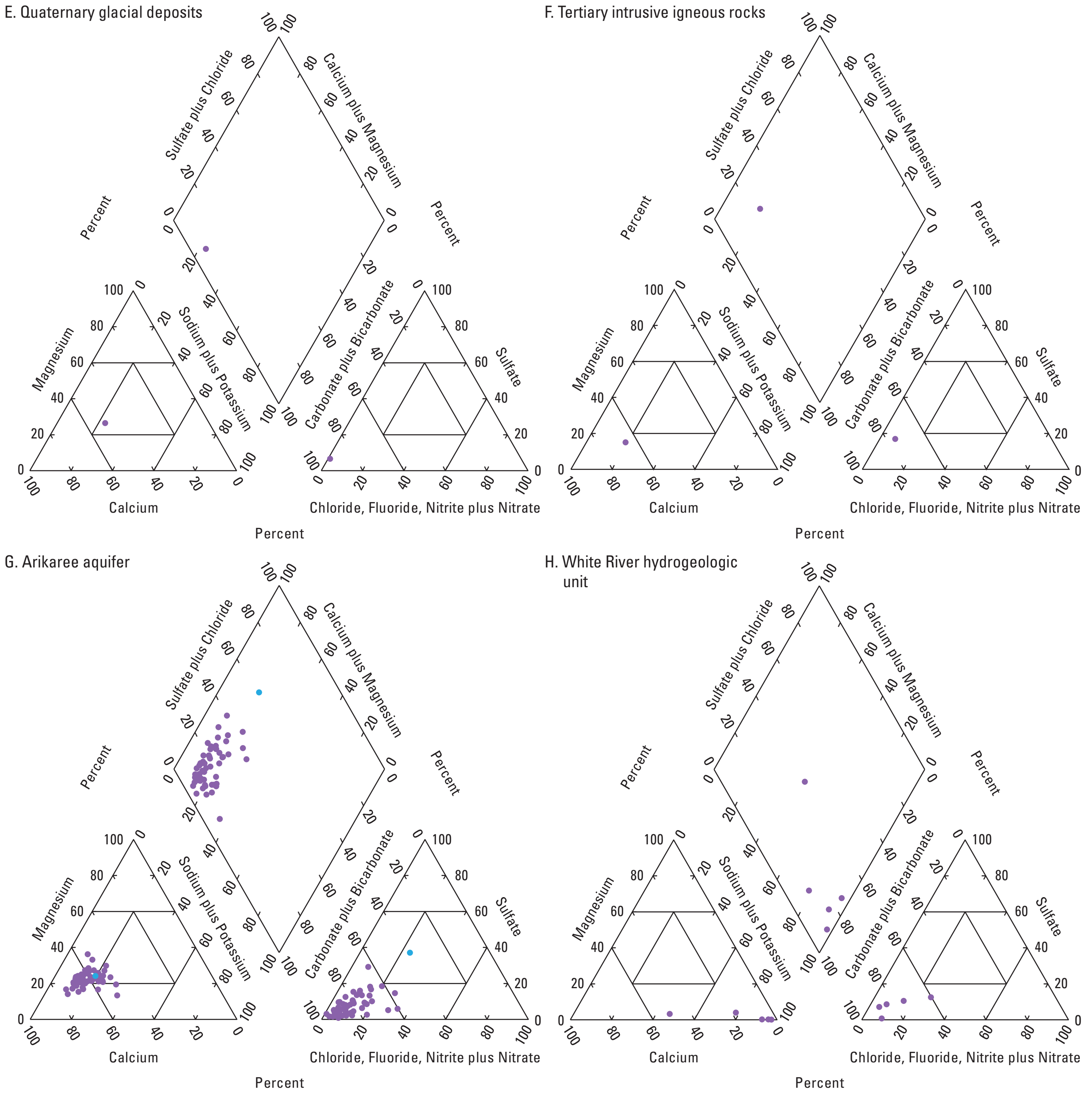


EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix I–1. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.



EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
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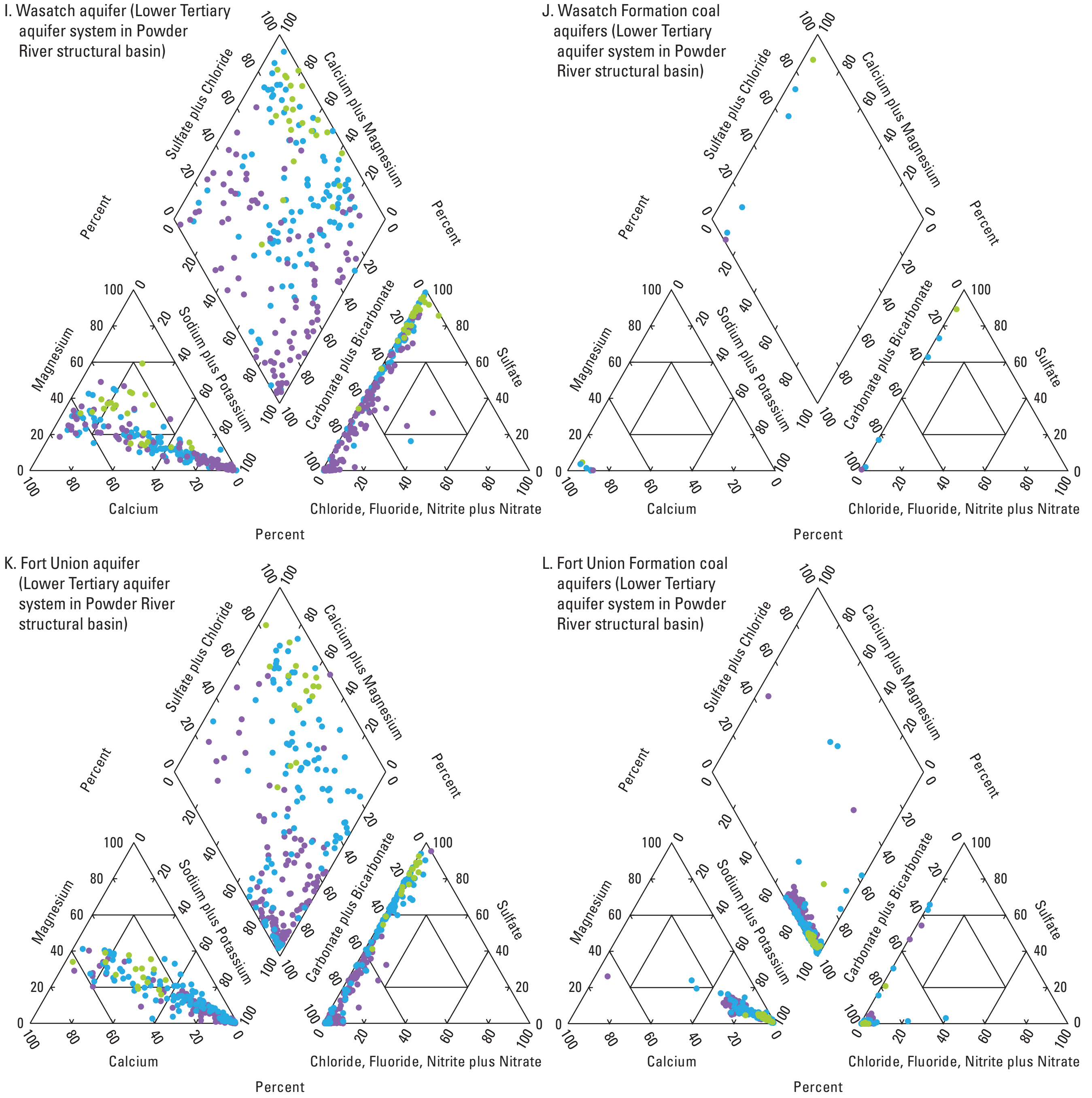
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix I–1. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued



EXPLANATION

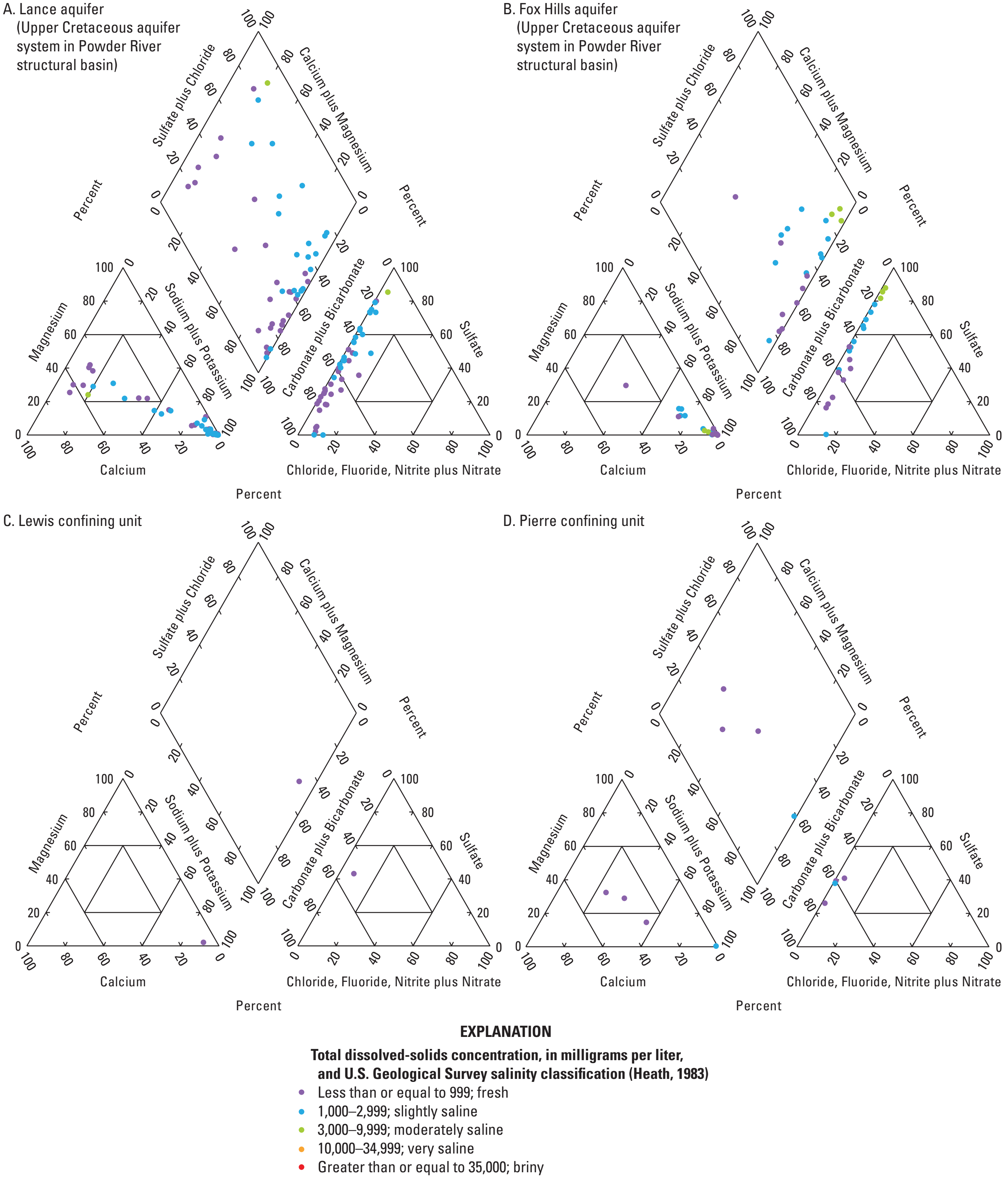
Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix I–1. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued

Appendix I-2

Trilinear diagrams for environmental samples from Mesozoic-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming



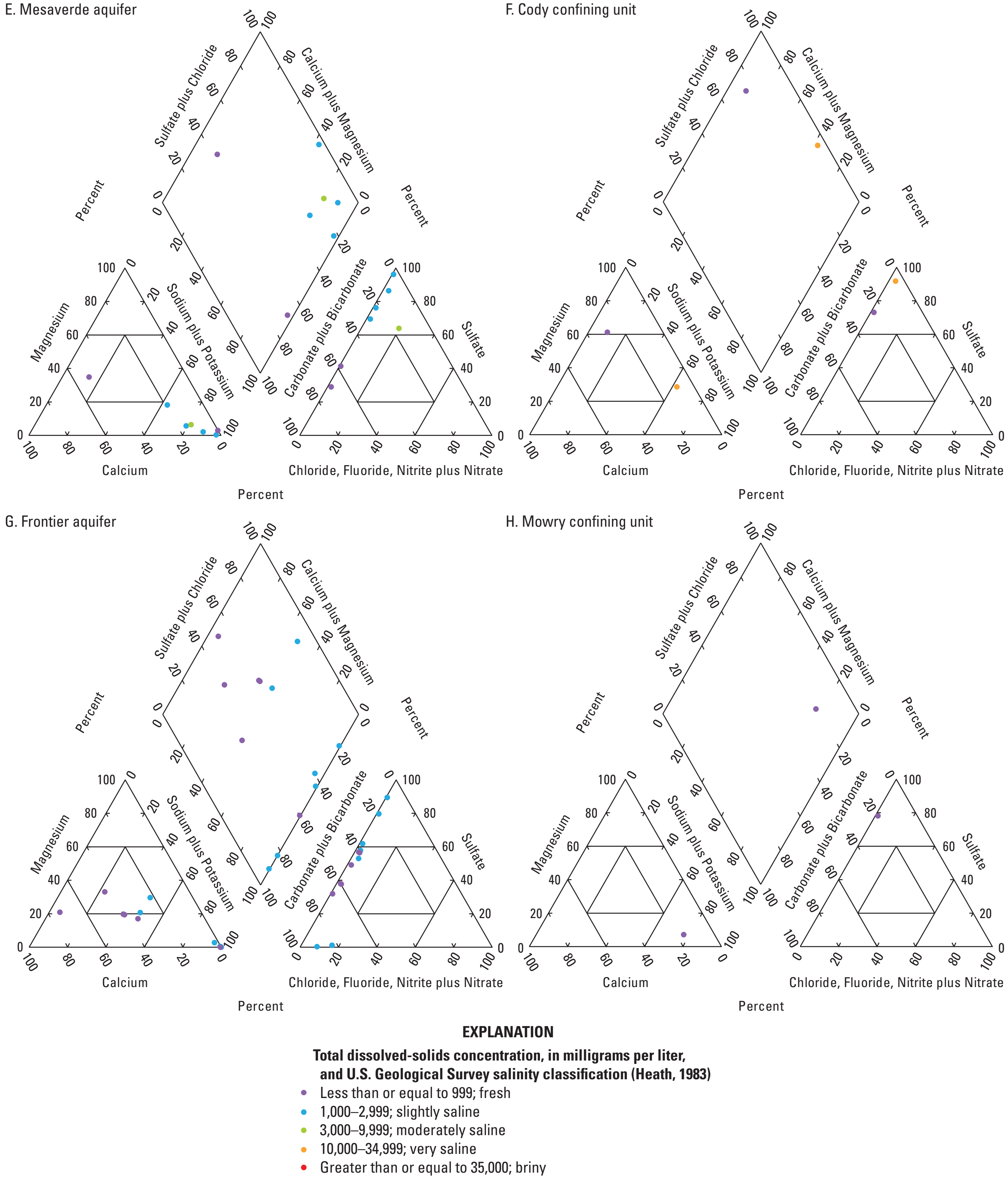
A. Lance aquifer (Upper Cretaceous aquifer system in Powder River structural basin)

B. Fox Hills aquifer (Upper Cretaceous aquifer system in Powder River structural basin)

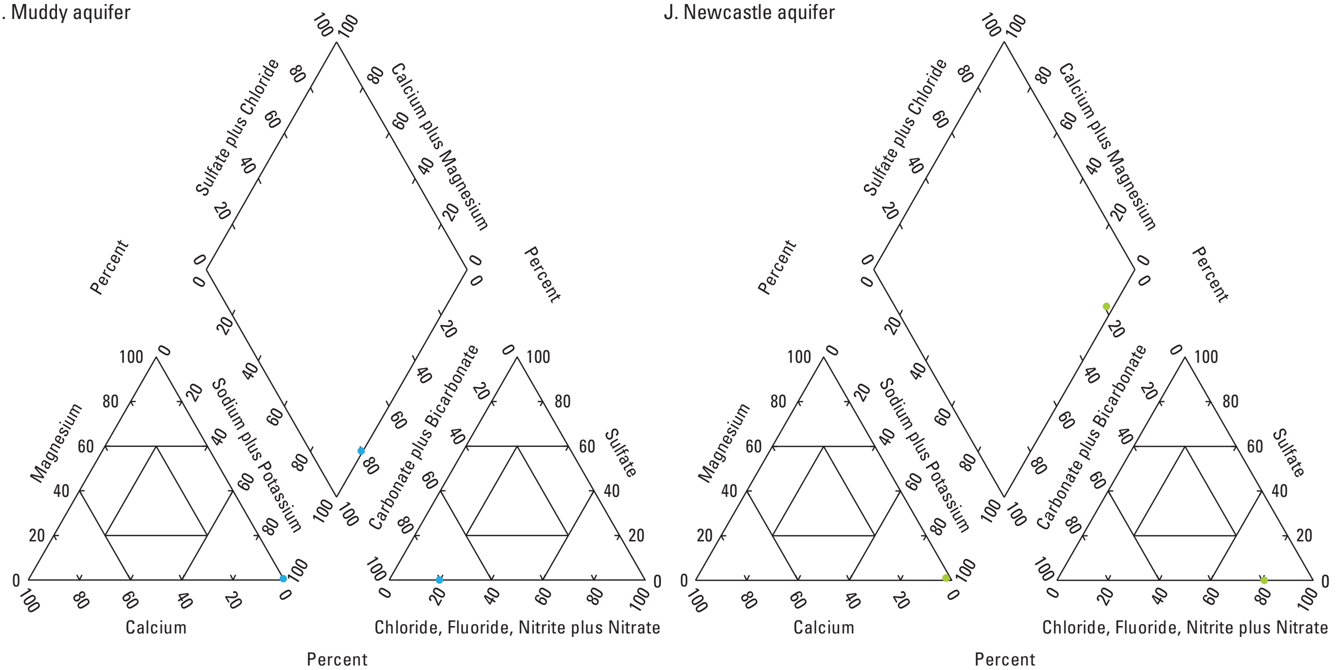
C. Lewis confining unit

D. Pierre confining unit

Appendix I–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.

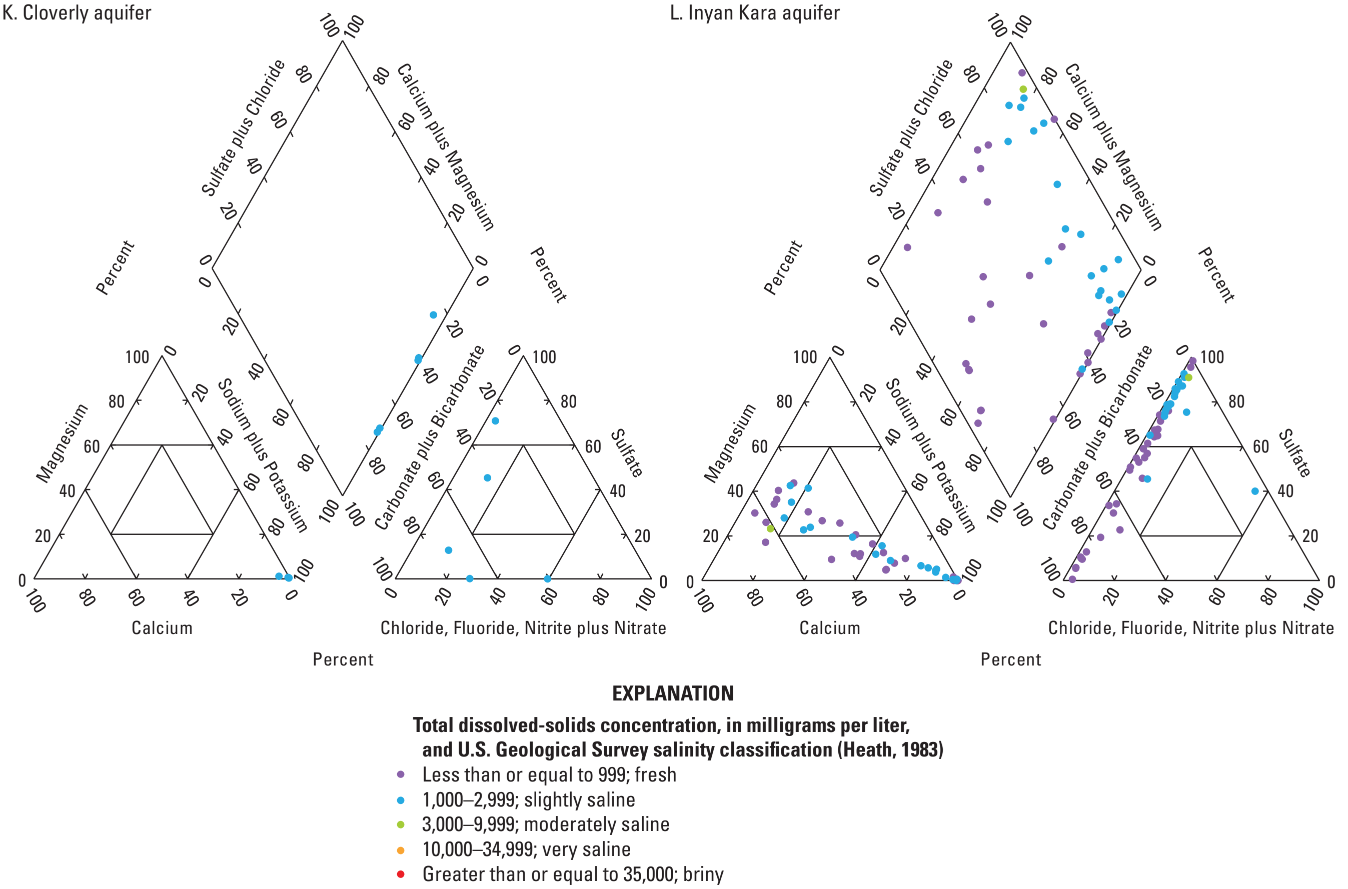


Appendix I–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued



I. Muddy aquifer

J. Newcastle aquifer



K. Cloverly aquifer

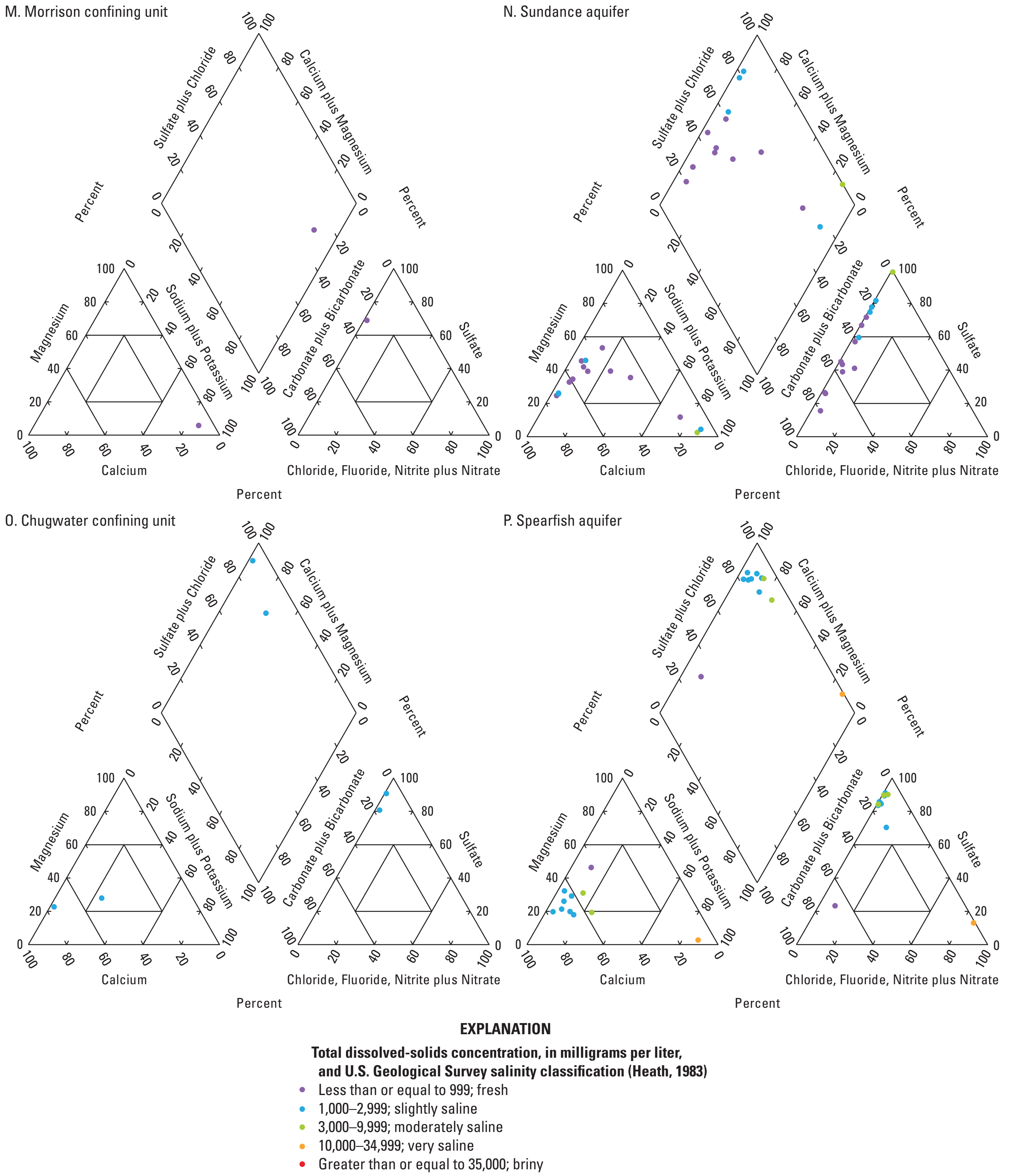
L. Inyan Kara aquifer

EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

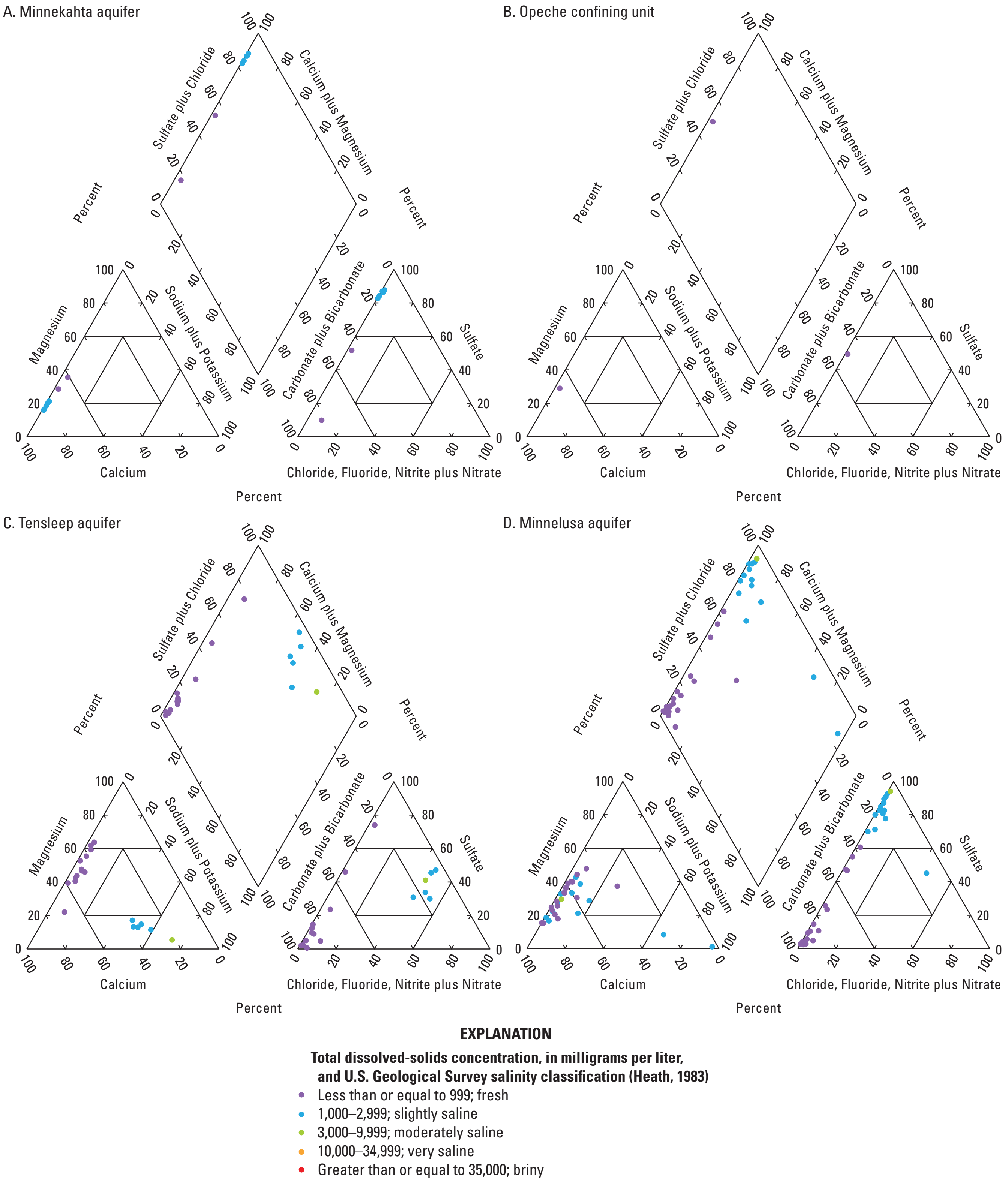
Appendix I–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued



Appendix I–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued

Appendix I-3

Trilinear diagrams for environmental samples from Paleozoic- and Precambrian-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming

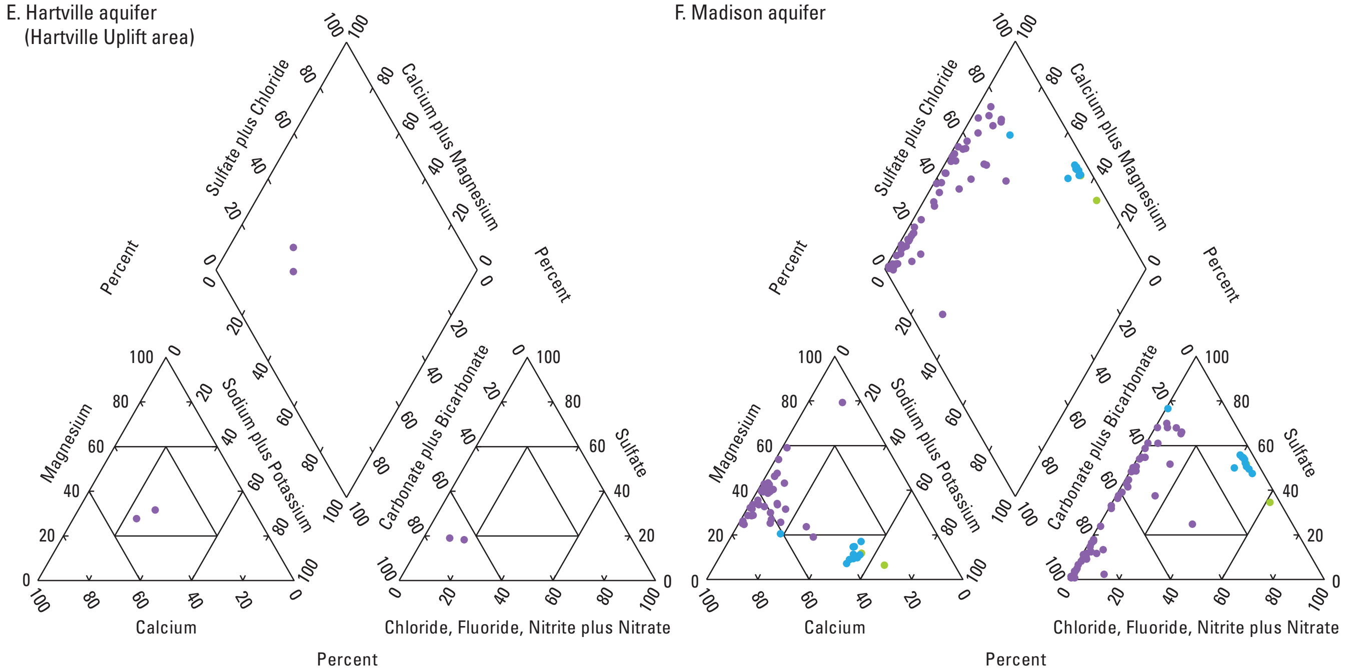

A. Minnekahta aquifer

B. Opeche confining unit

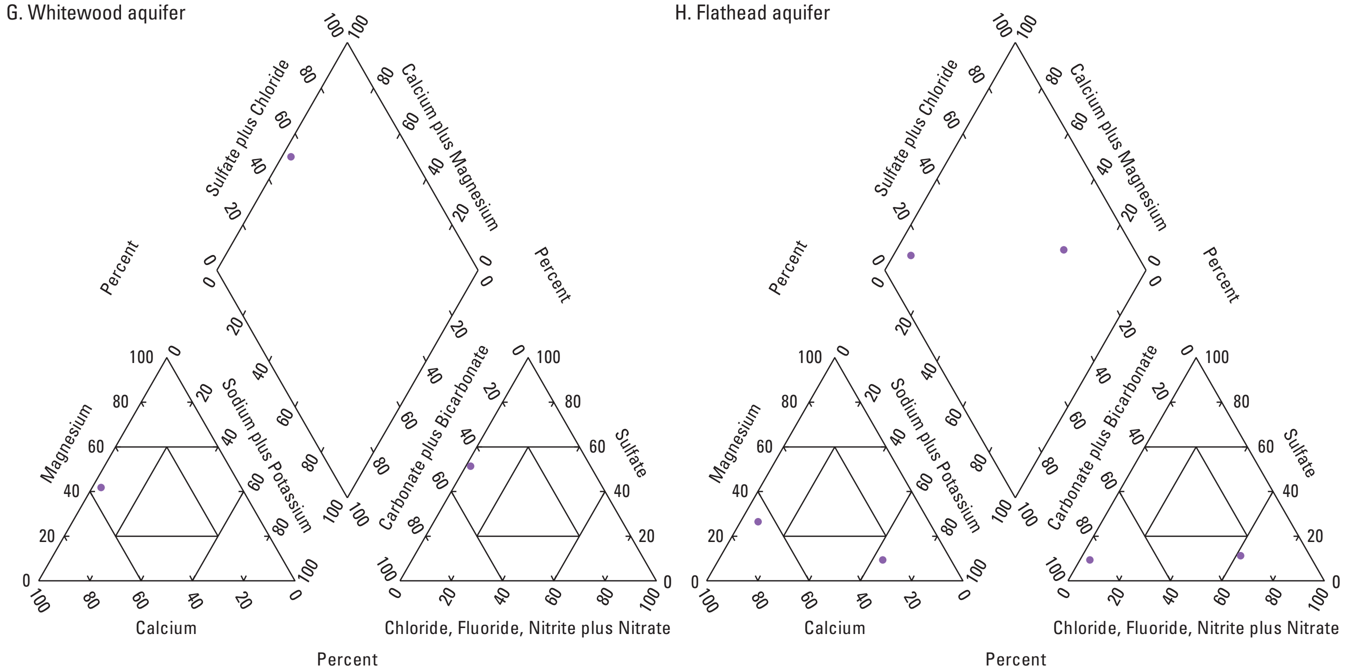
C. Tensleep aquifer

D. Minnelusa aquifer

Appendix I–3. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.


E. Hartville aquifer (Hartville Uplift area)

F. Madison aquifer


G. Whitewood aquifer

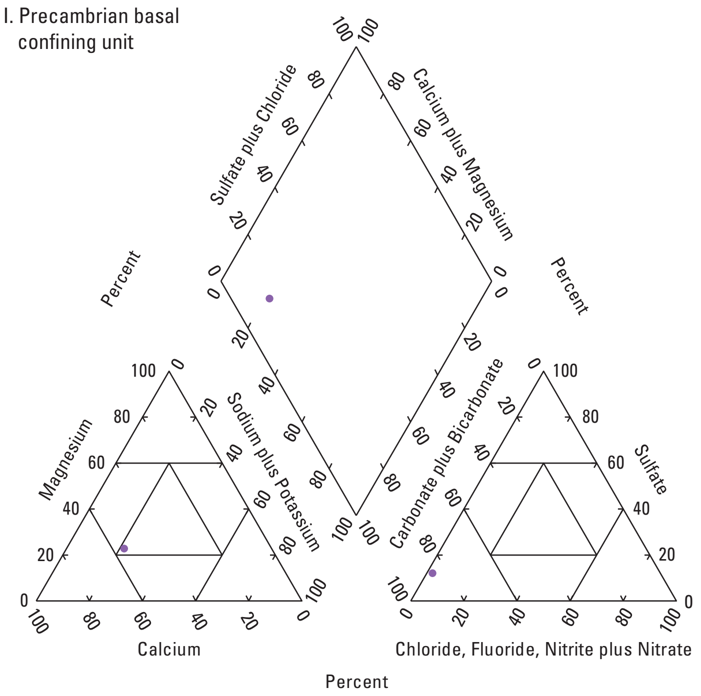
H. Flathead aquifer

EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix I–3. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued



EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

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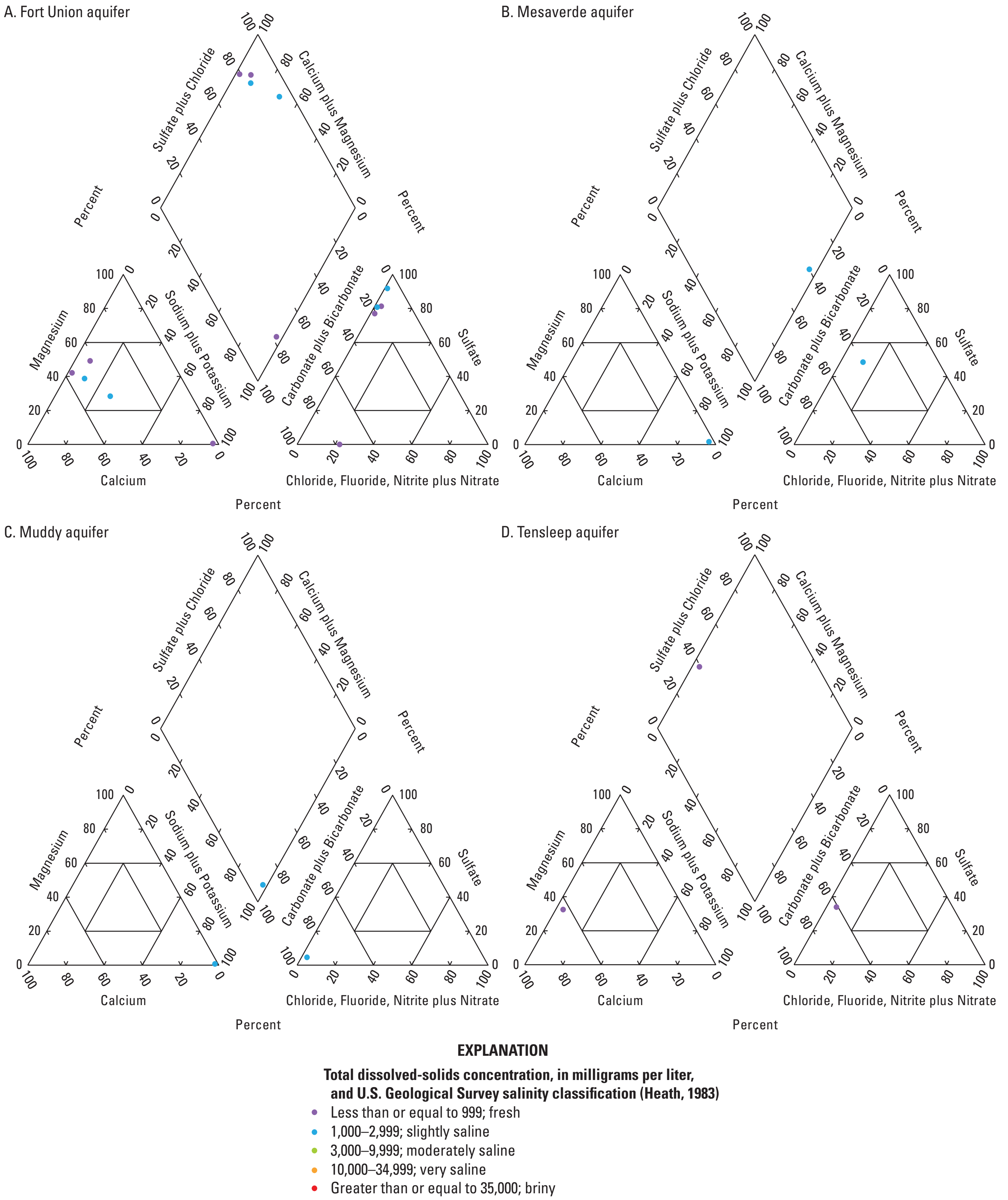
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix I–3. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued

Appendix J

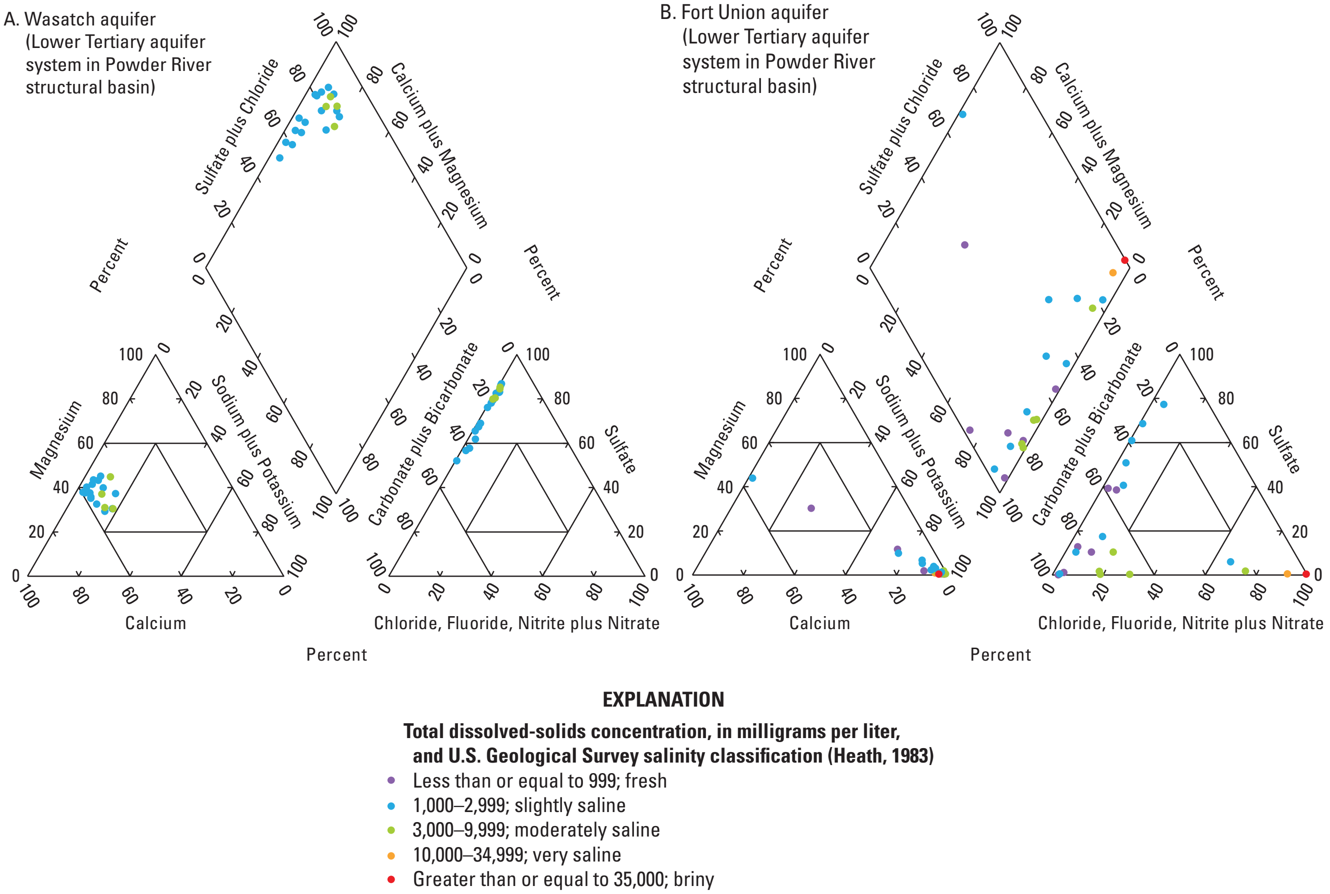
Trilinear diagrams for environmental samples from hydrogeologic units in the Wind River structural basin within the NERB, Wyoming



Appendix J. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for environmental water samples from hydrogeologic units in the Wind River structural basin within the Northeastern River Basins study area, Wyoming.

Appendix K-1

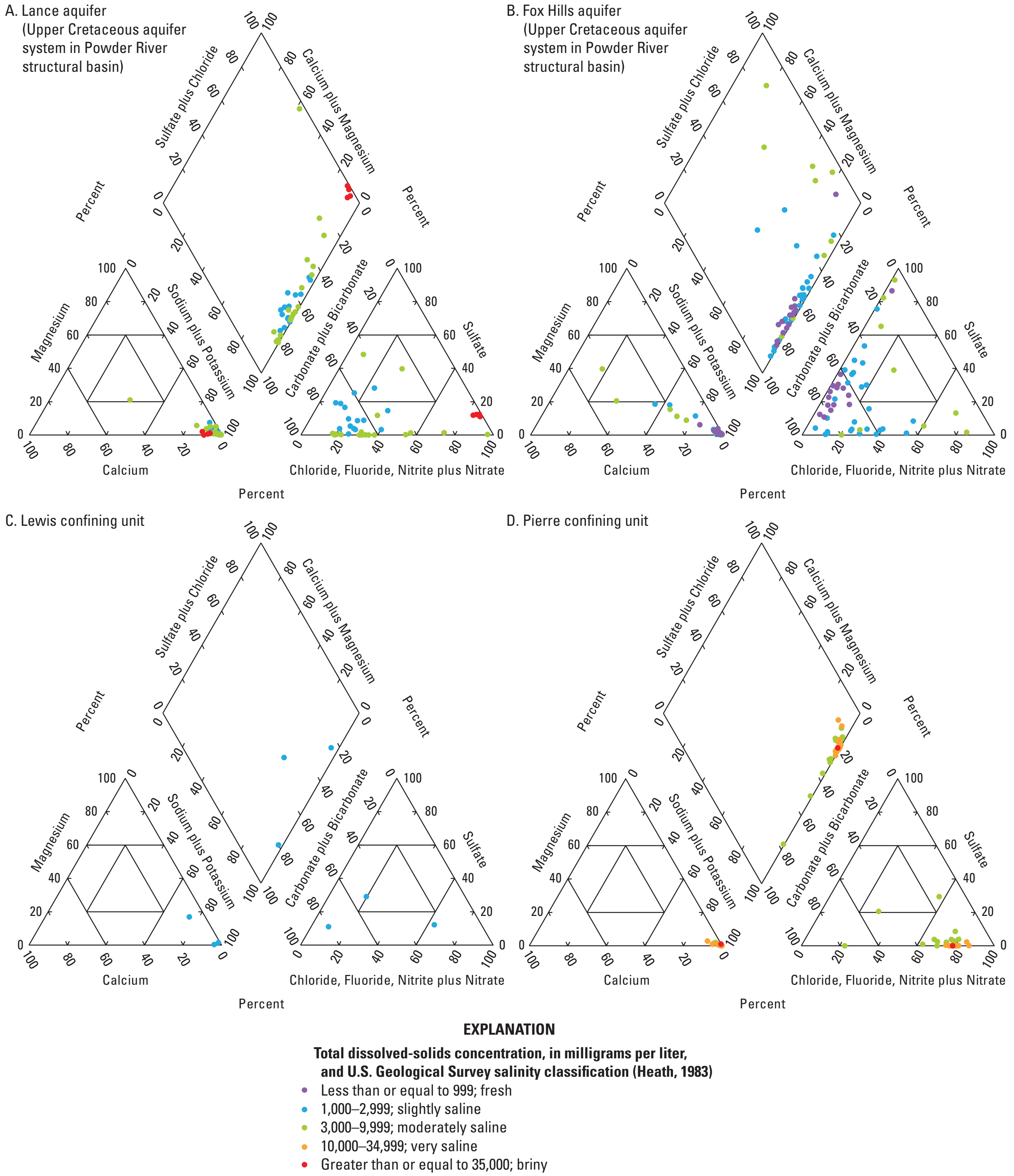
Trilinear diagrams for produced-water samples from Cenozoic-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming



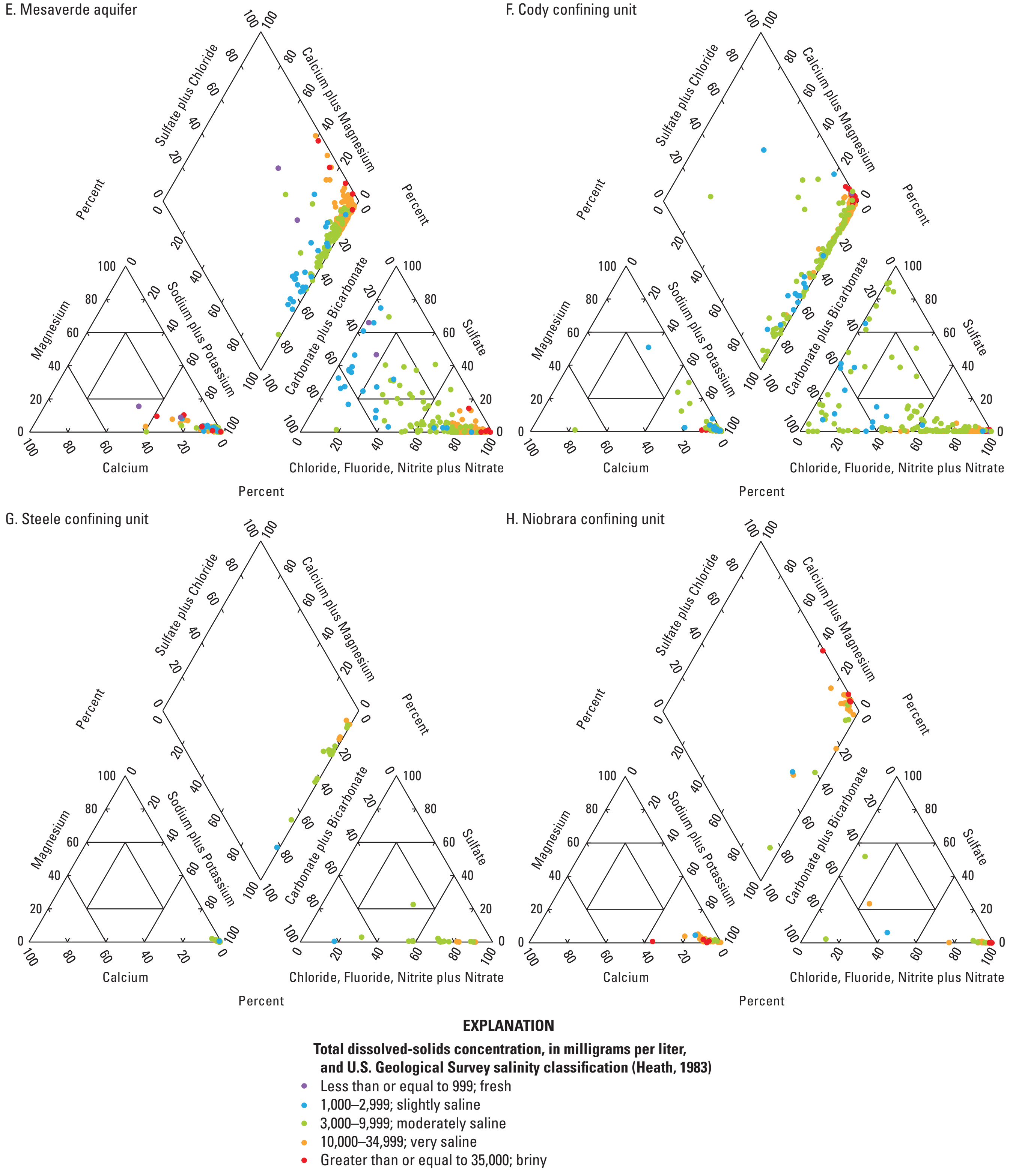
Appendix K–1. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Cenozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.

Appendix K-2

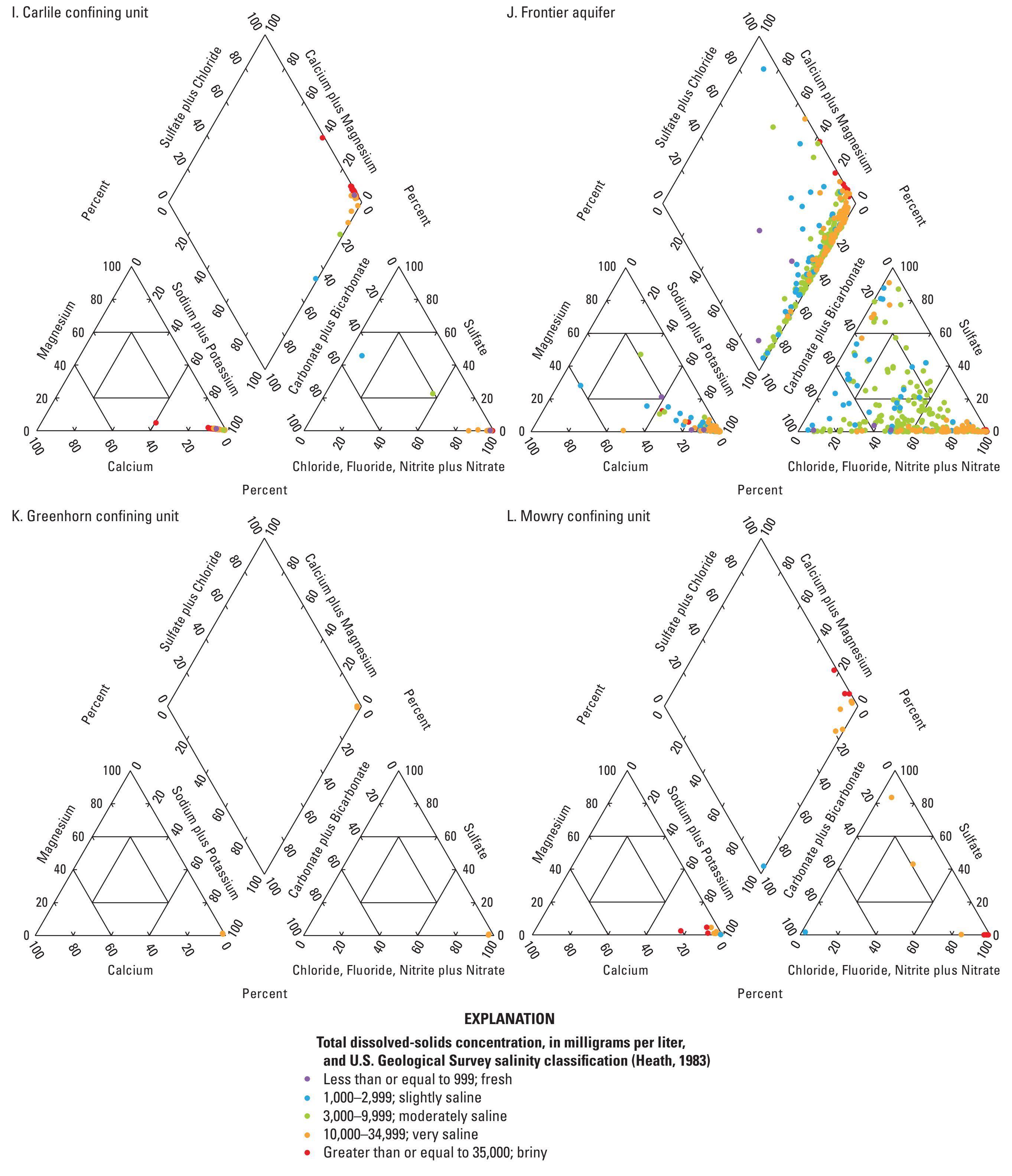
Trilinear diagrams for produced-water samples from Mesozoic-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming



Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.



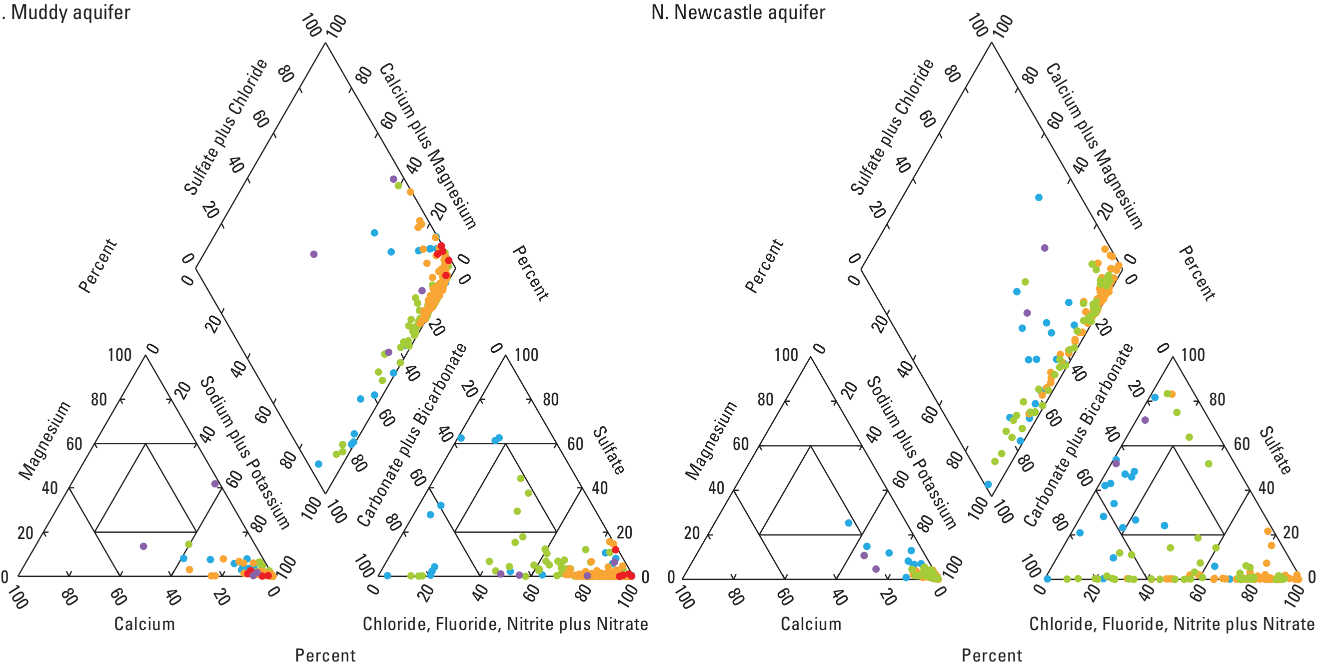
Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.–Continued



Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.–Continued

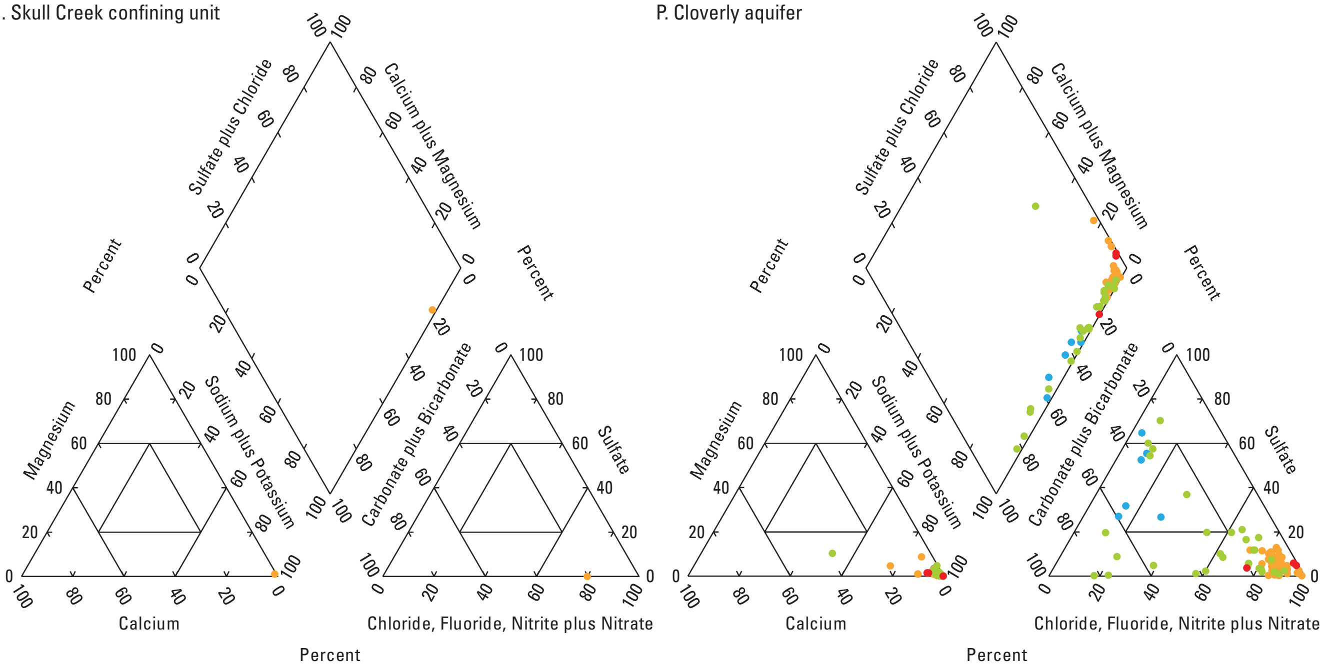
M. Muddy aquifer

N. Newcastle aquifer



O. Skull Creek confining unit

P. Cloverly aquifer

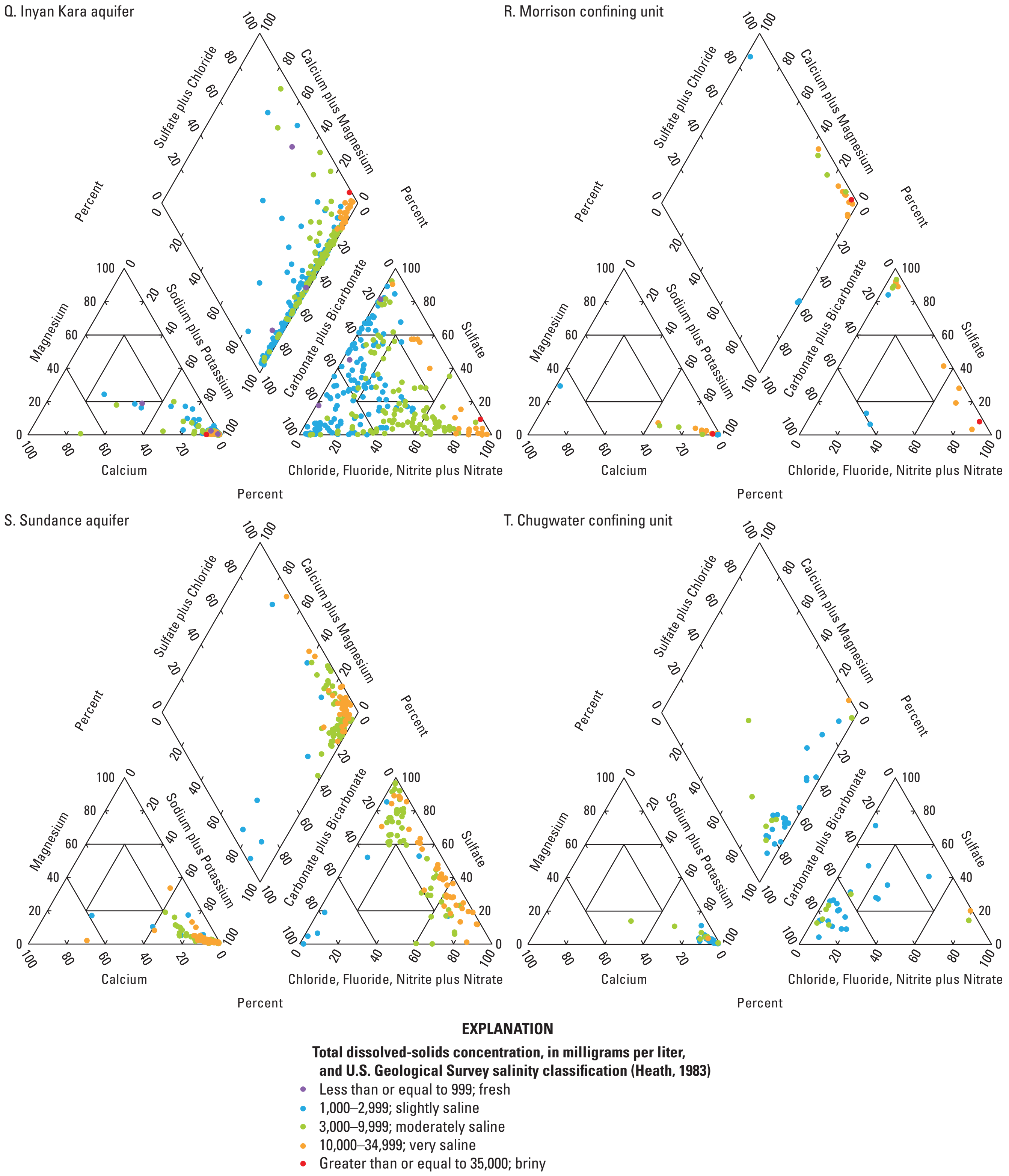


EXPLANATION

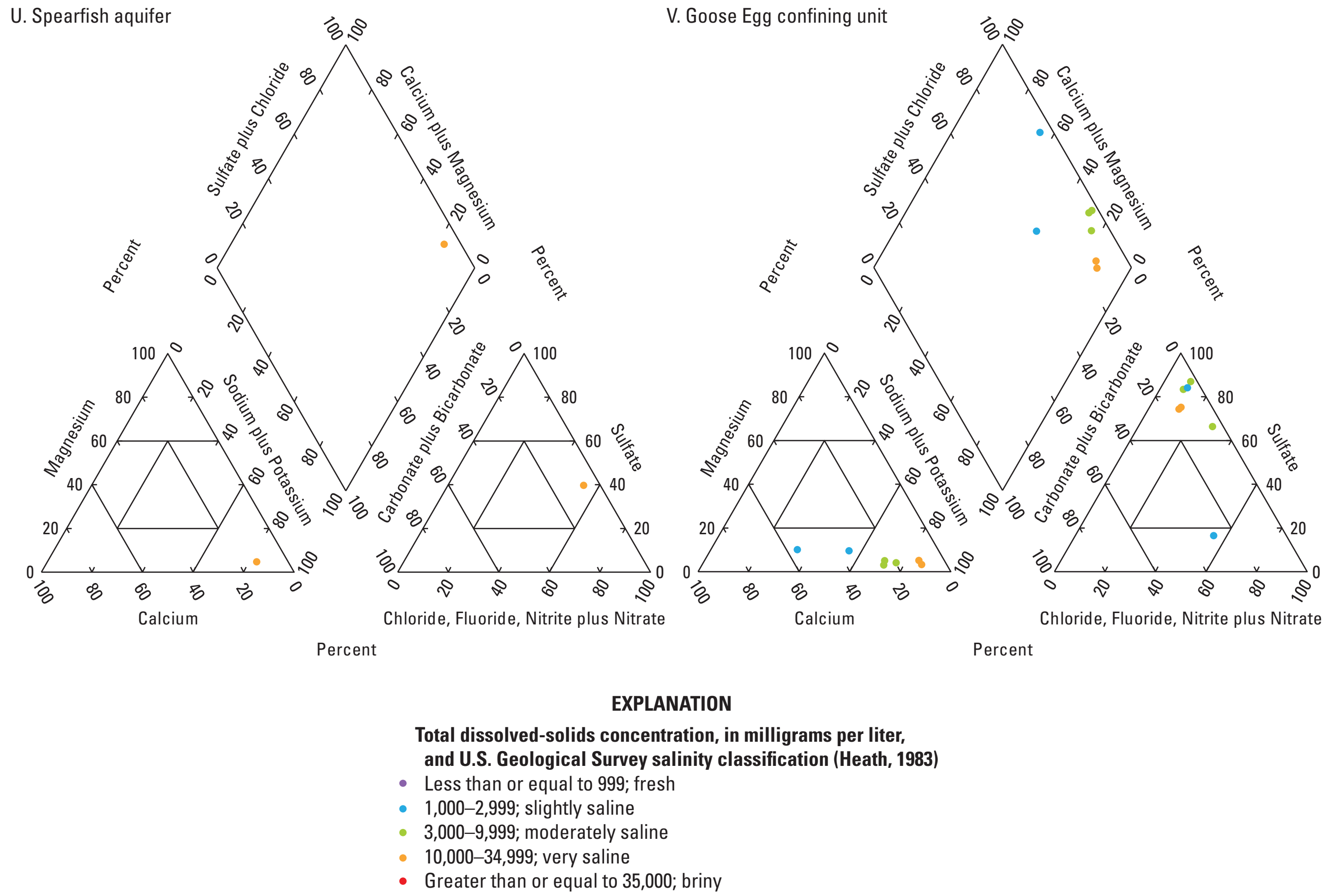
Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.–Continued



Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.–Continued

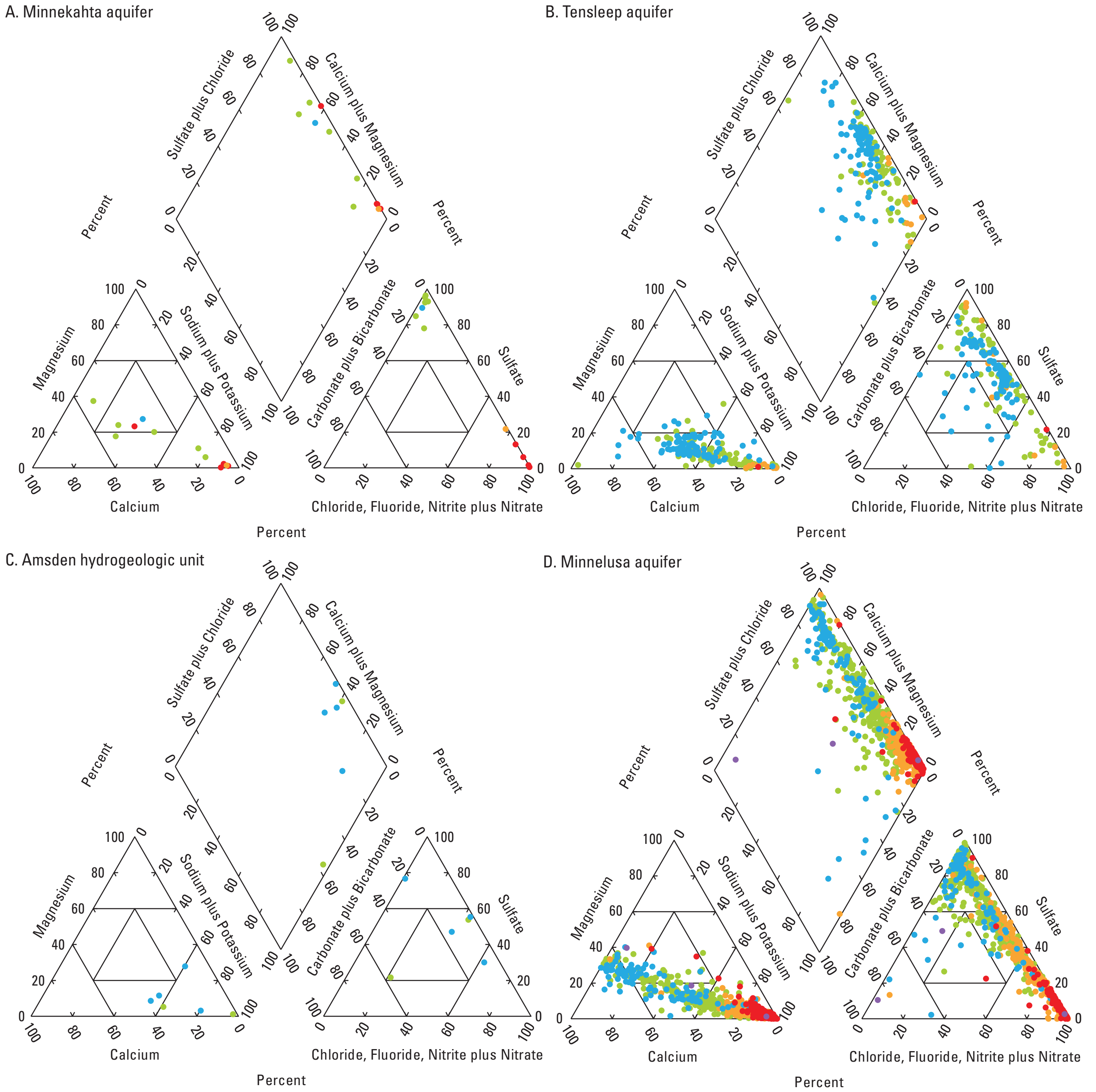

U. Spearfish aquifer

V. Goose Egg confining unit

Appendix K–2. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Mesozoic-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.–Continued

Appendix K-3

Trilinear diagrams for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the NERB, excluding Wind River structural basin, Wyoming


A. Minnekahta aquifer

B. Tensleep aquifer

C. Amsden hydrogeologic unit

D. Minnelusa aquifer

EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
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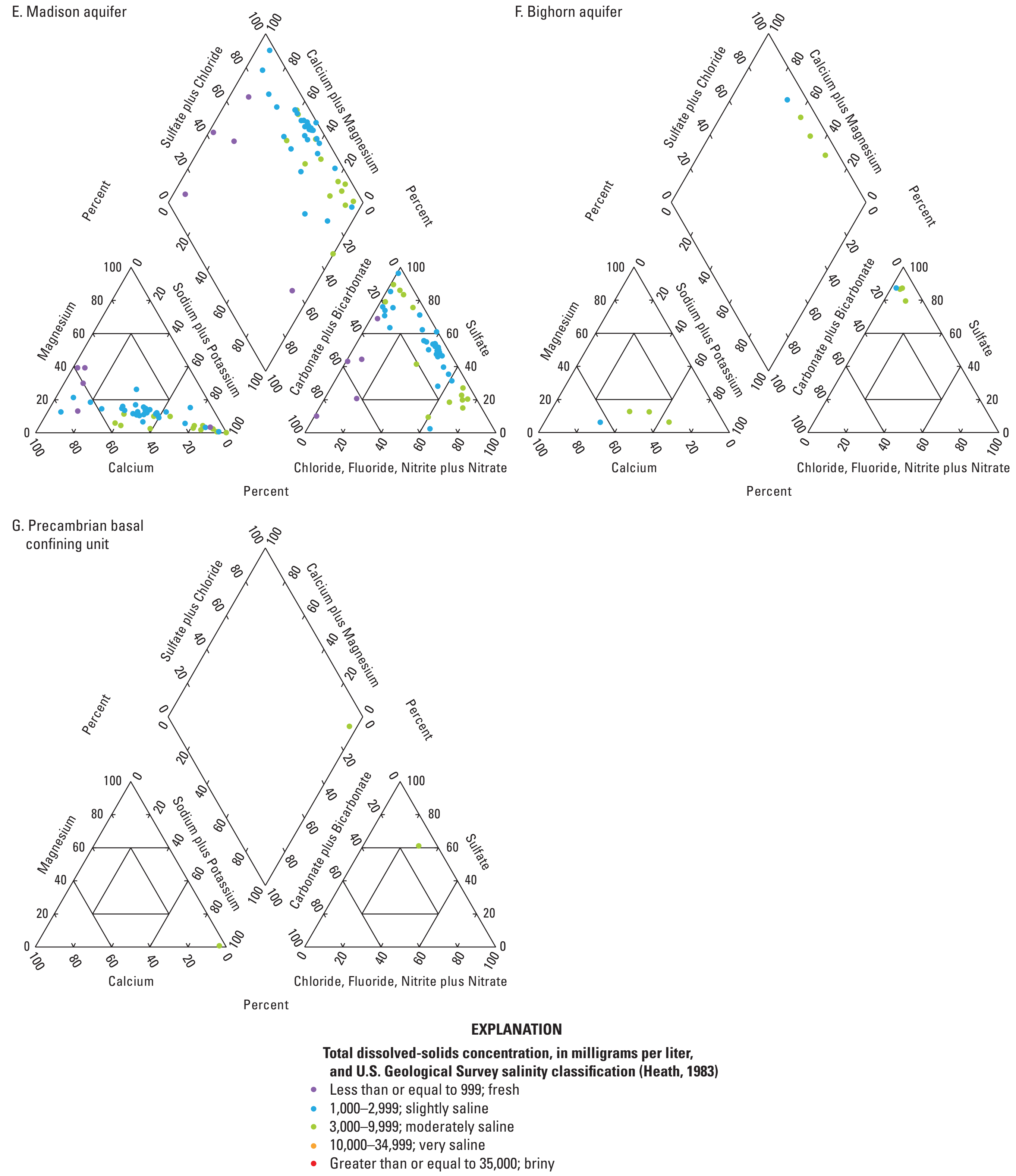
- ● Greater than or equal to 35,000; briny

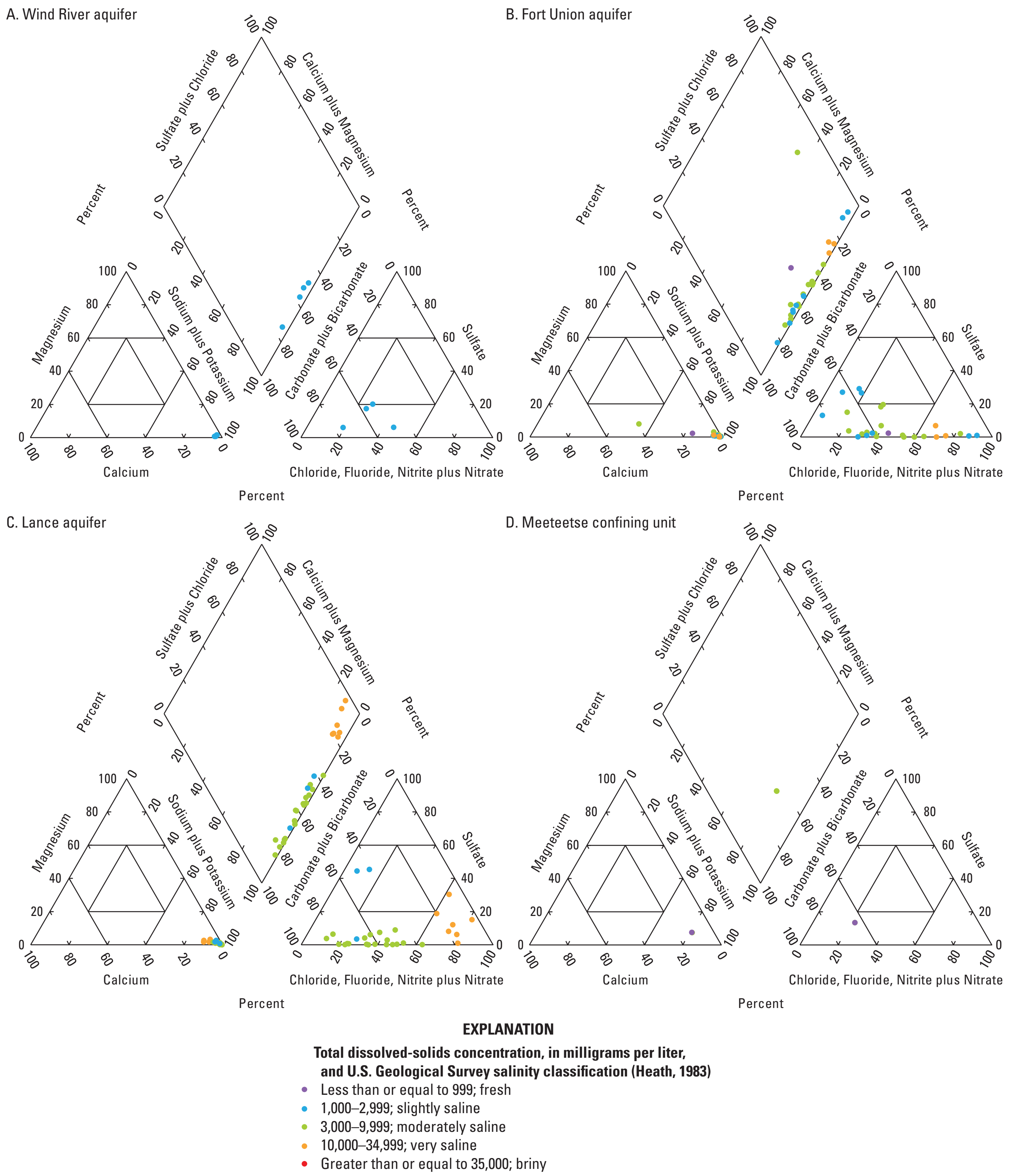
Appendix K–3. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.



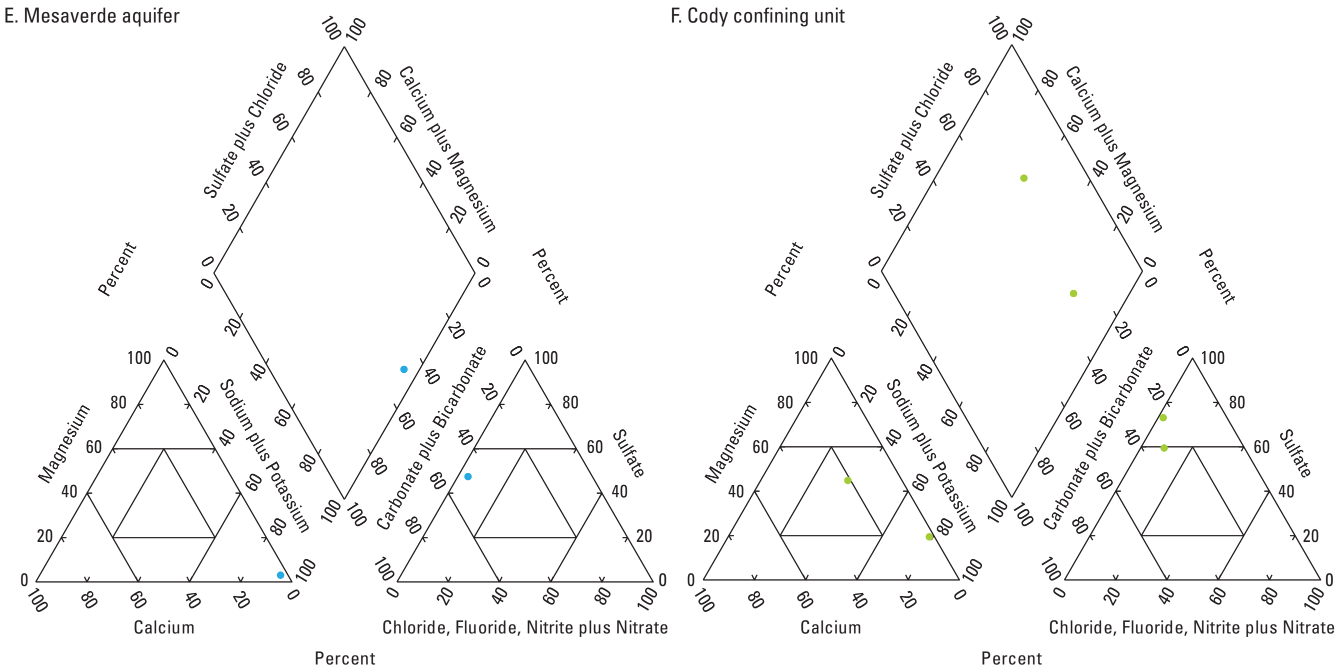
Appendix K–3. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from Paleozoic- and Precambrian-age hydrogeologic units in the Northeastern River Basins study area, excluding Wind River structural basin, Wyoming.—Continued

Appendix L

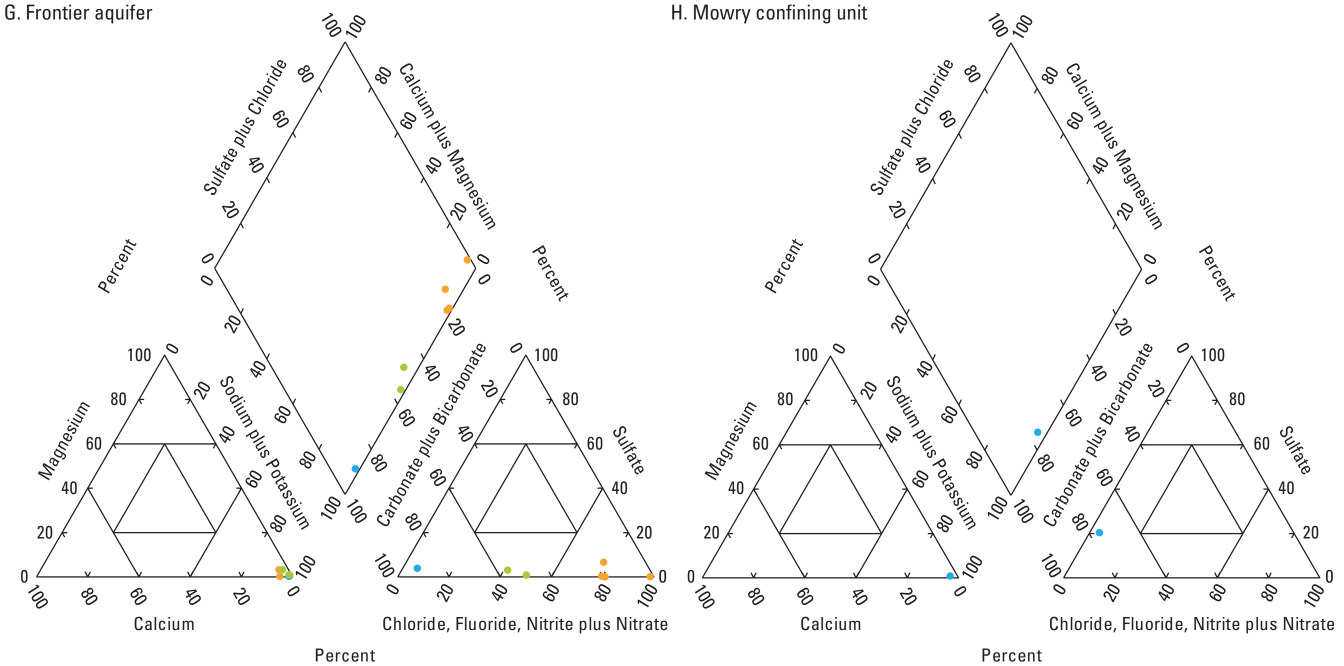
Trilinear diagrams for produced-water samples from hydrogeologic units in the Wind River structural basin within the NERB, Wyoming



Appendix L. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from hydrogeologic units in the Wind River structural basin within the Northeastern River Basins study area, Wyoming.


E. Mesaverde aquifer

F. Cody confining unit


G. Frontier aquifer

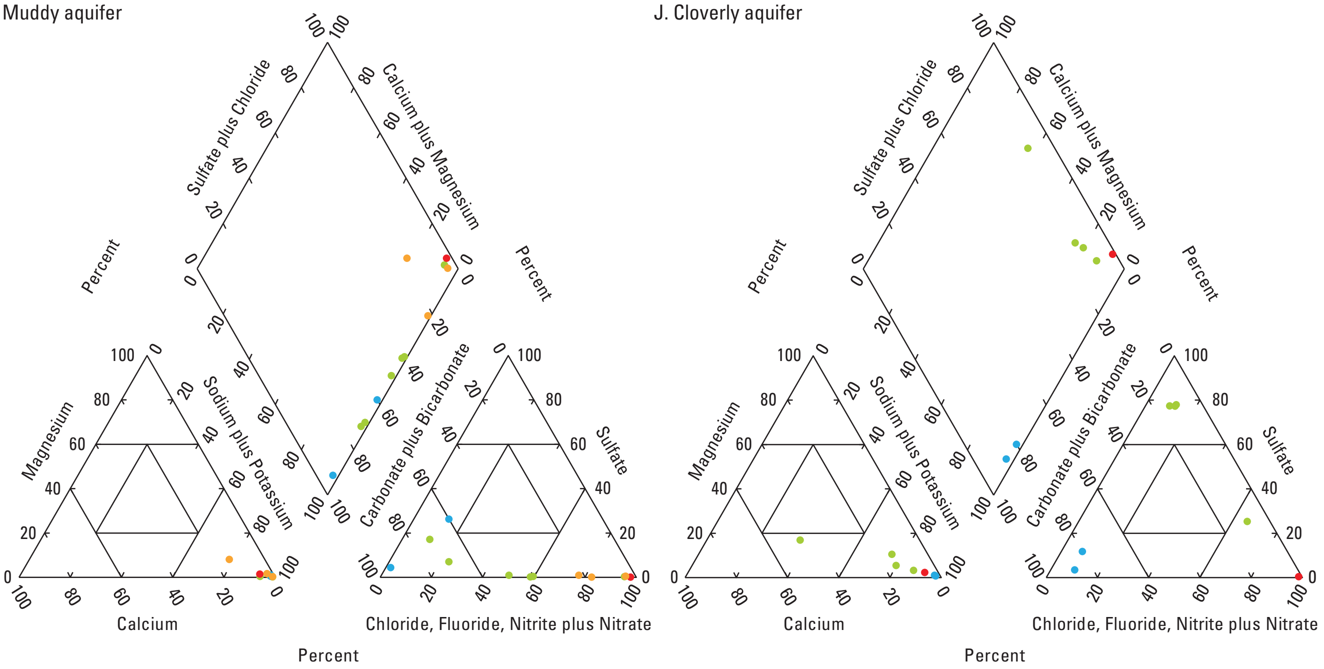
H. Mowry confining unit

EXPLANATION

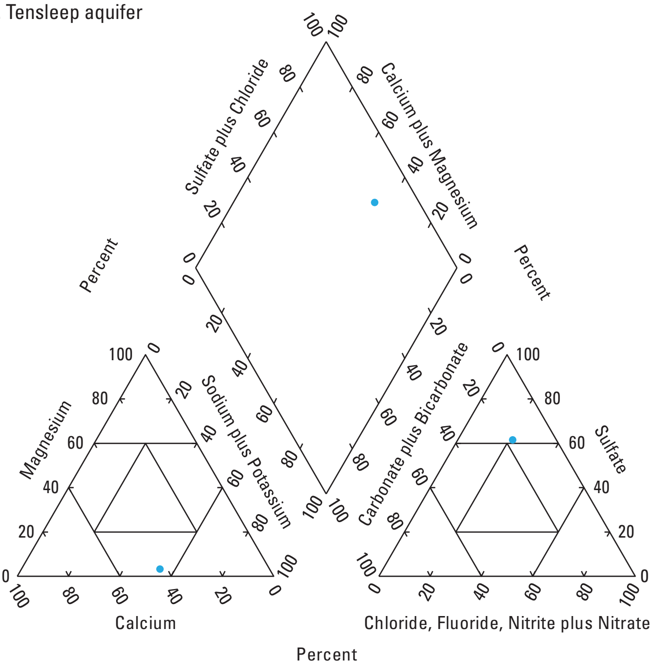
Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix L. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from hydrogeologic units in the Wind River structural basin within the Northeastern River Basins study area, Wyoming.—Continued


I. Muddy aquifer

J. Cloverly aquifer


K. Tensleep aquifer

EXPLANATION

Total dissolved-solids concentration, in milligrams per liter, and U.S. Geological Survey salinity classification (Heath, 1983)

- ● Less than or equal to 999; fresh
- ● 1,000–2,999; slightly saline
- ● 3,000–9,999; moderately saline
- ● 10,000–34,999; very saline
- ● Greater than or equal to 35,000; briny

Appendix L. Trilinear diagrams showing major-ion composition and total dissolved-solids concentrations for produced-water samples from hydrogeologic units in the Wind River structural basin within the Northeastern River Basins study area, Wyoming.—Continued

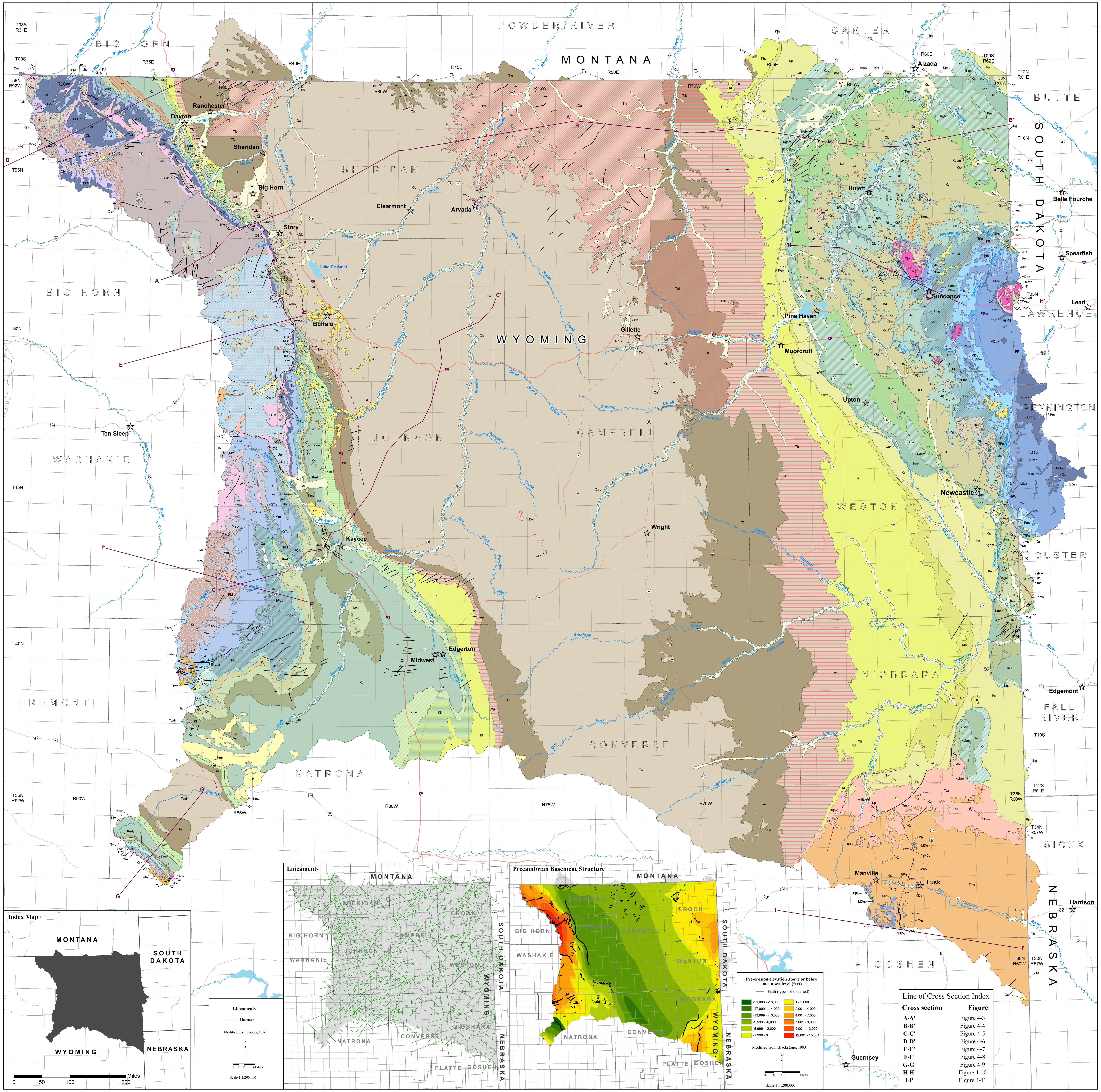
WYOMING STATE GEOLOGICAL SURVEY
Erin A. Campbell, Director and State Geologist
Laramie, Wyoming

Interpreting the past, providing for the future

Powder, Tongue, and Northeast River Basins Plan II - Available Groundwater Determination Technical Memorandum

Plate I

Bedrock Geology - Powder, Tongue, and Northeast River Basins



Line of Cross Section Index

Cross section	Figure
A-A'	Figure 4-3
B-B'	Figure 4-4
C-C'	Figure 4-5
D-D'	Figure 4-6
E-E'	Figure 4-7
F-F'	Figure 4-8
G-G'	Figure 4-9
H-H'	Figure 4-10
I-I'	Figure 4-11

Bedrock Geology - Powder, Tongue, and Northeast River Basins
Wyoming, Montana, Nebraska, and South Dakota

compiled by
Jacob D. Carnes, James E. Stafford, Andrea M. Loveland, and James R. Rodgers

Magnetic Declination = 9.03° E
at center of map
(November 5, 2019)

0 5 10 15 20 25 30 Miles

Scale 1:400,000

Explanation

Interstate highway
U.S. highway
State highway
Normal fault—dotted where concealed
Thrust fault—dotted where concealed
A—A′ Line of cross section
☆ City or town
☐ Township boundary
County boundary
State boundary
Lake or reservoir
River or creek

Bedrock Geology

Wyoming Geologic Units

CENOZOIC

Quaternary

Qa	Alluvium and colluvium
Qt	Gravel, pediment, and fan deposits
Qg	Glacial deposits
Qls	Landslide deposits
Qs	Dune sand and loess
Qu	Surficial deposits, undivided

Quaternary-Tertiary

QTg	Terrace gravels

Tertiary

Tmu	Upper Miocene rocks
Tml	Lower Miocene rocks
Tmo	Lower Miocene and Upper Oligocene rocks
Twr	White River Formation
Tid	Dacite and quartz latite intrusive and extrusive igneous rocks
Twb	Wagon Bed Formation
Tai	Alkalic intrusive and extrusive igneous rocks
Tw	Wasatch Formation
Twmo	Moncrief Member of the Wasatch Formation
Twk	Kingsbury Conglomerate Member of the Wastach Formation
Tie	Intrusive and extrusive igneous rocks
Twdr	Wind River Formation
Tim	Indian Meadows Formation
Tfu	Fort Union Formation
Tftr	Tongue River Member of the Fort Union Formation
Tfl	Lebo Member of the Fort Union Formation
Tft	Tullock Member of the Fort Union Formation
Tftl	Tongue River and Lebo members of the Fort Union Formation
Tflt	Lebo and Tullock members of the Fort Union Formation

MESOZOIC

Cretaceous

Kl	Lance Formation
Klm	Lance Formation, Fox Hills Sandstone, Meeteetse Formation, and Bearpaw and Lewis shales
Kfh	Fox Hills Sandstone
Kfl	Fox Hills Sandstone and Lewis Shale
Kfb	Fox Hills Sandstone and Bearpaw Shale
Kml	Meeteetse Formation and Lewis Shale
Kmv	Mesaverde Group
Kc	Cody Shale
Kf	Frontier Formation
Kft	Frontier Formation and Mowry and Thermopolis shales
Kp	Pierre Shale
Kn	Niobrara Formation
Knc	Niobrara Formation and Carlile Shale
Kcl	Carlile Shale
Kgb	Greenhorn Formation and Belle Fourche Shale
Kgbm	Greenhorn Formation and Belle Fourche and Mowry shales
Kmr	Mowry Shale
Kmt	Mowry and Thermopolis shales
Kns	Newcastle Sandstone and Skull Creek Shale

Cretaceous-Jurassic

KJ	Cloverly and Morrison formations (W/SW) or Inyan Kara Group and Morrison Formation (E/SE)
KJs	Cloverly, Morrison, and Sundance formations
KJg	Cloverly, Morrison, Sundance, and Gypsum Spring formations

Jurassic

Jsg	Sundance and Gypsum Spring formations

Triassic

Ѓcd	Chugwater and Dinwoody formations
Ѓc	Chugwater Formation

MESOZOIC AND PALEOZOIC

Triassic-Permian

ЃPcg	Chugwater and Goose Egg formations
ЃPs	Spearfish Formation
ЃPg	Goose Egg Formation

PALEOZOIC

Pzr	Paleozoic units, undifferentiated

Permian

Pp	Phosphoria Formation and related rocks
Pmo	Minnekahta Limestone and Opeche Shale

Permian-Pennsylvanian

PIPh	Hartville Formation
PIPm	Minnelusa Formation

Permian-Mississippian

PM	Tensleep Sandstone and Amsden Formation

Mississippian

Mm	Madison Limestone or Group

Mississippian-Devonian

MD	Madison Limestone or Darby Formation
MDg	Guernsey Formation
MDe	Pahasapa and Englewood limestones

Mississippian-Ordovician

MO	Madison Limestone and Bighorn Dolomite

Ordovician-Cambrian

O€	Whitewood Dolomite, and Winnipeg and Deadwood formations (E), or Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone (W)

Ordovician

Ob	Bighorn Dolomite

Cambrian

€r	Cambrian rocks

PRECAMBRIAN

Proterozoic

Xsv	Pelitic schist, marble, granite gneiss, layered amphibolite, and felsic gneiss

Archean

Wmu	Amphibolite
Wg	Granite and minor amounts of metasedimentary rocks
WVsv	Amphibolite, hornblende gneiss, biotite gneiss, quartzite, iron-formation, metaconglomerate, marble, and pelitic schist
WVg	Quartz diorite to quartz monzonite
Ugn	Oldest gneiss complex

Montana Geologic Units

CENOZOIC

Quaternary

Qal	Alluvium

Tertiary

Tw	Wasatch Formation
Tfu	Fort Union Formation

MESOZOIC

Cretaceous

Khc	Hell Creek Formation
Kfh	Fox Hills Sandstone
Kp	Pierre Shale
Kfb	Fox Hills Sandstone and Bearpaw Shale
Kjr	Judith River Formation
Kn	Niobrara Formation
Kce	Carlile Shale
Kg	Greenhorn Formation
Kbf	Belle Fourche Shale
Kmo	Mowry Formation

Triassic

Ѓu	Triassic units, undifferentiated

Montana Geologic Units (continued)

PALEOZOIC (continued)

Pennsylvanian

PNu	Pennsylvanian units, undifferentiated

Mississippian-Devonian

Mu	Mississippian units, undifferentiated

Ordovician

Ou	Ordovician units, undifferentiated

Nebraska Geologic Units

CENOZOIC

Tertiary

Ta	Arikaree Group
Tw	White River Group

MESOZOIC

Cretaceous

Kp	Pierre Shale

South Dakota Geologic Units

CENOZOIC

Quaternary

Qal	Alluvium
Qt	Terrace deposits
Ql	Landslide deposits

Tertiary

Tt	Trachytic intrusive rocks

MESOZOIC

Cretaceous

Kp	Pierre Shale
Kn	Niobrara Formation
Kg	Greenhorn Formation
Kb	Belle Fourche Shale
Kms	Mowry Shale, Newcastle Sandstone, and Skull Creek Shale
Kfl	Inyan Kara Group

Jurassic

Jms	Morrison Formation, Unkpapa Sandstone, Sundance Formation, and Gypsum Spring Formation

MESOZOIC AND PALEOZOIC

Triassic-Permian

ЃPs	Spearfish Formation

PALEOZOIC

Permian

Pmo	Minnekahta Limestone and Opeche Shale

Permian-Pennsylvanian

PIPm	Minnelusa Formation

Mississippian-Devonian

MDpe	Madison Group

Ordovician-Cambrian

O€wd	Whitewood Limestone, and Winnipeg and Deadwood formations

PRECAMBRIAN

Proterozoic

XWp	Pegmatite
XWb	Metabasalt
XWgw	Metagraywacke

Map Projection: Universal Transverse Mercator (UTM), zone 13
False Easting: 500000, False Northing: 0
Central Meridian: -106.0 degrees West
Linear Unit: Meter
Horizontal Datum: North American Datum of 1983 (NAD 83)

Map layout by James R. Rodgers and James E. Stafford
Map edited by Suzanne C. Luhr

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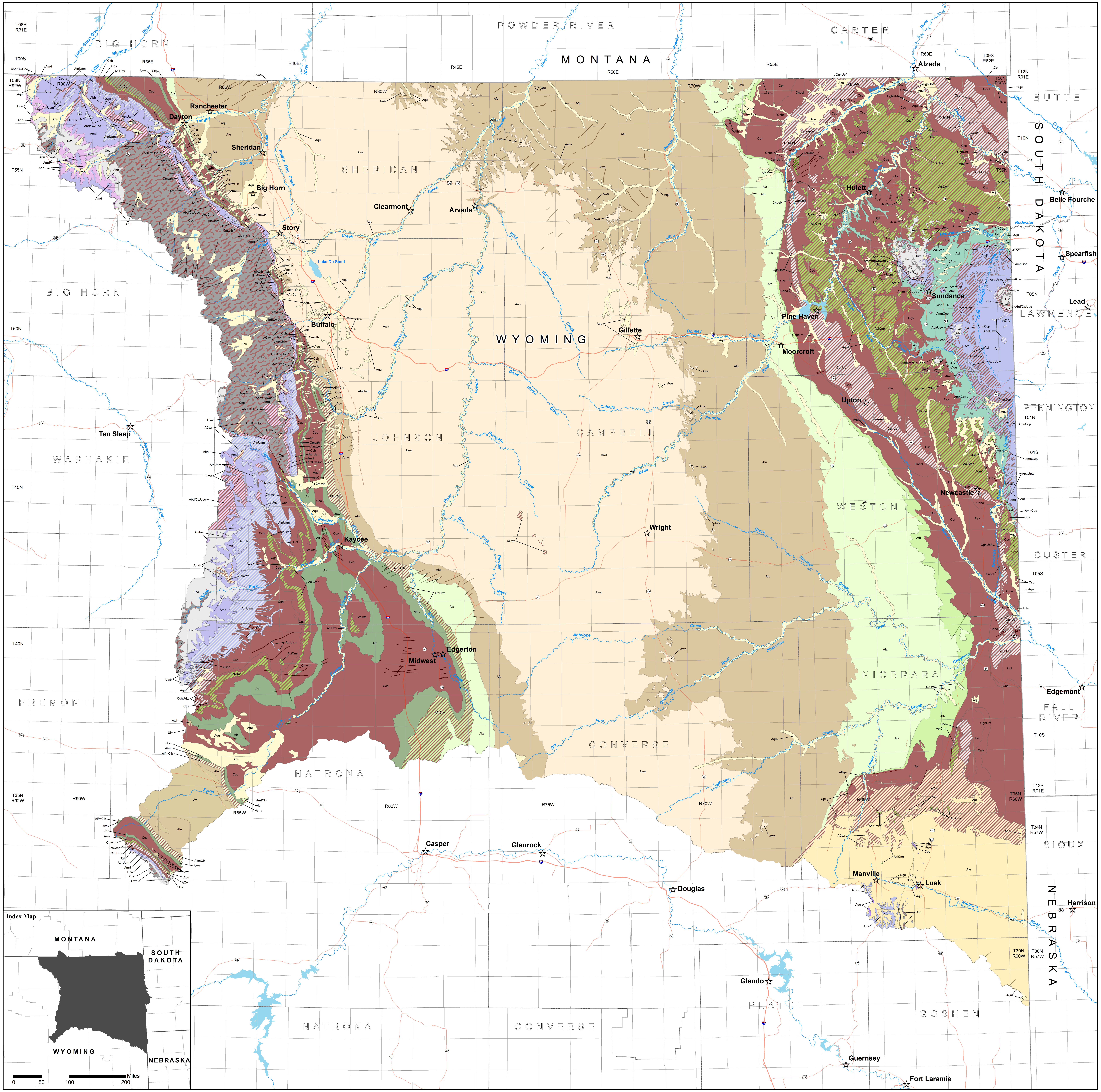
WYOMING STATE GEOLOGICAL SURVEY
Erin A. Campbell, Director and State Geologist
Laramie, Wyoming

Geology - Interpreting the past - providing for the future

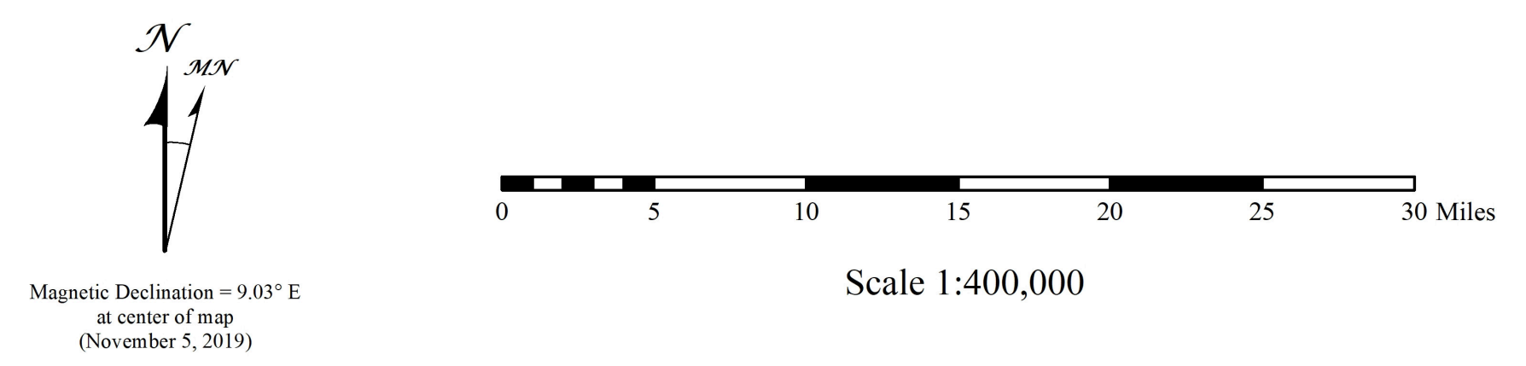
Powder, Tongue, and Northeast River Basins Plan II - Available Groundwater Determination Technical Memorandum

Plate II
Hydrogeology - Powder, Tongue, and Northeast River Basins



Hydrogeology - Powder, Tongue, and Northeast River Basins Wyoming

compiled by
Timothy T. Bartos and James E. Stafford



Magnetic Declination = 9.03° E
at center of map
(November 5, 2019)

Scale 1:400,000

Explanation

- Interstate highway
- U.S. highway
- State highway
- City or town
- Township boundary
- County boundary
- State boundary
- Lake or reservoir
- River or creek
- Normal fault—dotted where concealed
- Thrust fault—dotted where concealed

Hydrogeology

Hydrogeologic Units - Compiled from Figures 7-2 and 7-8

CENOZOIC

Quaternary

Aqu	Quaternary unconsolidated-deposit aquifer

Quaternary-Tertiary

Uqt	undefined Quaternary-Tertiary glacial deposits

Tertiary

Uum	undefined Upper Miocene
Ulm	undefined Lower Miocene
Aar	Arikaree aquifer
Umo	undefined Lower Miocene and Upper Oligocene
ACwr	White River aquifer and confining unit
Uwb	undefined Wagon Bed
Uiv	undefined igneous volcanic
Awi	Wind River aquifer
Awa	Wasatch aquifer
Uim	undefined Indian Meadows
Afu	Fort Union aquifer

MESOZOIC

Cretaceous

Ala	Lance aquifer
AlfmClb	Lance, Fox Hills, and Meeteetse aquifers, Lewis and Bearpaw confining units
Afh	Fox Hills aquifer
Cbp	Bearpaw confining unit
AfhClw	Fox Hills aquifer and Lewis confining unit
AmtClb	Meeteetse aquifer, and Lewis and Bearpaw confining units
Cpr	Pierre confining unit
Amv	Mesaverde aquifer
Cco	Cody confining unit
Cnb	Niobrara confining unit
Cnbcl	Niobrara and Carlile confining units
Ccl	Carlile confining unit
Afr	Frontier aquifer
AfrCth	Frontier aquifer and Thermopolis confining unit
CghUbf	Greenhorn confining unit and undefined Belle Fourche
Cmw	Mowry confining unit
Cmwth	Mowry and Thermopolis confining units
Csc	Skull Creek confining unit

Cretaceous-Jurassic

AciCmr	Cloverly and Inyan Kara aquifers, and Morrison confining unit
AcsCmg	Cloverly and Sundance aquifers, and Morrison and Gypsum Spring confining units
AcsCmr	Cloverly and Sundance aquifers, and Morrison confining unit

MESOZOIC (continued)

Jurassic

Cgs	Gypsum Spring confining unit

Triassic

CchUdw	Chugwater confining unit and undefined Dinwoody
Cch	Chugwater confining unit

MESOZOIC AND PALEOZOIC

Triassic-Permian

Asf	Spearfish aquifer
Cge	Goose Egg confining unit

PALEOZOIC

Undivided

AmmmpCoUed	Minnekahta, Minnelusa, Madison, and Pahasapa aquifers, Opeche confining unit, and undefined Englewood and Darby

Permian

ACpp	Phosphoria aquifer and confining unit
AmnCop	Minnekahta aquifer and Opeche confining unit

Permian-Pennsylvanian

Ahv	Hartville aquifer
Ami	Minnelusa aquifer

Permian-Mississippian

AtnUam	Tensleep aquifer and undefined Amsden

Mississippian-Devonian

Amd	Madison aquifer
Agu	Guernsey aquifer
ApaUew	Pahasapa aquifer and undefined Englewood

Mississippian-Ordovician

Amb	Madison and Bighorn aquifers

Ordovician-Cambrian

AbdfCwUoc	Bighorn, Deadwood, and Flathead aquifers, Winnipeg confining unit, and undefined Ordovician/Cambrian

Ordovician

Abh	Bighorn aquifer

Cambrian

Uca	undifferentiated Cambrian

PRECAMBRIAN

Cpc	Precambrian basal confining unit

Map Projection: Universal Transverse Mercator (UTM), zone 12
False Easting: 500000, False Northing: 0
Central Meridian: -106.0 degrees West
Linear Unit: Meter
Horizontal Datum: North American Datum of 1983 (NAD 83)

Map layout by James E. Stafford
Map editied by Suzanne C. Luhr

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Geographic region	Spring discharge		Well yield								Specific capacity		Transmissivity														Hydraulic conductivity		Storativity/storage coefficient		Permeability				Porosity		Sources
	Flowing		Flowing		Pumped or unknown		Wells associated with oil/gas exploration and development		All wells (pumped or flowing)				Flow test		Constant rate test		Recovery		Observation well		Drill stem or other oil/gas exploration and development field test		Unspecified/other		All tests		Wells associated with oil/gas exploration and development				Wells associated with oil/gas exploration and development		All other data		Wells associated with oil/gas exploration and development		
	Count	Range (median) (gal/min)	Count	Range (median) (gal/min)	Count	Range (median) (gal/min)	Count	Range (median) (gal/min)	Count	Range (median) (gal/min)	Count	Range (median) [(gal/min)/ft]	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft^2/day)	Count	Range (ft/day)	Count	Range (unitless)	Count	Range (md)	Count	Range (md)	Count	Range (percent)	
Cenozoic hydrogeologic units																																					
Quaternary alluvial aquifers																																					
NERB			1	2	109	1–1,000 (15)			110	1–1,000 (15)	59	0.11–62 (3.0)					1	1,300					13	28.1–10,700	14	28.1–10,700							7	770–60,000			1, 30, 52, 62–64, 74
Quaternary terrace-deposit aquifers																																					
NERB	1	320			10	4.1–25 (12.5)			10	4.1–25 (12.5)	5	1–20 (3.1)											2	938; 2,410													1, 30, 52, 74
Quaternary dune sand (eolian) deposits																																					
NERB					2	2.75; 5			2	2.75; 5																											1, 8
Quaternary landslide deposits																																					
NERB	1	50																																			30
Quaternary glacial deposits																																					
NERB	1	395																																			1, 63
Arikaree aquifer																																					
NERB			2	1; 150	156	0.3–2,000 (500)			158	0.3–2,000 (500)	78	0.13–230 (8.2)			3	80–8,890	4	56–17,800	2	3,300; 15,900			6	1,070–11,300	15	56–17,800	2	1.2; 1.3	3	0.001–0.006			4	1,600–17,000			1, 3, 12, 40, 54, 62, 73
White River hydrogeologic unit																																					
NERB					10	3–6 (5)			10	3–6 (5)	7	0.03–3 (0.17)																									1, 62
Wind River aquifer																																					
WRSB	1	5	2	1.25; 1.25	4	5–20 (6.5)			6	1.25–20 (5)	1	3.3																									1, 16
Wasatch aquifer																																					
NERB	9	0.06–12 (2)	95	0.25–80 (3)	453	0.1–1,470 (7)			548	0.1–1,470 (7)	290	0.004–350 (0.19)			1	10.7	4	5.4–295	1	8.7					6	5.4–295			1	0.00006							1, 17, 21, 28–30, 52, 59, 63, 74
Coal aquifers					4	3–15 (11)			4	3–15 (11)	3	0.11–0.28 (0.17)											1	69.7	1	69.7			1	0.02			1	360			1, 30
Fort Union aquifer																																					
NERB	5	4–200 (9)	160	0.25–60 (5.75)	432	0.5–1,500 (15)			592	0.25–1,500 (10)	230	0.003–2,200 (0.39)			32	12.7–1,330	38	1.3–474	10	73.7–470			10	4.02–236	90	1.3–1,330	2	0.37; 0.39	18	0.00001–0.008			7	27–430			1–2, 13, 17–23, 28–30, 32, 35, 38, 43–45, 47–50, 52, 59, 62–65, 74
Coal aquifers			3	0.71–5 (2)	12	0.5–111 (5)			15	0.5–111 (5)	2	0.004; 0.03																									30
WRSB					1	15			1	15																											1
Mesozoic hydrogeologic units																																					
Lance aquifer																																					
NERB	1	5	4	1.2–5 (2.7)	190	0.75–300 (10)			194	0.75–300 (10)	54	0.01–1.8 (0.24)			4	16.2–40.2	3	13.5–80.4	1	17			7	22.8–281	15	13.5–281			2	0.0001; 0.03			3	330–1,900			1, 17, 21, 30, 33, 52, 55, 57, 62–64, 74
Fox Hills aquifer																																					
NERB					46	2–5,000 (10)			46	2–5,000 (10)	23	0.03–4.9 (0.25)					2	214; 324					1	214	3	214–324							1	1,900			1, 4, 16, 21, 29, 33, 44, 62, 64
Lewis confining unit																																					
NERB					1	6			1	6																											30
Pierre confining unit																																					
NERB					7	2–60 (8)			7	2–60 (8)	4	0.14–1.3 (0.36)																									1, 62, 64
Mesaverde aquifer																																					
NERB			1	0.5	20	2–130 (8)	5	12.5–34 (24)	26	0.5–130 (11)	8	0.06–1.4 (0.17)									8*	0–47.8	1	201	9*	0–201					9*	0–230			5*	15–21	1, 15–17, 21, 30, 51–52, 63, 67–68, 74
Cody confining unit																																					
NERB			2	0.25; 6	13	1.5–15 (5)	2	1; 19	17	0.25–19 (5)	5	0.02–1.4 (0.1)									5	0.05–15.7			5	0.05–15.7					5	2–280			5	12–25	1, 15–17, 21, 51–52, 63, 68, 74
Steele confining unit																																					
NERB							8	10–40 (20.8)	8	10–40 (20.8)											7	9.8–295			7	9.8–295					7	11–330					51
Frontier aquifer																																					
NERB			25	0.08–5 (2)	18	0.28–16 (5)	2	7 (flowing); 7 (pumping)	45	0.08–16 (3)	5	0.02–0.64 (0.11)									15*	0.03–18.9			15*	0.03–18.9					9	0.5–520			10	12–21	1, 8, 15–16, 21, 30, 52, 63, 67, 74
Mowry confining unit																																					
NERB	1	3	2	0.25; 2	6	0.28–40 (17)			8	0.25–40 (8)																											1, 16, 28, 52
Muddy aquifer																																					
NERB			1	45	1	10	1	0.5	3	0.5–45 (10)											13*	0.1–19.6			13*	0.1–19.6					18*	2.4–588			21*	2–22	1, 15–16, 21, 51–52, 67, 69–71, 74
WRSB					1	10			1	10																											1
Newcastle aquifer																																					
NERB					1	25			1	25											12*	0.01–8.3			12*	0.01–8.3					13*	<1–330			10	9.3–23	1, 15, 21, 62, 67
Skull Creek confining unit																																					
NERB					1	0.3			1	0.3																											1
Cloverly aquifer																																					
NERB	1	<1	2	0.18; 25	5	0.08–18 (2)	2	1; 19	9	0.08–25 (2)	3	0.02–0.15 (0.02)									7*	0.5–31	2	26.8; 37.5	9*	0.5–37.5					8*	14–410			7	11–18	1, 8, 15–16, 21, 30, 52, 67–68
WRSB	1	5																																			1
Inyan Kara aquifer																																					
NERB	2	12; 104	47	0.2–150 (5)	60	1–300 (10)			107	0.2–300 (8)	25	0.01–3.1 (0.25)	2	29.5; 109	2	381; 1,510	1	208	1	441	8	4.8–29.2	5	38.1–2,120	19	4.8–2,120					9*	0–730	2	110; 770	8	14–24	1, 6, 14, 21, 53, 60, 62, 64, 66–67, 69, 71–72
Morrison confining unit																																					
NERB	1	31			3	3.5–6.2 (5)			3	3.5–6.2 (5)	2	0.2; 0.26											2	21.4; 21.4	2	21.4; 21.4							2	220; 270			1, 64
Sundance aquifer																																					
NERB	6	1–50 (6.5)	3	0.5–5 (2)	9	1.5–40 (8)	1	13	13	0.5–40 (5)	3	0.02–0.06 (0.04)									3	0.02–52.8			3	0.02-52.8					3	<1–440			3	12–21	1, 14–16, 21, 52, 64, 67–68
Chugwater confining unit																																					
NERB	2	5; 120			1	8			1	8																											1, 16, 52, 74
Spearfish aquifer																																					
NERB	1	1			12	2–10 (6)			12	2–10 (6)	3	0.26–0.61 (0.54)											2	20; 50	2	20; 50							2	330; 440			1, 64
Paleozoic and Precambrian hydrogeologic units																																					
Minnekahta aquifer																																					
NERB			1	12	2	3; 25			3	3; 25 (12)																							1	240			1, 11
Tensleep aquifer																																					
NERB			6	9–2,620 (125)	11	5–1,200 (22)	2	32; 54	19	5–2,620 (33)	2	0.33; 10									12*	0.003–255			12*	0.003–255					9*	0.01–700			8*	0.4–20	1, 15–17, 21, 24, 28, 34, 51–52, 63, 67–68, 74
WRSB			1	20					1	20																											16
Amsden hydrogeologic unit																																					
NERB	1	1	1	0.5					1	0.5																							1	24			11, 34, 52
Minnelusa aquifer																																					
NERB	1	15	13	5–375 (41)	32	1.5–301 (13.5)			45	1.5–375 (15)	19	0.1–38 (0.6)			1	1,620	2	1,580–3,800	1	2,130	6*	0.1–92			20*	0.1–3,800	2	6.5; 14	3	0.005–0.008	29*	0.5–>1,000			30*	5.8–25	1, 11, 15, 21, 41–42, 61, 64, 67–68, 71
Hartville aquifer																																					
NERB					1	104			1	104																											73
Madison aquifer																																					
NERB	2	200; 2,700	39	0.25–9,480 (200)	50	7.2–1,500 (265)	1	30	90	0.25–9,480 (238)	55	0.2–52 (1.6)	7	28.7–2,200	10	53.6–1,920	15	0.6–5,000			1	4.3	8	6.7–40,200	41	0.6–40,200	1	2.1	1	0.0002			4	2.2–120,000			1, 5–7, 9–11, 14, 16, 21, 24–27, 31, 36–37, 39, 41, 44, 46, 51–52, 56, 58, 61, 74
Bighorn aquifer																																					
NERB							1	28	1	28											1	5.1			1	5.1					1	5.5					51
Whitewood aquifer																																					
NERB																																	1	35,000			11
Flathead aquifer																																					
NERB	1	10	1	55	2	15; 20			3	15–55 (20)	2	0.57; 0.75																									1, 11, 30
Precambrian basal confining unit																																					
NERB	15	0.3–11 (2)			1	12			1	12	1	12																									1, 30, 63

[NERB, Northeastern River Basins study area excluding Wind River structural basin; WRSB, Wind River structural basin; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot of drawdown; ft^2/day, feet squared per day; ft/day, feet per day; md, millidarcy. *Values reported as range or average in original source so count cannot be determined.]

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Plate 3. Summaries of spring discharge, well yield, and hydraulic properties, Northeastern River Basins study area, Wyoming.

STATE OF WYOMING
1933
GEOLOGICAL SURVEY

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