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Table 2.--Description of the Madison aquifer (geology adapted from Sandberg (1972), and Rocky Mountain Association of Geologists (1972))

Topic	Area of greatest interest	Northern Montana, excluding area of greatest interest	North Dakota	South Dakota, excluding area of greatest interest
Distribution of aquifer (outcrop areas, subsurface extent, and overlying and underlying beds)	Aquifer crops out in Bighorn, Pryor, and Laramie Mountains, Hartville Uplift, and Black Hills, and occurs in subsurface in rest of area. Madison rocks are overlain by Pennsylvanian rocks. They are underlain by Devonian rocks in northern part of area, Silurian rocks in a small area in the north-central part, Ordovician rocks in central part of area and east of Black Hills, Cambrian rocks in southern part of area and southeast of Black Hills, and Precambrian rocks southeast of Black Hills in eastern South Dakota.	Aquifer crops out in areas west of study area and occurs in subsurface in entire area. Madison rocks are overlain by Pennsylvanian rocks in extreme southern part of area, Big Snowy Group rocks in central and northeastern parts, and Jurassic rocks in northwestern part. Madison rocks are underlain by Devonian rocks in most of area except for a small area in west-central part where they are underlain by Ordovician and Cambrian rocks.	Aquifer does not crop out but occurs in subsurface in entire area. Madison rocks are overlain by Big Snowy Group rocks in most of area except in northern and eastern parts where they are overlain by Pennsylvanian rocks and in extreme eastern part where they are overlain by Triassic and Jurassic rocks. Madison rocks are underlain by Bakken Formation except in extreme eastern and southern parts of area where they are underlain by Devonian rocks.	Aquifer does not crop out but occurs in subsurface in entire area. Madison rocks are overlain by Big Snowy Group rocks in northwestern part of area and Pennsylvanian rocks in rest of area except in eastern part where they are overlain by Cretaceous rocks. Madison rocks are underlain by Devonian rocks in entire area except in extreme southern and eastern parts where they are underlain by Ordovician and Precambrian rocks.
Structure and thickness of aquifer	Main structures are Bighorn, Pryor, and Laramie Mountains, Casper Arch, Powder River and Williston Basins, and Hartville, central Montana, and Black Hills Uplifts. (See figure 2.) Madison aquifer dips steeply into Powder River Basin from Bighorn Mountains on west and Laramie Mountains on south; folding and faulting are significant. Aquifer dips less steeply from Black Hills. Top of Madison rocks ranges from 10,000 ft below sea level (about 10,000 ft below land surface) in southwestern part of basin to land surface in outcrop. Madison rocks are 0 to 800 ft thick east of Black Hills, 200 ft thick at southern end of Powder River Basin, and 1,400 ft thick at northern end. Overlying rocks that may be part of aquifer are as much as 800 ft thick. Underlying rocks that may be part of aquifer are less than 100 ft thick at southern end of Powder River Basin, as much as 1,400 ft thick at northern end, and are absent in southern part of South Dakota.	Folding and faulting are significant in western half of area. Top of Madison rocks ranges from about 6,400 ft below sea level (8,500 ft below land surface) to land surface in outcrop just west of study area. Madison rocks are about 700 ft thick at northwestern edge of area and 2,100 ft thick at eastern edge.	Main structure is Williston Basin. Top of Madison rocks ranges from about 6,700 ft below sea level (10,000 ft below land surface) in the center of the basin to about 1,000 ft below sea level (3,000 ft below land surface) in eastern part. Madison rocks are about 2,300 ft thick in center of basin and about 400 ft thick in northeastern part.	Main structure is Williston Basin. Top of Madison rocks ranges from about 900 ft below sea level (2,500 ft below land surface) in southeastern part of area to 5,000 ft below sea level (8,500 ft below land surface) in northwestern part. Madison rocks are not present in southeastern part of area but are about 1,300 ft thick in the northwestern part.
Physical description of aquifer (lithology, and type and distribution of porosity and permeability (hydraulic conductivity development)	Madison rocks are mainly carbonate in northern part of area, basal part is clayey, and upper part contains evaporites. Overlying Pennsylvanian rocks are carbonate, sandstone, and shale; basal part is calcareous or clayey; middle part contains mainly limestone, which is sandy toward top; and upper part is mainly sand and sandy limestone grading into limestone eastward. Devonian rocks are interbedded shale, sandstone, and carbonate at top, and carbonate containing thin shale and siltstone interbeds at base. Silurian rocks are carbonate. Ordovician rocks are mainly carbonate in upper part, sandstone in middle part, and interbedded sandstone, calcareous sandstone, and shale at base. Cambrian rocks are mainly sandstone containing some carbonate at top, and interbedded rocks in middle part. Development of porosity and permeability in Madison aquifer is poorly documented but seems to be related to solution and collapse-breccia zones associated with unconformities and fracturing. Porosity and permeability related to unconformities occur at top of Madison and Ordovician rocks, and to a lesser extent at top of Devonian and Cambrian rocks, in surface exposures in Bighorn and Laramie Mountains and in Black Hills. Porosity and permeability related to fracturing caused by folding and faulting occur along flanks of Bighorn and Laramie Mountains and in Black Hills. Oil-test records of lost-circulation zones, large yields from wells, and drill-stem tests indicate that porosity and permeability may be well developed in the subsurface. Dolomitization of carbonate and solution of evaporites may also be important factors controlling porosity and permeability. Geophysical logs indicate porosity, but individual zones have not been correlated in subsurface.	Madison rocks are mainly carbonate; basal part is clayey and upper part contains abundant evaporites. Big Snowy Group is mainly continental clastic rocks and has abrupt facies changes. Pennsylvanian rocks are mainly shaly carbonate and shale where they are in contact with Madison, and shaly carbonate and carbonate in rest of area. Jurassic rocks are mainly shale but some are sandstone. Devonian rocks are shale at top and carbonate at base and contain thick evaporites in northeastern part of area. Silurian rocks are mainly carbonate. Ordovician rocks are mainly carbonate at top, sandstone and shaly sandstone in middle, and carbonate at base. Cambrian rocks are mainly sandstone in eastern part of area, and interbedded sandstone, shale, and carbonate in rest of area. Development of porosity and permeability in Madison aquifer is poorly documented but occurs in outcrops west of study area and is probably significant in subsurface where unconformities occur, or where solution of evaporites or enlargement of fractures has occurred. Drill-stem tests and borehole geophysical data are available in much of area but few have been analyzed.	Madison rocks are mainly carbonate: basal part is calcareous shale and shaly limestone in western part of area, and shaly limestone and limestone in eastern part: middle part is mainly carbonate containing evaporites at top and upper part is mainly evaporites containing interbedded carbonate. Big Snowy Group rocks are mainly calcareous shaly sandstone and sandy shale. Pennsylvanian rocks are mainly carbonate: basal part is shale, sandy shale, lime shale, sandstone, and carbonate with abrupt facies changes: middle part is limestone and shaly limestone: and upper part is shaly and sandy carbonate and carbonate. Devonian rocks are black shale in the northern part of area and sandstone, shale, and carbonate in the southern and eastern parts at the top, and mainly carbonate at base containing thick evaporites in the northern part. Silurian rocks are carbonate. Ordovician rocks are shaly limestone at top, carbonate in middle, shale and sandy shale at base. Cambrian rocks are sandstone in the eastern part of area and interbedded sandstone, shale, and limestone in the western part. Development of porosity and permeability in Madison aquifer is poorly documented, but is probably significant where unconformities, solution of evaporites, or enlargement of fractures occur in the subsurface. Drill-stem tests and borehole geophysical data are available but few have been analyzed.	Madison rocks are mainly carbonate: some evaporites occur near top in northern part of area. Big Snowy Group rocks are mainly calcareous sandy shale and sandy carbonate. Pennsylvanian rocks are mainly carbonate and clastic; basal part is similar to North Dakota section; middle part is shaly carbonate; and upper part is similar to North Dakota section but contains more clastics. Devonian rocks are mainly carbonate containing interbedded sandstone and shale in upper part, shale in middle part, and carbonate in lower part. Silurian and Upper Ordovician rocks are mainly carbonate. Middle Ordovician rocks are mainly shale and sandy shale. Lower Ordovician and Upper Cambrian rocks are mainly sandstone containing some calcareous sandstone at top.
Hydraulic characteristics (transmissivity, storage coefficient, and vertical hydraulic conductivity)	Transmissivity of Madison, estimated from an aquifer test in Montana, is 5,400 ft²/day, and estimated from specific capacity of one well in Wyoming, is 4,000 ft²/day. Flow-net analysis of potentiometric surface near Midwest, Wyo., indicates transmissivity of about 1,000 ft²/day. Data from drill-stem tests and water wells indicate both higher and lower values: all data have not been analyzed. Data to determine transmissivity are available for overlying rocks, but scarce for underlying rocks. Storage coefficient has been estimated to range between 2.5×10^{-4} and 10^{-5}. Vertical hydraulic conductivity is not known but probably is variable and very significant.	Transmissivity data have not been calculated for these areas. Many drill-stem tests are available for the Madison aquifer in northern Montana and western North Dakota; fewer tests are available for eastern North Dakota and South Dakota. Storage coefficient has been estimated to be about 10^{-4}. Vertical hydraulic conductivity is not known.		
Potentiometric surface and movement of water (shape, direction, altitude and depth, relation to springs and streams, and water-level changes)	Potentiometric data for Madison aquifer are mainly from drill-stem tests or water wells on flanks of Bighorn and Laramie Mountains and Black Hills; few data are available in central or deeper parts of basin. Data for Pennsylvanian rocks are most abundant; data for underlying rocks are available only for northern part of area. Potentiometric gradient is steep in western and southern parts of area, gentle from outcrops in Black Hills, and essentially flat in center of Powder River Basin. Potentiometric contours indicate water movement is from outcrop areas to center of basin and then northward; some water moves southeast around southern end of Black Hills and some moves into basin from Casper Arch. East of Black Hills water movement is east-northeast. Potentiometric surface is as much as 1,200 ft below land surface in high areas northeast of Casper, Wyo., and on interstream divides, above land surface along most major streams, and as much as 1,000 ft above land surface along Yellowstone River at northern end of area. Springs occur in outcrop areas of Madison aquifer and gaining and losing streams cross these outcrops. Potentiometric lows caused by pumping occur near Midwest, Glenrock, and Newcastle, Wyo., but data in rest of area are not sufficient to determine water-level changes, if any.	Potentiometric data for Madison aquifer are mainly from drill-stem tests. In eastern part of area data are available for both Madison and underlying rocks; in northern and southwestern parts few data are available. Data for overlying rocks are available for most of area. Potentiometric data for Madison indicate water movement is east-northeast; average gradient is about 15 ft/mi. Potentiometric surface is above land surface in much of area; springs occur in outcrops west of area and wells completed in aquifer along major streams will flow. Sufficient data to determine water-level changes are not available. Vertical head relationships in Madison aquifer have not been determined. Water from Madison aquifer is used mainly for secondary recovery of oil; some is used for stock water in study area and for irrigation west of area; total number of wells and total use are not known. Most data are from drill-stem tests; some are from water-supply wells. Largest confirmed reported yield from Madison is 270 gal/min, unconfirmed reported yield is about 1,400 gal/min.	Potentiometric data for Madison aquifer are mainly from drill-stem tests. Most available data are for western part of area. Interpretations have not been made.	Potentiometric data for Madison aquifer are mainly from drill-stem tests. Data indicate water movement is east-northeast. Potentiometric surface is above or near land surface in most of area.
Water use and well yields (use, yields, and specific capacities)	Water from Madison aquifer is used for municipal, stock, domestic, irrigation, fish hatchery, and industrial supplies: total number of wells is not known. Water use in 1973 was about 25,000 acre-ft in Wyoming and 3,600 acre-ft in Montana. Maximum measured yield from Madison was 7,200 gal/min on short-term test of well near Midwest, Wyo.; other well yields in Wyoming range from less than 50 gal/min to about 5,000 gal/min. Maximum yield in Montana was 1,300 gal/min at Bell Creek oil field. Data for overlying and underlying rocks have not been compiled. Specific capacities in Wyoming range from 0.25 to 49 (gal/min)/ft drawdown; for Midwest, Wyo., area, most were less than 2.5 (gal/min)/ft drawdown. Water-use, well-yield, and specific-capacity data have not been fully documented in South Dakota.	Water from Madison aquifer is used mainly for secondary recovery of oil; some is used for stock water in study area and for irrigation west of area; total number of wells and total use are not known. Most data are from drill-stem tests; some are from water-supply wells. Largest confirmed reported yield from Madison is 270 gal/min, unconfirmed reported yield is about 1,400 gal/min.	Water use and well yield for Madison aquifer are poorly documented; most data are from drill-stem tests. Some water is pumped with oil, and some is pumped from water wells and used mainly for secondary recovery of oil.	Water use and well yield for Madison aquifer are poorly documented; most data are from drill-stem tests. Wells, flowing as much as 100 gal/min from Madison, have been developed for stock and municipal supplies in central part of area. Specific capacity data are not available.
Water quality	Dissolved-solids concentration of water from Madison Limestone ranges from about 150 mg/l in Bighorn Mountains and Black Hills to as much as 5,000 mg/l in northeastern part of Powder River Basin. Most data are from wells near Midwest, Glenrock, Newcastle, Wyo., and Bella Creek, Mont.; other data are mainly from drill-stem tests. Data are not available for central part of Powder River Basin. Data for overlying rocks have not been compiled. Data are available for underlying rocks only in northern part of area. Quality of water in Madison aquifer east of Black Hills is poorly documented. Calcium, magnesium, and sulfate are major chemical constituents of water near edge of Powder River Basin; sodium and chloride concentrations increase basinward and to northeast. Detailed geochemical data are not available.	Dissolved-solids concentration of water from Madison Limestone ranges from about 1,430 mg/l from springs west of study area to more than 100,000 mg/l from wells in eastern part. Most data are from drill-stem tests, but some analyses are for water produced with oil. Data for water from rocks other than Madison have not been compiled. Calcium, magnesium, and sulfate are major chemical constituents of Madison water in the western and southwestern parts of area; sodium and chloride increase eastward, and are main constituents in eastern part. Detailed geochemical data are not available.	Water-quality data are available from drill-stem tests and from water pumped with oil; data are not compiled. Dissolved-solids concentration probably exceeds 35,000 mg/l and may be greater than 100,000 mg/l. Sodium and chloride are the major chemical constituents.	Little data are available; mainly from drill-stem tests. Water apparently contains less than 2,000 mg/l dissolved-solids in southern part of area, but contains larger amounts in northern part. Calcium, magnesium, and sulfate are the major chemical constituents.