INTRODUCTION

This investigation of the ground-water resources of the Wind River basin area was made in cooperation with the Wyoming State Engineer to obtain general information of the quantity and quality of ground water that is being used, and to determine the possibility of additional development of ground-water resources.

Data for many wells were obtained from records of the Bureau of Land Management and from water-well drillers operating in the area; however, when possible, depths to water and depths of wells were measured by the authors. A reconnaissance sampling of water from wells provides general information of the chemical quality of water in the aquifers.

The geologic map was adapted and generalized from a preliminary map compiled by W. R. Keefer, Toni D. Dunrud, and R. L. Koogle from previous geologic investigations in the Wind River Basin. The authors are grateful for permission to use this map, in advance of publication of the more detailed map in a U.S. Geological Survey professional paper. Descriptions of stratigraphic units on sheet 3 were abstracted largely from published works, which are listed in the selected references. A ground-water study of the Riverton irrigation project (Morris, D. A., and others 1959), an area of about 470 square miles, provided much of the hydrologic data in that part of the project area.

The project area of this report consists of about 12,000 square miles in central and west-central Wyoming and includes all of Fremont County and parts of western Natrona and northern Carbon Counties. Altitudes in the Wind River Basin range from about 4,600 feet where the Wind River enters the Wind River Canyon to 13,785 feet on Gannett Peak in the Wind River Mountains, the highest point in Wyoming. The average altitude of the Basin is about 5,500 feet, although numerous isolated mountains and escarpment of Beaver Rim rise several hundred feet above the general surface.

Perennial streams in the Wind River Basin are the Wind, Little Wind, and Popo Agie Rivers, whose tributaries rise on the flanks of the Wind River, Washakie, and Owl Creek Mountains and drain most of the area north of Beaver Rim (about two-thirds of the region). The North Platte River and its tributary, the Sweetwater River, drain the region south and east of Beaver Rim. The northeastern part of the project area is drained by the Powder River. Streams rising within the Basin, such as the Powder River, generally are intermittent or ephemeral, flowing in response to sporadic precipitation.

The climate ranges from humid in the Wind River and Owl Creek Mountains to arid in the central part of the area and seasonal temperatures and precipitation vary greatly. The mean annual temperature at Riverton, the most centrally located weather-reporting station in the Basin, was 33.6°F (1931-63); winter temperatures frequently drop below 0°F for short periods, and summer temperatures commonly exceed 100°F. During the same period (1931-63), the annual precipitation at Riverton ranged from 4.85 to 14.74 inches, and the average annual precipitation was 8.55 inches. The average annual precipitation (1953-63) at Shoshoni, in the northern part of the Basin, and at Lander, at the base of the Wind River Mountains, was 5.5 and 12.63 inches, respectively.

GENERAL GEOLOGIC FEATURES

The Wind River Basin is a large structural depression (structural feature map). Large scale overthrusting, or reverse faulting, accompanied uplift along the northern and eastern margins of the Basin, particularly along the southern flank of the Owl Creek Mountains (Geologic section) and the western limb of the Casper arch. As the Basin subsided with reference to the bordering mountains, several thousand feet of Tertiary deposits accumulated within the depression. The thickest accumulations were along the northern (Geologic section) and eastern margins (Keefer, 1965a, p. A6). Strata of pre-Tertiary age, which are exposed largely around the periphery of the Basin, dip basinward at angles ranging from 10° to 20° on the flanks of the Wind River Mountains.
to vertical or overturned along the base of the Owl Creek Mountains.

That small part of the project area south of the Sweetwater uplift is not a part of the Wind River Basin proper, but was included to join a hydrologic atlas of the Great Divide and Washakie Basins (Welder and McGreevy, 1966, sheet 1). The area south of the Granite Mountains is underlain by strata that have been extensively folded and faulted by the southwestward overthrusting of the Granite Mountains block, which marks the axis of the Sweetwater uplift.

The stratigraphic section and geologic map are generalized for the purposes of this report. The geology of most of the area has been mapped previously in considerable detail, and the reader is referred to the list of selected references for publications giving more complete descriptions.

GROUND WATER

Ground water occurs under both artesian and water-table conditions. Artesian conditions are prevalent in the Wind River Formation and in older sedimentary rocks. These older formations, except for the massive sandstone and limestone that occur near the base of the sequence, consist largely of nearly impermeable shale and siltstone interbedded with relatively permeable sandstone. Water in an unconfined (water-table) condition occurs in the outcrop areas of artesian aquifers, in the Arikaree Formation, and in alluvial and windblown sand deposits.

The physical and water-bearing characteristics of the geologic formations in the project area are summarized on sheet 3. The following discussion of the occurrence of ground water in the aquifers supplements that table and is based largely on records of wells and drillers’ logs. Because the younger rocks are generally more important aquifers, rock units are discussed from youngest to oldest. There has been little development of ground water in the older rocks because of their considerable depth below land surface in most of the basin. Conclusions regarding the older rocks are based principally on data from other areas. In this report, the comparative terms “small,” “moderate,” and “large,” as applied to quantities of water, are given arbitrary values of less than 50 gpm (gallons per minute), 50-300 gpm, and more than 300 gpm, respectively.

ROCKS OF QUATERNARY AGE

Alluvial deposits (Qel on geologic map) in the valleys of perennial streams that head in the Wind River and Owl Creek Mountains contain coarse sand and gravel beds that are capable of yielding moderate to large quantities of water to wells penetrating a sufficient saturated thickness. Lander obtains an estimated 4,000 gpm from a collection gallery using 1,600 feet of 24-inch perforated pipe buried in the alluvium of the Middle Popo Agie River about 3 miles southwest of the city. A shallow well in the alluvium of the Little Wind River at Ft. Washakie reportedly produced 40 gpm with a drawdown of only 0.5 foot during a 5½-hour pumping test. Alluvial deposits of perennial streams have not yet been developed as a source of water for irrigation, because surface-water supplies generally are adequate for present needs.

Alluvial deposits along ephemeral and intermittent streams that rise within the basin generally consist of fine to coarse sand intermixed with silt and clay and normally yield to wells only enough water for stock or domestic supplies. Recharge is mainly from precipitation on the drainage area, and the amount of ground water available to wells fluctuates accordingly. During prolonged dry periods, yields of wells may become inadequate, or the wells may go dry.

Test holes angered across the valley of the Sweetwater River (Lithologic sections) penetrated a maximum thickness of 63 feet of saturated material consisting predominantly of coarse sand and gravel, and test holes angered in the alluvium of Kirby Draw penetrated as much as 45 feet of saturated material. Alluvial deposits along Muddy and Fivemile Creeks, tributaries to the Wind River, average 30 feet and 40 feet in thickness, respectively, and contain a large proportion of gravel (Morris and others, 1959, p. 38). The alluvium along the Wind and Little Wind Rivers and the lower reach of the Popo Agie River is generally less than 45 feet thick. An irrigation well in the valley of the Middle Popo Agie River near Lander, however, penetrated 45 feet of sand and gravel apparently without reaching bedrock.

Terrace deposits contain extensive bodies of ground water in areas where surface water has been applied for irrigation. Wells drilled in these areas generally yield adequate quantities of water for stock or domestic supplies, although yields fluctuate in response to irrigation, and some of the shallower wells go dry or yield inadequate supplies during the winter. Wells rarely penetrate the full thickness of the deposits, and deeper drilling in most cases would assure a more dependable supply. The construction of deeper wells, however, is complicated by the difficulty of drilling through the cobble and boulder beds that occur in some places.

The chemical quality of water in alluvial depo-
its differs from place to place, depending on the source and amount of recharge, and the type of bedrock underlying the alluvium. Water in the flood-plain deposits of perennial streams is generally good in the upper reaches of the stream, but the quality deteriorates downstream. A well drilled in the alluvium of the Wind River valley in the NW 1/4 NW 1/4 sec. 13, T. 2 N., R. 1 E., yields a calcium bicarbonate water that contains 272 ppm of dissolved solids; whereas, a well in the SE 1/4 SW 1/4 sec. 31, T. 1 N., R. 4 E., about 16 miles downstream, yields a sodium sulfate water that contains 1,230 ppm (parts per million) of dissolved solids. Water samples from two shallow dug wells in the alluvium at the confluence of the Little Popo Agie and Popo Agie Rivers which supply the town of Hudson were of a similar chemical type but contained 743 and 1,430 ppm of dissolved solids, respectively. The well yielding the better quality water taps alluvial deposits that are recharged largely by water from the Popo Agie River and a nearby irrigation ditch; whereas, the other well yields water that probably is derived, in part, from infiltration of irrigation water. The water is more mineralized because it has more contact with soluble material in the soils. The water quality reportedly fluctuates seasonally and is best during late spring when streamflow is augmented by snowmelt in the headwaters. The quality gradually deteriorates as the irrigation season progresses.

The quality of water in the alluvium of the Sweetwater River valley is similar to that in the underlying Arikaree Formation, which apparently contributes much of the recharge to the alluvium (Lithologic sections).

Water from the alluvial deposits underlying the Riverton irrigation project area, including the ground-water discharge into Ocean Lake and Fivemile Creek, generally is highly mineralized and unsuitable for domestic and irrigation use and often marginal for stock use. Water in these alluvial deposits is derived mostly from irrigation water. Ocean Lake occupies a natural basin that was gradually filled by the rising water table after irrigation began in the area.

Ground water in the flood-plain deposits of intermittent and ephemeral streams in the project area is likely to be moderately to highly mineralized. Water samples from two test holes augered in Kirby Draw had dissolved-solids contents of 1,460 and 4,090 ppm, and a sample from an augered test hole in the valley of Beaver Creek had a dissolved-solids content of 1,300 ppm. A 240-foot well drilled in the Wind River Formation at Moneta yields water that is believed to be contaminated by water from the alluvium of Poison Creek; it had a dissolved-solids content of more than 3,000 ppm. A well of similar depth about 300 feet away yields water from the Wind River Formation that had a dissolved-solids content of 1,790 ppm.

Springs issuing from terrace deposits along the Wind River in the northwestern part of the project area, principally in the vicinity of Dubois, yield as much as 500 gpm. The source of much of the water is leakage from irrigation ditches and seepage from irrigation water applied on the terraces, because the yields of the springs fluctuate widely and are greatest during the irrigation season. The water is of good quality, and some of the smaller springs have been developed for domestic supplies.

Deposits of windblown sand (Qs on geologic map) in the northeastern part of the project area are important sources of small quantities of ground water where the deposits are underlain by rocks of low permeability, or by rocks that yield water of poor quality. Yields from the windblown sand are small, but generally adequate for stock or domestic supplies, and the water is of good quality. The water in the windblown sand deposits is derived principally from local precipitation.

**ROCK OF TERTIARY AGE**

The Arikaree Formation contains water under water-table conditions, and depths to water are governed largely by the local topography—a well drilled in a topographically low area will penetrate the water table at a shallower depth than a well drilled on a nearby hillside or ridge crest. Depths of wells range from 40 to 850 feet and average about 190 feet. Depths to water range from 6 to 374 feet and average 92 feet. About 70 percent of the wells penetrate less than 100 feet of the saturated zone in the Arikaree Formation and 40 percent penetrate less than 50 feet.

Yields of wells in the Arikaree Formation differ greatly, depending on the permeability of the water-bearing material, the depth of penetration, and well construction. Some outcrops of the Arikaree indicate that fractures may greatly increase the permeability of the formation in some areas.

Logs of stock wells drilled in the formation in the upland areas bordering the Sweetwater River valley generally show a fine-grained friable sandstone interbedded with subordinate amounts of shale. Bailing tests made when the wells were completed indicate that most of these wells yield less than 0.5 gpm per foot of drawdown. The low yield of some wells may be attributable to sand invading the casing and thereby reducing the entrance area for water. Logs of two industrial wells
drilled in the Sweetwater River valley near Jeffer-
y City describe fine-grained sandstone under-
lain by a "sandstone conglomerate" that yielded
800 and 1,100 gpm during 24-hour pumping
tests. The specific capacities of the wells were 9
and 15 gpm per foot of drawdown, respectively.

Water from the Arikaree Formation is charac-
teristically a calcium bicarbonate type and is good
for most uses though generally hard. The specific
conductances of water from most of the wells
tested were less than 500 micromhos per centi-
meter, indicating a dissolved-solids content of less
than 350 ppm. The relation of dissolved solids
to specific conductance for most of the water samples
from the Arikaree Formation averaged about 0.67.

The Wagon Bed and White River Formations
have not been extensively developed as sources of
ground water because, except in small areas of
outcrop, they are overlain by aquifers that yield
adequate supplies to stock and domestic wells. The
Wagon Bed Formation, which is exposed only in
the Beaver Rim escarpment, yields a highly min-
eralized (2,550 ppm) magnesium calcium sulfate
water to one spring. The sample contained 0.01
ppm selenium. Several wells drilled in White
River outcrops on Beaver Divide have yields that
are comparable to those of wells tapping the
Arikaree Formation, and the chemical quality of
the water is similar.

The Wind River Formation consists largely of
an interbedded sequence of shale and siltstone
that contains lenticular beds of fine- to coarse-
grained sandstone of variable thickness and ex-
tent. The coarser material is more abundant along
the margins of the Wind River Basin. The altitude
of the piezometric surface may differ appreciably
between individual sandstone beds, indicating
there is little hydrologic connection between them.

Depths of 173 wells in the Wind River Forma-
tion range from 50 to 1,200 feet, and the average
depth is about 250 feet. Water levels in 136 wells
range from flows at the land surface to depths of
480 feet, and the average depth to water is about
80 feet. Most stock and domestic wells yield only
small quantities of water because drilling usually
is terminated when an adequate supply is assured.
Specific capacities of 52 stock wells, determined
from bailing tests made when the wells were com-
pleted, ranged from 0.02 gpm (essentially a dry
hole) to 2.25 gpm per foot of drawdown. The aver-
age specific capacity was 0.48 gpm per foot of
drawdown.

The Riverton and Shoshoni municipal wells
yield water from the Wind River Formation. Pump-
age from the Riverton well field (11 wells
500 to 600 feet deep) in 1965 was 193,240,000
gallons. Most of the pumps are set to yield about
200 gpm, but not all of them are operated at the
same time except during the summer. The draw-
down at this pumping rate is not known, but a
450-foot well drilled in the Wind River Forma-
tion in the SE1/4SW1/4 sec. 4, T. 1 S., R. 4 E., had
a drawdown of 167 feet after being pumped 129
hours at an average rate of 350 gpm. The specific
capacity was 2.1 gpm per foot of drawdown. The
two wells that supply the town of Shoshoni are
about 500 feet deep; one of the wells had a water
level about 17 feet below the land surface in 1951.
In 1954, the wells were individually pump tested
at 300 gpm for 48 and 72 hours; drawdowns in
the wells were 194 and 242 feet, respectively, and
the specific capacities were 1.55 and 1.24 gpm per
foot of drawdown. A well in the SW1/4NE1/4 sec.
29, T. 38 N., R. 94 W., not shown on figure 4, 446
feet deep, had a drawdown of 111 feet at a sus-
tained yield of 250 gpm—a specific capacity of
2.25 gpm per foot of drawdown—when tested
in 1951.

Several wells in the Gas Hills area produce
water from the Wind River Formation for indus-
trial and domestic supplies. Depths of the wells
range from about 100 to 400 feet, and reported
depths to water range from 20 to 125 feet. A well
in the NE1/4NE1/4 sec. 32, T. 33 N., R. 90 W., 200
feet deep, had a reported specific capacity of 20
gpm per foot of drawdown after 18 hours of
pumping, and a 415-foot well in the SW1/4SW1/4
sec. 28, T. 33 N., R. 90 W. had a reported specific
capacity of 10 gpm per foot of drawdown after 16
hours of pumping. Several other wells yield 250
to 350 gpm, but drawdowns are not known.

The quality of water in the Wind River Forma-
tion differs throughout the project area. Analyses
of water samples (table 1) from 34 wells indicate
that water in the Wind River Formation is pre-
dominantly a sodium sulfate (17 samples) or
calcium sulfate (8 samples) type. Six samples
were sodium bicarbonate type and three were cal-
lcium bicarbonate. Concentrations of dissolved sol-
ids range from 284 to 4,530 ppm; however, 63
percent of the samples contained less than 1,000
ppm of dissolved solids. Specific conductances of
water from 56 additional wells indicate that 64
percent yield water containing less than 1,000 ppm
of dissolved solids. Water of lowest mineralization
was generally from wells that are more than 250
feet deep. To convert specific conductance to dis-
solved-solids concentration, a factor of 0.72 gen-
erally is applicable for water from the Wind River
Formation.

Water from the Wind River Formation in the
Gas Hills area is consistently a calcium sulfate
type and is very hard, and water from the for-
mation in the Riverton area is chiefly a sodium
bicarbonate type and is very soft. Uraniferous
zones in the formation in the Gas Hills area yield
water that contains dangerous amounts of radio-
activity, and water should be analyzed before it
is used for a domestic or stock supply. Selenium,
which is reportedly present in ground water in
some parts of the Wind River Basin, was not
detected or showed only a trace in samples analyzed
for selenium. Several samples contained unde-
sirable amounts of fluoride for domestic use. The
high percentage of sodium in most of the water
samples indicate that water from the Wind River
Formation is generally unsuitable for irrigation
except on soils of good permeability that have
adequate drainage.

The Fort Union Formation is known to yield
water to several wells in the project area, and there
are probably other wells in the formation that
were not visited by the authors. A well in the SE\(\frac{1}{4}\)
sec. 36, T. 36 N., R. 86 W. penetrates about 600
feet of the formation and yields 15 gpm of water
that has a specific conductance of more than 2,500
micromhos per centimeter and contains a high
concentration of iron. A well in the NW\(\frac{3}{4}\) sec. 9,
T. 1 S., R. 2 E. is 430 feet deep and yields about
2 gpm of water that has a dissolved-solids con-
tent of 995 ppm (table 1). The water is a sodium
bicarbonate type and contains high concentrations
of chloride and fluoride. Two deep oil tests drilled
in T. 36 N., R. 90 W. reportedly found water of
good quality (746 and 1,068 ppm dissolved solids)
in the Fort Union and underlying Lance Forma-
tions (table 1). Moderate to large yields might be
developed from the Fort Union in some areas, but
the cost of the deep wells probably would be
prohibitive for most uses.

The Wiggins, Tepee Trail, Aycross, and Indian
Meadows Formations, and undifferentiated rocks
of Tertiary age, might yield moderate to large
supplies of water from coarse sandstone and con-
glomerate beds that are widely distributed in the
formations. These rocks have not been tested as
potential sources of ground water, but the Battle
Spring Formation (included in F5 on geologic
map), which crops out in the south central part
of the area, is considered to be a potential source
of large quantities of ground water in the Great
Divide Basin (Welder and McGreevy, 1965).

ROCKS OF CRETACEOUS AGE

Rocks of Cretaceous age consist principally of
shale containing minor amounts of fine-grained
silty sandstone and siltstone and, except near the
margins of the Wind River Basin or in areas of
local uplift, lie at great depths. Although water in
these formations is generally under artesian pres-
sure and water levels in wells are likely to be
near the surface, Cretaceous rocks commonly are
not considered good aquifers because of their gen-
erally low permeability and poor quality of the
water. The few wells that penetrate Cretaceous
strata are where a better source of water is not
economically available. The Lance and Cloverly
Formations may be exceptions to this generaliza-
tion, however, but areas in which the forma-
tions lie within economical drilling depths are small.

The Cloverly Formation is the principal source
of domestic water in some parts of the Gas Hills
area because water from the shallow aquifers often
contains large amounts of radioactive material.

The wells range in depth from 484 feet in the
NW\(\frac{3}{4}\) sec. 15, T. 33 N., R. 89 W. to 1,720
feet in the NE\(\frac{3}{4}\) sec. 22, T. 33 N., R. 90 W.
and reportedly yield from 45 to 350 gpm. The
water is under artesian pressure, and water levels
in wells range from 28 to 356 feet below the land
surface. Drawdowns generally are great, and the
specific capacities of the wells average only about
0.25 gpm per foot of drawdown. The water is a
sodium sulfate or sodium bicarbonate type and
dissolved-solids concentrations are generally less
than 1,000 ppm (table 1).

No wells in the project area are known to yield
water solely from the Lance Formation. Wells
drilled in the Lance in the adjacent Powder River
Basin generally yield supplies adequate for stock
and domestic use, but the water is usually too
mineralized for a desirable domestic supply.

Water from the few wells in the project area
that tap the Mesaverde Formation, Cody Shale, or
Frontier Formation is generally unfit for domes-
tic use, and in some wells it is so unpalatable that
stock will not drink it. Wells that were sampled
yield a sodium sulfate or sodium bicarbonate
water. One sample from the Frontier Formation
contained 3.8 ppm of fluoride.

ROCKS OF PRE-CRETACEOUS AGE

Formations underlying rocks of Cretaceous age
are deeply buried throughout most of the project
area. They form narrow outcrops on the flanks of
the Wind River, Owl Creek, and Bighorn Moun-
tains and in some of the major anticlinal struc-
tures within the basin. Few wells in the project
area penetrate these formations because drilling
depths are great, except in or near the outcrops.

The Morrison Formation yields water to only
three of the wells inventoried during the investiga-
tion. A 215-foot well drilled on the axis of a
plunging anticline in the SW\(\frac{1}{4}\) sec. 23, T.
Sodium sulfate water that contains 1,720 ppm dissolved solids. Two wells drilled in Morrison outcrops in the foothills of the Wind River Mountains (SE1/4NE1/4 sec. 24, T. 1 S., R. 2 W. and SE3/4SE1/4 sec. 26, T. 33 N., R. 100 W.) are 41 feet and 98 feet deep and reportedly yield 12 gpm and 20 gpm; the drawdown at these pumping rates are not known. The water contains only about 420 ppm of dissolved solids. A sample from one of the wells was a calcium sulfate type and very hard.

The Sundance Formation probably is the source of water for a 350-foot well drilled in the NW1/4 NE1/4 sec. 34, T. 32 N., R. 99 W. The well yields 6 gpm with 150 feet of drawdown, and the water is a sodium sulfate bicarbonate type that contains 799 ppm of dissolved solids. Water samples from both the Morrison and Sundance contained undesirable concentrations of fluoride. The Gypsum Spring Formation is likely to yield water that is highly mineralized and unfit for most uses.

Little is known of the potential yield of the Nugget Sandstone, but examination of outcrops suggests that the formation would yield at least moderate quantities of water where the formation is saturated, and perhaps large amounts if the rock is fractured. The only well in the Nugget that was inventoried during the investigation is in the outcrop in the SE1/4SW1/4 sec. 24, T. 1 S., R. 1 W. and taps about 25 feet of saturated material. The well reportedly yielded 10 gpm with a drawdown of 2.5 feet during a 2-hour pumping test. The indicated specific capacity (4 gpm per foot of drawdown) is somewhat larger than would be expected unless the rock were fractured or weathered. No water samples were obtained from the Nugget Sandstone, but it should be of good chemical quality in or near the outcrop.

The Chugwater Formation should yield at least small quantities of water to wells, but its potential yield is not known because only two of the wells inventoried produce solely from the formation. The well in sec. 26, T. 1 S., R. 2 W. is 56 feet deep and yielded 9 gpm with a drawdown of 2 feet during a 2-hour pumping test. If the reported test data are reliable, the formation at this site probably is fractured; the apparent specific capacity is much greater than can be expected at most places. Normally, a specific capacity of 1 gpm or less per foot of drawdown can be expected. Wells penetrating a great saturated thickness might yield moderate quantities of water, but pumping lifts probably would be proportionately great. The chemical quality of water in the Chugwater Formation is not known, but it should be suitable for stock use in or near areas of outcrop.

The Park City formation and equivalents apparently yield large quantities of water from two wells in T. 30 N., R. 96 and 97 W. One well, which is 260 feet deep, flows a reported 700 gpm from the upper 43 feet of the Park City and equivalents; the yield was increased to 900 gpm with a booster pump in the line to supply water for a road construction project. The other well is 408 feet deep, penetrates 258 feet of the formation, and has a water level that is about 50 feet below the land surface. It yields 150 gpm with a drawdown of about 17 feet. These higher yields from the Park City and equivalents are, undoubtedly, due to fractures and solution cavities in the formation, because normally the interbedded limestone, dolomite, and sandstone are relatively impermeable. The abnormally high temperature (71°F) of water from the flowing well suggests that the source of the water is not from local recharge to the Park City and equivalents but that it is coming from a deeper zone, perhaps the Tensleep Sandstone. The water from these wells is a calcium sulfate type. The dissolved-solids content ranges from 877 ppm to 1,020 ppm, and the water is very hard.

The Tensleep Sandstone yields water to several wells in the central and western parts of the project area, and probably is the source of the water issuing from Chief Washakie Hot Spring in the NE1/4 sec. 2, T. 1 S., R. 1 W. Three wells in the Gas Hills area drilled for industrial and domestic supplies range from 1,362 to 1,685 feet in depth. The wells penetrate 63 feet, 94 feet, and 250 feet of Tensleep, and the reported specific capacities are 270 gpm, 2 gpm, and 12 gpm per foot of drawdown, respectively.

Two irrigation wells 700 and 900 feet deep in the foothills of the Wind River Mountains in T. 33 N., R. 100 and 101 W. reach the Tensleep Sandstone at depths of 400 and 500 feet, respectively. The shallower well had a measured flow of 75 gpm, and the other had a reported flow of 100 gpm. The well in the NE1/4SW1/4 sec. 25, T. 3 N., R. 100 W. drilled to supplement the Lander municipal supply is 3,334 feet deep and reportedly flowed 539 gpm from the uppermost 300 feet of Tensleep when completed in 1942. An oil test drilled to a depth of about 2,800 feet on the north end of Dallas Dome, about 6 miles southeast of Lander, had an estimated flow of about 500 gpm from the Tensleep. Chief Washakie Hot Spring reportedly flowed about 1,200 gpm in 1945. A large spring in the NW1/4 sec. 15, T. 32 N., R. 81 W. flows 7,500 gpm from a sandstone in the Casper Formation.
that may be, in part, the equivalent of the Tensleep Sandstone. The large-yield springs and the most productive wells are associated with local structures where fracturing and solution have increased the permeability of the formations.

The two water samples from the Tensleep in the Gas Hills area were a calcium sulfate and calcium sodium sulfate type and had a dissolved-solids content of 1,010 and 1,418 ppm, respectively. Samples from water wells and from several oil test holes in the western part of the project area are a calcium bicarbonate type, and dissolved-solids concentrations range from 205 to 245 ppm. Chief Washakie Hot Spring yields water that is a calcium sulfate type, and has a dissolved-solids content of 801 ppm. Water sampled from the Tensleep is suitable for irrigation, and except for the water from the Gas Hills wells and from Chief Washakie Hot Spring, which has undesirable concentrations of sulfate and fluoride, is suitable for domestic use, though generally hard. The presence of hydrogen sulfide in water from most wells causes the water to be unpalatable until it has been aerated. The water from the spring in the Casper Formation is a calcium bicarbonate sulfate type and has a dissolved-solids content of 387 ppm.

The Madison Limestone yields water to an industrial well in the NW1/4NW3/4 sec. 13, T. 30 N., R. 99 W. The well is 1,627 feet deep, and reached the top of the Madison at a depth of 1,013 feet. The water level is 446 feet below the land surface. The Madison at this location has a low permeability and yielded only 130 gpm with a drawdown of 900 feet (a specific capacity of 0.13 gpm per foot of drawdown). In many areas, outcrops of the Madison contain cavernous zones that were developed by the solvent action of water. A spectacular example of cavern development is in Sinks Canyon west of Lander where the normal flow of the Middle Popo Agie River disappears into an opening in the Madison and reappears about half a mile downstream. Where fractured and cavernous zones are saturated, they will yield large quantities of water to wells penetrating them. Flows of as much as 2,500 gpm are obtained from some irrigation wells drilled into the Madison Limestone near Hyattville, in the eastern part of the Bighorn Basin (Lowry, M.E., 1962, table 1).

The one water sample from the Madison Limestone was a calcium bicarbonate type and contained 397 ppm of dissolved solids. The water is suitable for domestic use but very hard. Mineralization of water in the formation normally will increase with depth and with distance from the outcrop, but the water should be suitable for most uses where the Madison lies at economical drilling depths.

Formations underlying rocks of Mississippian age in the project area are either deeply buried or crop out in inaccessible areas and, therefore, have not been tapped by wells. Numerous springs issue from pre-Mississippian rocks in the mountains. The water is of good quality (less than 300 ppm of dissolved solids), as indicated by field measurements of specific conductance. The chemical analysis of one sample from a spring issuing from Precambrian granite shows that the water is a sodium bicarbonate type with a dissolved-solids content of 267 ppm.

**POTENTIAL SOURCES OF LARGE SUPPLIES OF WATER**

Alluvial deposits in the valleys of the Wind, Little Wind, Popo Agie, and Sweetwater Rivers would yield moderate to large supplies of ground water, but surface-water supplies along these streams are generally adequate to meet existing irrigation needs. The quality of the ground water is generally inferior to that of surface water and in some areas, such as the Riverton irrigation project area, it may be unsuitable for some types of irrigation.

The Wind River and Arikaree Formations contain permeable zones that are capable of yielding large supplies of water to wells at depths of less than 500 feet, and yields of most wells could be increased by deeper drilling. Large yields are obtained from coarse deposits in the Wind River Formation along the margin of the basin and in the Arikaree Formation near granite outcrops. Unconsolidated zones, particularly in the Arikaree, are potential sources of large supplies of water, but special drilling and completion techniques may be required to properly develop wells in them. Many wells have been terminated in these zones because of the difficulty in keeping the hole open when special drilling and casing techniques are not used.

Water from the Wind River Formation ranges widely in quality, but it apparently improves with depth. However, the deepest well known to yield water from this formation is only 1,200 feet deep and the quality-depth relation may not extend to greater depths. Water from the Arikaree Formation is suitable for most purposes.

Large supplies of water can be obtained locally from sandstone and limestone formations in zones of secondary permeability (permeability due to fracturing or solution). Several large yielding springs and wells derive water from the Park City and equivalents and Casper Formations and from the Tensleep Sandstone. A well tapping the Nugget Sandstone and a well tapping the Chugwater
Formation had yields larger than expected for the aquifer, suggesting secondary permeability. Fractures observed in outcrops of the Arikaree, if present at depth, would yield large supplies of water to wells.

WATER QUALITY CRITERIA

Criteria have been established for determining the suitability of water for different uses, but in many parts of the project area, water is utilized that does not meet the suggested suitability standards.

The U.S. Public Health Service (1962) has recommended the following standards for water used for drinking and culinary purposes on interstate carriers:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Recommended maximum concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>0.3</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.65</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>250</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>250</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>8–1.7</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>1,500</td>
</tr>
</tbody>
</table>

Hardness in water is caused principally by calcium and magnesium in solution. It is classified as follows: 60 ppm or less, soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; and more than 180 ppm, very hard.

Studies at the Wyoming Agricultural Experiment Station have resulted in the following classification of the suitability of water for stock (Beath and others, 1953).

<table>
<thead>
<tr>
<th>Dissolved solids (ppm)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1,000</td>
<td>Good</td>
</tr>
<tr>
<td>1,000 to 3,000</td>
<td>Fair (usable)</td>
</tr>
<tr>
<td>3,000 to 5,000</td>
<td>Poor (usable)</td>
</tr>
<tr>
<td>5,000 to 7,000</td>
<td>Very poor (questionable)</td>
</tr>
<tr>
<td>More than 7,000</td>
<td>Not advisable</td>
</tr>
</tbody>
</table>

The most significant properties that affect the suitability of water for irrigation are the dissolved-solids content (salinity hazard), the percent sodium, and the sodium concentration relative to the calcium and magnesium concentrations (sodium-adsorption ratio). The salinity hazard of a water having a specific conductance of less than 250 is low; 250–750, medium; 750–2,250, high; and greater than 2,250, very high (U.S. Salinity Lab. Staff, 1954, p. 80). Water in which the concentration of sodium is appreciably greater than 50 percent of the total cations is of limited suitability for irrigation, and the limitations increase as the sodium percentage increases.

The sodium-adsorption ratio is a refinement of the percent sodium criterion, and is more significant in the evaluation of the suitability of water for irrigation. The following approximate relation between sodium-adsorption ratio (SAR) and the sodium (alkali) hazard in water of high sodium content for irrigation has been established by the U.S. Salinity Laboratory Staff (1954, fig. 25).

<table>
<thead>
<tr>
<th>SAR (approx)</th>
<th>Sodium (alkali) hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>Low</td>
</tr>
<tr>
<td>10–18</td>
<td>Medium</td>
</tr>
<tr>
<td>18–26</td>
<td>High</td>
</tr>
<tr>
<td>More than 26</td>
<td>Very high</td>
</tr>
</tbody>
</table>

SELECTED REFERENCES


### Table 1—Chemical analyses of ground water in the Wind River basin area, central Wyoming

[Analyses by U.S. Geological Survey except as indicated. Analytical results in parts per million except as indicated.]

| Location | Section | T. | R. | Depth (ft) | Potential temperature (°F) | Date of collection | Temperature (°F) | Silica (mg/L) | Total iron (mg/L) | Calcium (pmol/L) | Magnesium (pmol/L) | Sodium (mg/L) | Potassium (mg/L) | Calcium carbonate (mg/L) | Calcium (mg/L) | Chloride (mg/L) | Fluoride (mg/L) | Nitrate (mg/L) | Dissolved solids | Hardness as CaCO₃ | Specific conductance at 25°C (µmhos/cm) | pH | Dose of sodium adsorption ratio | H₂S, dissolved in water |
|----------|---------|----|----|-----------|----------------------------|-------------------|-----------------|---------------|----------------|----------------|-----------------|--------------|----------------|----------------|----------------------------|---------------|----------------|----------------|---------------|----------------|----------------|--------------------------------|----|---------------------|------------------|

**Precambrian granite**

| Location | Section | T. | R. | Depth (ft) | Potential temperature (°F) | Date of collection | Temperature (°F) | Silica (mg/L) | Total iron (mg/L) | Calcium (pmol/L) | Magnesium (pmol/L) | Sodium (mg/L) | Potassium (mg/L) | Calcium carbonate (mg/L) | Calcium (mg/L) | Chloride (mg/L) | Fluoride (mg/L) | Nitrate (mg/L) | Dissolved solids | Hardness as CaCO₃ | Specific conductance at 25°C (µmhos/cm) | pH | Dose of sodium adsorption ratio | H₂S, dissolved in water |
|----------|---------|----|----|-----------|----------------------------|-------------------|-----------------|---------------|----------------|----------------|-----------------|--------------|----------------|----------------|----------------------------|---------------|----------------|----------------|---------------|----------------|----------------|--------------------------------|----|---------------------|------------------|

**Madison Limestone**


**Tensleep Sandstone**


**Park City Formation and equivalents**


**Park City Formation, Dinwoody, and Chugwater Formations**


**Sundance Formation**


**Morrison Formation**


## Cloverly Formation

<table>
<thead>
<tr>
<th>SW</th>
<th>NE</th>
<th>NW</th>
<th>SE</th>
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</thead>
<tbody>
<tr>
<td>15</td>
<td>89</td>
<td>1,611</td>
<td>1,070</td>
</tr>
<tr>
<td>22</td>
<td>90</td>
<td>89</td>
<td>44</td>
</tr>
<tr>
<td>23</td>
<td>90</td>
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<td>33</td>
</tr>
<tr>
<td>28</td>
<td>90</td>
<td>1,048</td>
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</table>

## Muddy Sandstone Member of Thermopolis Shale

<table>
<thead>
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<th>NW</th>
<th>SE</th>
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</thead>
<tbody>
<tr>
<td>13</td>
<td>89</td>
<td>1,611</td>
<td>1,070</td>
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</tbody>
</table>

## Frontier Formation

<table>
<thead>
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<th>SW</th>
<th>E</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>44</td>
<td>33</td>
<td>20</td>
</tr>
<tr>
<td>14</td>
<td>44</td>
<td>33</td>
<td>20</td>
</tr>
<tr>
<td>18</td>
<td>44</td>
<td>33</td>
<td>20</td>
</tr>
</tbody>
</table>

## Cody Shale

<table>
<thead>
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<th>NW</th>
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</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>44</td>
<td>33</td>
<td>20</td>
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## Mesaverde Formation

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</thead>
<tbody>
<tr>
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<td>44</td>
<td>33</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>44</td>
<td>33</td>
<td>20</td>
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</tbody>
</table>

## Lance and Fort Union Formations

<table>
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<th>W</th>
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<tbody>
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<td>33</td>
</tr>
<tr>
<td>2</td>
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<td>33</td>
<td>33</td>
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</tbody>
</table>

## Fort Union Formation

<table>
<thead>
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<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Location</td>
<td>T.</td>
<td>R.</td>
<td>Depth (ft)</td>
</tr>
<tr>
<td>----------</td>
<td>----</td>
<td>----</td>
<td>-----------</td>
</tr>
<tr>
<td>SW42E14</td>
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<tr>
<td>SW42E34</td>
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</tr>
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</table>

### Table 1—Chemical analyses of ground water in the Wind River basin area, central Wyoming—Continued

[Analyses by U.S. Geological Survey except as indicated. Analytical results in parts per million except as indicated]
<table>
<thead>
<tr>
<th>SWEN#</th>
<th>Alluvium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>SW#</td>
<td>4th</td>
</tr>
<tr>
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<tr>
<td>12</td>
<td>100</td>
</tr>
<tr>
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<td>14</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>100</td>
</tr>
</tbody>
</table>

*In solution at time of analysis.*

*Analysis by Wyoming Department of Agriculture.*