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Wyoming Water Planning Program
Report No. 11

WATER & RELATED LAND RESOURCES

OF THE

BIGHORN RIVER BASIN, WYOMING

October 1972

**A Report from the**

# WYOMING WATER PLANNING PROGRAM

**State Engineer's Office**

**Cheyenne, Wyoming**

Wyoming Water Planning Program
Report No. 11

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# OF THE

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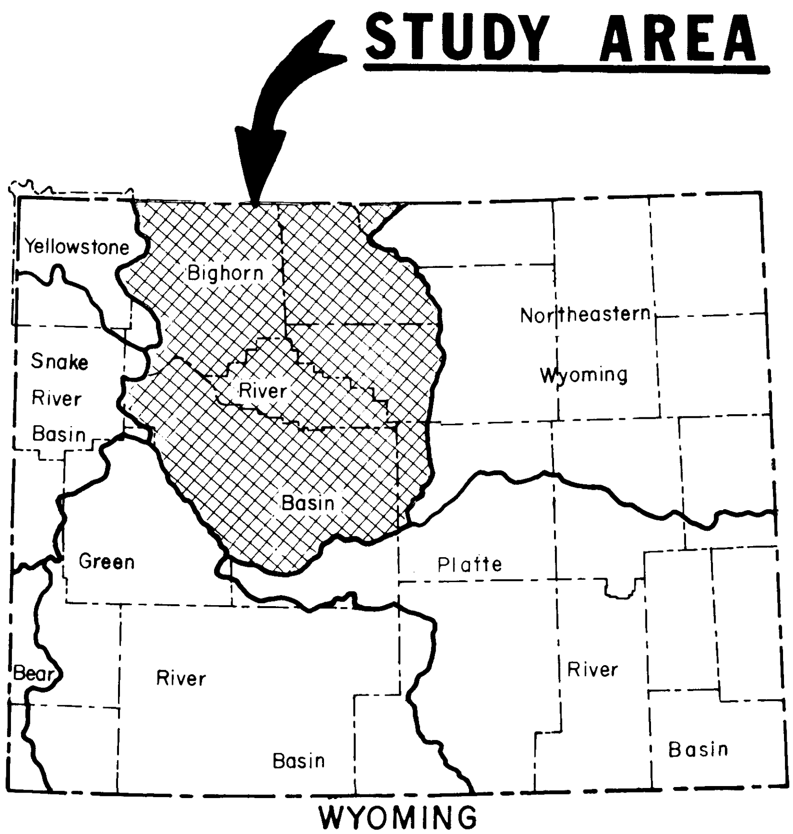

WATER AND RELATED LAND RESOURCES
OF THE
BIGHORN RIVER BASIN, WYOMING

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ILLUSTRATIONS (continued)



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TABLES (continued)

TABLES (continued)

# PREFACE

This report on the Bighorn River Basin of Wyoming has been prepared for the people of Wyoming as part of a "State Water Plan." The work upon which this report is based was supported by funds provided by the Wyoming Legislature and by the Water Resources Council under Title III of the Water Resources Planning Act of 1965 (Public Law 89-80). The report is presented as part of the planning effort authorized by the 39th Legislature of the State of Wyoming, which directed that, "The State Engineer is responsible for the coordination of Wyoming's water and related land resources planning and is authorized to enter into contracts and agreements with the United States of America or its duly authorized representative agency for planning pertaining to the development of Wyoming's water and related land resources." As a result of this legislation, the Water Planning Program was established as a division of the State Engineer's Office, under the general supervision and direction of the State Engineer.

The report discusses water and related land resources in the Bighorn River Basin of Wyoming and provides a means of evaluating the water needs and resources of the Basin relative to the overall water needs and resources of Wyoming. The complete "State Water Plan" will incorporate this analysis of the Bighorn River in the formulation of a Statewide plan, with alternatives, to develop the water and related land resources of Wyoming.

In this report, the present water uses in the Bighorn River Basin are inventoried and future water needs are determined. Potential water development projects are identified. Alternatives for future water resources development are presented.

This report does not attempt to prescribe a course of action. Rather, it attempts to provide information so that practical decisions can be made by the citizens of Wyoming concerning future water and related land resource development in the State.

The Governor's Interdepartmental Water Conference provides a coordinating forum for the water planning effort. State agencies with water resource responsibilities contribute useful data to the Water Planning Program and through regularly held meetings keep informed of policy, planning, and legislative considerations. Contributions to this report were made by several agencies. The member agencies of the Governor's Interdepartmental Water Conference are:

Governor Stanley K. Hathaway

State Engineer's Office

State Department of Agriculture

Department of Economic Planning and Development

Department of Health and Social Services

Game and Fish Commission

The Geological Survey of Wyoming

Wyoming Highway Department

Wyoming Recreation Commission

University of Wyoming

Agriculture Extension Service

College of Law

Water Resources Research Institute

Data were also obtained from reports by the Bureau of Reclamation, the Bureau of Indian Affairs, the U. S. Geological Survey, the Soil Conservation Service, the U. S. Corps of Engineers, and others.

Members of the staff of the Wyoming Water Planning Program who contributed to the report include:

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Floyd A. Bishop, Wyoming State Engineer, provided invaluable guidance, contributions, and reviews both in the studies leading to the report, and in the report writing process.

# C H A P T E R  I

# D E S C R I P T I O N  O F  T H E  B A S I N

# D E S C R I P T I O N  O F  T H E  B A S I N

## LOCATION AND SIZE

The study area (shown on the Location Map, Figure I-1) for this report includes approximately 20,592 square miles in north-central Wyoming. This area, frequently referred to in this report as the Basin, extends southward from the Wyoming-Montana State line, latitude 45°00' North, to latitude 42°27' North, a distance of approximately 175 miles. The Basin extends eastward from the eastern boundary of Yellowstone National Park, about longitude 110°13' West, to about longitude 107°00' West, a distance of approximately 155 miles.

The study area includes all the area in Wyoming drained by the Wind-Bighorn River, the Clarks Fork of the Yellowstone River, and the Little Bighorn River. The Wind River's name changes to the Bighorn River at the Wedding of the Waters in the Wind River Canyon. In this report the entire river may be referred to as the Wind-Bighorn River for clarity. Otherwise, the Wind River and the Bighorn River are referred to in the normal context.

Of the total area, about 6 percent or 1,245 square miles are in the Clarks Fork drainage and 19,347 square miles are in the Wind-Bighorn River drainage. All of the Big Horn, Hot Springs, and Park Counties, nearly all of Fremont and Washakie Counties, portions of Natrona and Sheridan Counties, and very small parts of Johnson, Teton, and Sublette Counties are included in the study area. The area coincides geographically with the administrative Wyoming Water Division Number Three, except that the study area also includes the drainage of the Little Bighorn River in Sheridan County, which is in Water Division Number Two.

## HISTORY

### Early Inhabitants

There is evidence that people lived near the present site of Cody as much as 6,800 years ago. About 6,000 years ago the region became a desert and apparently was uninhabited for about 1,500 years. As the climate improved people returned, and various Middle Period sites dating from 2500 B.C. to A.D. 500 have been discovered in the Shoshone River Basin and some other areas of the State.

The prominent Indian tribes in or near the Basin were the Shoshone, Arapahoe, Blackfeet, Gros Ventre, Nez Perce, Sioux, and Crow. All these tribes stem from or were strongly affected by the Plains culture, which reached its peak in the early 1800's before the white man's invasion began. The Plains Indian culture was shaped largely by two animals, the buffalo and the horse. The rich bison meat provided the basic Indian diet. Hides were used to make tepees, robes, and shields. Ropes were made of buffalo rawhide and twisted hair. Buffalo sinews provided bow strings and thread. The stomach was used as a cooking pot. Buffalo bones were carved into tools; horns into spoons, ladles, and ornaments. Hooves were used to make glue, and the tail, fastened to a stick, became a fly brush (7).[1] However, the buffalo was difficult to hunt on foot. In the mid-eighteenth

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[1] Number in parentheses refers to a specific reference listed in the Bibliography of Selected References (by chapter) at the end of the report.

century horses brought to the New World by the Spaniards drifted into the Plains Indians' domain from the Southwest. The Plains Indians tamed and trained the new animals and became equestrian nomads. With millions of buffalo to hunt and horses to make the hunt easy, the Plains Indian had time to develop his art and religion into the forms familiar today.

Two tribes of Indians reside in the Basin today, both on the Wind River Indian Reservation. These are the Eastern (Wind River) Shoshones and the Northern Arapahoes.

The Eastern Shoshones left the Great Basin and moved eastward into the plains region about 1500, thereafter acquiring many of the cultural characteristics of the Plains Indians. Because the Shoshones often fought against the Plains tribes, they befriended the white men who invaded the area in the 1800's. Their friendliness was rewarded in the Fort Bridger Treaty of 1863, which gave the Shoshones title to some 44 million acres of land of their own choosing in Colorado, Idaho, Utah, and Wyoming (7). Later cessions to the white men reduced their reservation (Wind River) to its present size of about 1.9 million acres.

The Arapahoe tribe is a branch of the Algonquin family. Arapahoes participated in the Fort Laramie Treaty of 1851, but persisted in attacks against both whites and other tribes. In 1868 they relinquished claims to lands in Wyoming and moved to South Dakota. Unhappy there because the Sioux held the best hunting grounds, they agreed in 1876 to move to Indian Territory (now Oklahoma). While on the way south, the Indians stopped on the Platte River and insisted that the President of the United States be informed that they wanted a reservation in Wyoming. The Government obtained reluctant permission from the great Shoshone chief Washakie to place the Arapahoes temporarily on the Wind River Reservation with their old enemies, the Shoshones. There, over Shoshone protests, they remained.

The Shoshones in 1938 were awarded $4,453,000 as a judgement against the Federal Government for damages sustained because of the Arapahoe move. Earlier they had been awarded $1,581,000 as the price for the half interest in the reservation given to the Northern Arapahoes. An Arapahoe claim against the United States for land cessions, settled in 1963, netted that tribe approximately $3 million (7).

Although ancient enmity has faded, the Shoshones and Arapahoes still tend to live apart. Fort Washakie serves as agency for both tribes, but each tribe has its own Tribal Council to make policies and regulations. Often inter-tribal problems are handled by a Joint Council. Fort Washakie, Wind River, and Crowheart are Shoshone settlements, while Arapahoes live at Ethete, Arapahoe, and St. Stevens.

Oil and gas fields on the reservation, in addition to the grazing fees, farm rentals, and timber, produce substantial income for the two tribes. Almost all the rangeland and about one-third of the irrigated farmland is used by tribal members.

## Fur-Trapping Era

The first white man in the Basin (and possibly the State) is claimed to have been John Colter, a hunter with the Lewis and Clark Expedition. Colter

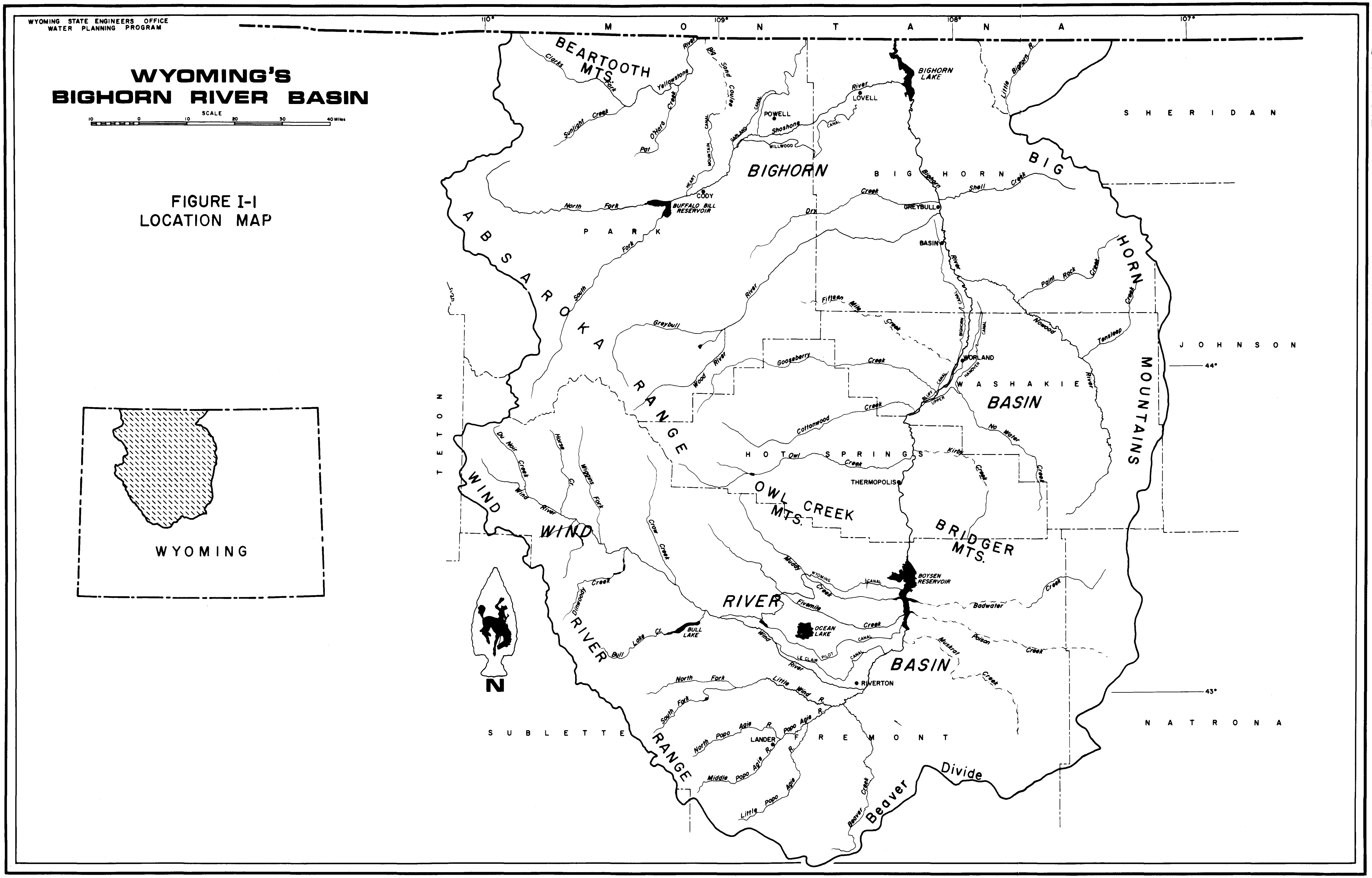

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM
WYOMING'S
BIGHORN RIVER BASIN
SCALE
10 0 10 20 30 40 Miles
FIGURE I-1
LOCATION MAP
WYOMING
N
M O N T A N A
110°
109°
108°
107°
44°
43°
BEARTOOTH MTS.
ABSAROKA RANGE
BIGHORN
BIG HORN
BIG HORN MOUNTAINS
WASHAKIE
BASIN
HOT SPRINGS
OWL CREEK MTS.
BRIDGER MTS.
WIND RIVER
WIND RIVER RANGE
RIVER BASIN
FREMONT
SHERIDAN
JOHNSON
NATRONA
SUBLETTE
TETON
PARK
Beaver Divide
BIGHORN LAKE
BUFFALO BILL RESERVOIR
BOYSEN RESERVOIR
OCEAN LAKE
BULL LAKE
POWELL
LOVELL
CODY
GREYBULL
BASIN
WORLAND
THERMOPOLIS
RIVERTON
LANDER
Clarks Fork
Yellowstone River
Sunlight Creek
O'Hara Creek
Pat
Big Sand Coulee
Shoshone River
North Fork
South Fork
Greybull River
Wood River
Dry Creek
Shell Creek
Paint Rock Creek
Nowood River
Tensleep Creek
Fifteen Mile Creek
Gooseberry Creek
Cottonwood Creek
Owl Creek
Kirby Creek
No Water Creek
Du Noir Creek
Horse Cr.
Wiggins Fork
Crow Creek
Dinwoody Creek
Bull Lake Cr.
Muddy Creek
Fivemile Creek
Badwater Creek
Poison Creek
Muskrat Creek
North Fork
Little Wind R.
South Fork
North Popo Agie R.
Middle Popo Agie R.
Little Popo Agie
Popo Agie R.
Beaver Creek
Little Bighorn R.
Bighorn River
HEART MOUNTAIN CANAL
GARLAND CANAL
WILLWOOD
CANAL
BIGHORN CANAL
HANOVER CANAL
BLUFF CANAL
UPPER
WYOMING CANAL
PILOT CANAL
LE CLAIR

FIGURE I-1

left the expedition in 1806 while returning eastward and spent the winter with two fur trappers in what is now Montana. The next year Colter roamed through the Bighorn and Wind River valleys befriending the Crow Indians and even helping them fight their enemies, the Blackfeet. After Colter came many more trappers, or mountain men, so that in the early 1830's there may have been as many as two hundred of them at one time in what is now Wyoming. Annually, the trappers got together at summer rendezvous held in the Wind River or Popo Agie valley, or outside the Basin on the Green River. Here, trappers traded their pelts to fur company bosses in exchange for wages or goods such as blankets, traps, firearms, salt, and whiskey. Besides business, the rendezvous were the scenes of games such as horse racing and wrestling, gambling and firearm contests, feasting and dancing. Silk hats came into vogue around 1832 and the market for beaver pelts disappeared. The mountain men left, but not without leaving their mark on the Basin through place names and discoveries of mineral deposits and passageways. It has been said that no Government explorer after 1840 made a western discovery that some of the fur trappers hadn't known about for years (8).

## Beginning of the Stock Growing Era

Captain William Sublette and other fur trappers took five cattle to the Wind River rendezvous in 1830. The Mormons drove the first breeding cattle into the State in 1848. Soon numerous cattle from Texas were being driven to Wyoming to take advantage of the free range.

Most of the cattle in the 1870's were concentrated in southeastern Wyoming. With the Indian threat removed, herds were pushed into the northeastern part of Wyoming Territory. Then in 1879 the Bighorn Basin was invaded. Charles Carter first brought three thousand or more Oregon cattle to the junction of the North and South Forks of the Stinking Water (Shoshone) River. Another herd belonging to an Englishman, Captain Henry Belknap, was brought from Montana to the South Fork of the Stinking Water in 1880. That same year, Otto Franc brought a herd from Montana to the Greybull River, and a Kansan, Henry T. Lovell, trailed two herds to the west side of the Bighorn River just above the mouth of Nowood Creek. Carter's Bug Ranch, Franc's Pitchfork, and Lovell's Home Ranch became famous in later years (3). John Luman trailed cattle from Idaho to Paint Rock Creek in 1881. That year or the next, George W. Baxter established the LU Ranch on Grass Creek and Joseph M. Carey sent a herd to the Greybull country in 1883. Meanwhile, many others had been scrambling to acquire choice locations in the Basin, so that the area was quite well stocked by 1884 (3).

Cattle were brought into Wyoming in such numbers that over-grazing soon became a problem. This, and the terrible winter of 1886-87, which covered the short grass with deep snow and froze stock water, caused the greatest catastrophe ever experienced by the Wyoming cattle business (5). Probably over 15 percent of Wyoming's range cattle died that winter. The remaining cattle were in very poor condition and brought little money when sold. The 1887 calf crop was very small. Many ranchers never recovered. One good facet of this catastrophe was that it brought about improved ranching methods such as range management and winter feeding, which have made possible the successful ranching business practiced in the Basin today.

Sheep were first brought to Wyoming at least ten years after the cattle, but their in-migration lasted nearly 40 years. In 1870 Wyoming Territory had about 36,000 head of sheep; by 1910 there were nearly 5,480,000 head.

Bitter disputes in the West between sheepmen and cowmen often resulted in violent conflicts, especially in the Bighorn River Basin. The conflicts reached a climax in 1909, when two wealthy wool growers and a herder were killed by masked men at Tensleep. The pattern of conflict between sheepmen and cowmen was complicated by the fact that many cattlemen switched to sheep when sheep appeared to be more profitable and sometimes vice versa (3).

## Industrial Mineral Development Era

Mountain men told Captain Bonneville in 1832 of a tar spring on the Little Popo Agie River southeast of the present-day town of Lander. In 1883 Wyoming's first flowing well was brought in southeast of Lander in what was to become known as the Dallas Field. Grass Creek and Elk Basin became other important oil producing areas in the Basin (3).

With the advent of the railroad, coal came into demand. In 1910 Gebo was an important coal producer. By 1918 a major mine was in production at Hudson.

In 1953 a Riverton man located a rich uranium deposit in the Gas Hills in eastern Fremont County. This area was destined to become the State's most productive uranium district. By around 1960 more than half of Wyoming's uranium production was in Fremont County, and Riverton became the State's uranium capital (3).

## Modern Water Development Era

It was discovered early that successful farming in most areas of the Basin required irrigation. Many ranchers in the 1890's were enjoying easily developed irrigation water from streams, even though the large rivers carried most of the Basin's water unused into other states.

In 1886, the Wyoming Legislature adopted a comprehensive law establishing procedures to be used for the appropriation of water for irrigation. This law replaced an 1875 statute which had maintained the common-law principle of riparian rights. In the Constitutional Convention of 1889 (Wyoming achieved Statehood in 1890), Wyoming made a major contribution to the establishment of water law in the West by adopting a complete system for State control of water.

The Carey Act of 1894 was designed to supply Federal and state aid to irrigation projects by providing for donation by the Federal Government of up to 1,000,000 acres of arid lands to each state having such lands, if the state would cause the lands to be reclaimed and settled by actual settlers on small tracts. Wyoming was the first state to accept this offer, and the Bighorn Basin was the site of this development. The Big Horn Basin Development Company received State approval in 1895 to take water from the Greybull River. The Shoshone Land and Irrigation Company received approval in 1895 to divert water from the South Fork of the Stinking Water River (renamed the Shoshone River in 1901) (3). In later years, other Carey Act projects followed in the Basin.

The Riverton Project, originally a private venture, provided for free Government land with irrigation water to be provided by the Wyoming Central Irrigation Company. After years of financial difficulty and delayed construction starts, the U. S. Bureau of Reclamation took over in 1920 and was able to irrigate about 53,000 acres.

The Reclamation Act of 1902 authorized the Federal Government to undertake reclamation projects with money obtained from the disposal of public lands. The Shoshone Project became the State's first Federal project. Buffalo Bill Dam was completed in 1910, and by that year crops could be grown on 15,000 acres in the vicinity of Ralston, Powell, and Garland. Since then other Federal dams have been constructed in the Basin, including Bull Lake, Boysen, and Anchor, and Yellowtail just north of the State line in Montana.

The expansion of irrigation using surface water slowed down as the more easily developed water supplies were utilized. This indicated a need for some method of division of the Basin's interstate streams between Wyoming and downstream states. The Yellowstone River Compact, which provides a basis for the division of interstate tributaries of the Yellowstone River between Wyoming, Montana, and North Dakota was established in 1950. Streams in the study area included in the Yellowstone River Compact are the Bighorn River and the Clarks Fork of the Yellowstone River.

## TRANSPORTATION

### Roads

Until about 1910, roads in Wyoming were under county jurisdiction. In 1911, the Wyoming Legislature enacted a bill to provide the first highway system in the State. The voluntary Wyoming Highways Association was formed in 1912 for the purpose of promoting through routes. The Wyoming Legislature of 1917 established a State Highway Department under a State Highway Commission and authorized the acceptance of Federal aid on a matching basis. By 1939, all main roads in the State had been paved.

The present U. S. and State Highway systems and county road systems permit traffic to move throughout the area and connect the Basin to other parts of the State, to Yellowstone Park, and to Montana. The highway system is shown in Figure I-2.

### Railroads

The Burlington Northern Railroad enters the Basin on the southeast from Casper and provides freight service to Shoshoni, Thermopolis, Worland, Lovell, and Frannie and points between before exiting the State near Frannie en route to Billings, Montana. A spur line from Frannie serves Cody. Lander is provided rail service via a Chicago and Northwestern spur line from Shoshoni.

### Air Transportation

Commercial air transportation is provided by Frontier Airlines through facilities at Riverton, Worland, and Cody.

## POPULATION

County data are used to describe the population characteristics and distribution in the Bighorn River Basin. Big Horn, Fremont, Hot Springs, Park, and Washakie Counties were selected to represent the study area. A small portion of the population in Fremont County resides outside the drainage area, and small numbers of people in Natrona and Sheridan Counties live within the study area.

Population in the five-county area increased by about 10,000 persons for each decade from 1940 to 1960 and then decreased slightly from 1960 to 1970. The 1970 population count was 68,427, not including 400 residents in Yellowstone National Park who are included in the Park County census. Fremont, Park, and Washakie Counties account for nearly all of the population growth during the period 1940 to 1970. Total population for the five counties, excluding Yellowstone National Park, is shown in Table I-1. The area experienced a net out-migration of 12,794 persons during this period.

TABLE I-1 Population Trends Bighorn River Basin, Wyoming

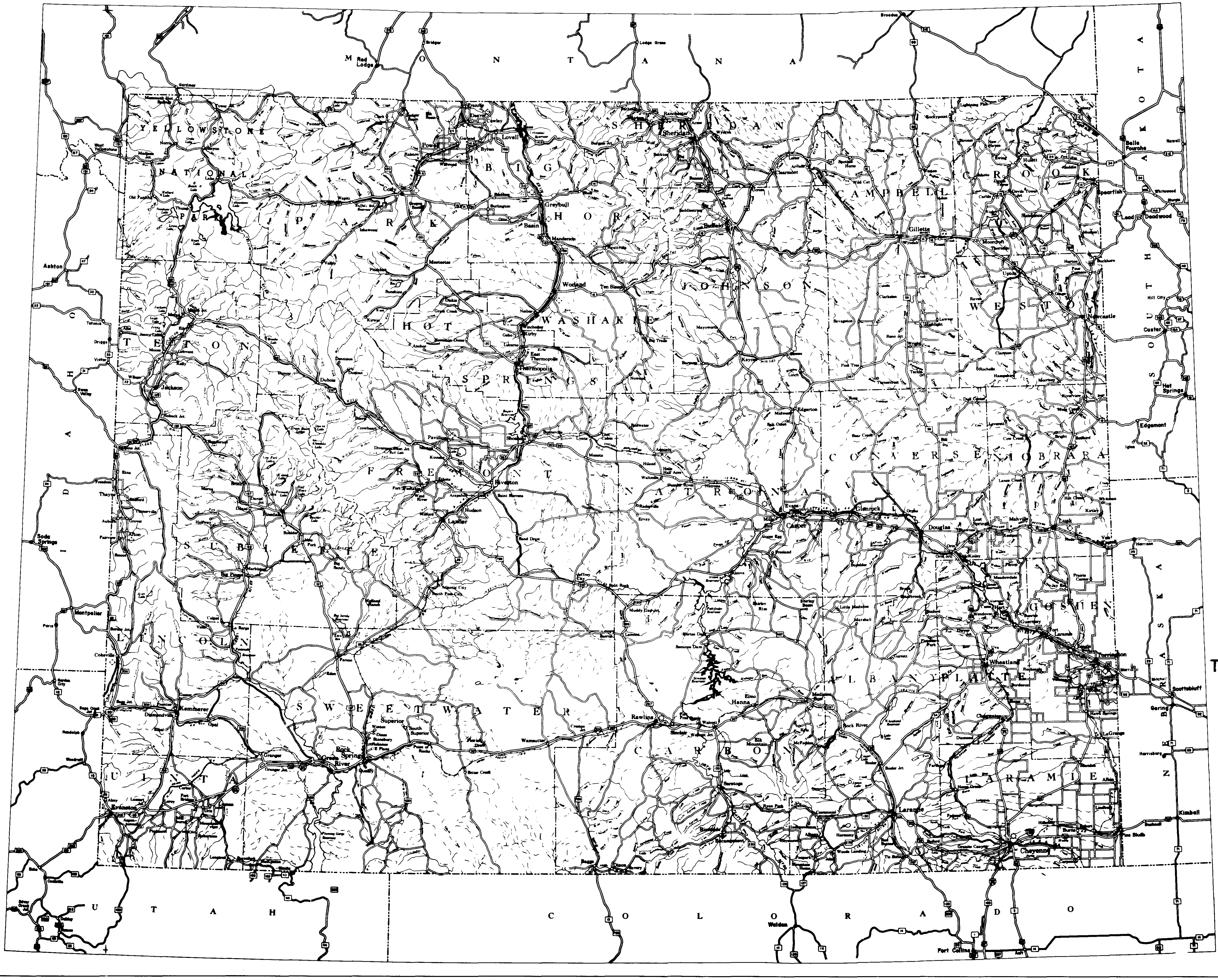
| County | 1940 | 1950 | 1960 | 1970 | Net Change Population 1940 - 1970 | Births 1940 to 1970 | Deaths 1940 to 1970 | Net Migration 1940 - 1970[1] |
|---|---|---|---|---|---|---|---|---|
| Big Horn | 12,911 | 13,176 | 11,898 | 10,202 | - 2,709 | 8,805 | 3,113 | - 8,401 |
| Fremont | 16,095 | 19,580 | 26,168 | 28,352 | 12,257 | 16,488 | 5,761 | 1,530 |
| Hot Springs | 4,607 | 5,250 | 6,365 | 4,952 | 345 | 3,654 | 1,912 | - 1,397 |
| Park | 10,976 | 15,182 | 16,874 | 17,352 [2] | 6,376 | 11,687 | 3,476 | - 1,835 |
| Washakie | 5,858 | 7,252 | 8,883 | 7,569 | 1,711 | 5,990 | 1,588 | - 2,691 |
| Total | 50,447 | 60,440 | 70,188 | 68,427 | 17,980 | 46,624 | 15,850 | -12,794 |

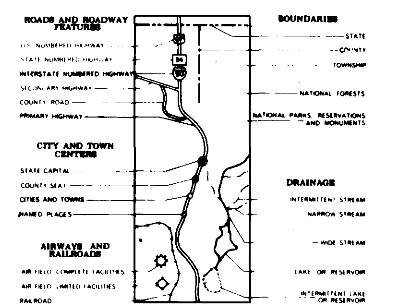
[1] Population change minus natural increase.

[2] Does not include Yellowstone Park residents. Census data shows a Park County population of 17,752 in 1970, of which 400 residents are in the Yellowstone Park division.

The area has been predominantly rural but is becoming more urban-oriented each year. This trend toward urbanization, reflecting a migration from rural agricultural sectors, is characteristic of most sections of the United States. In 1970 about 48.5 percent of the area's population lived in urban areas as compared to 20.6 percent in 1940. Riverton, Lander, Cody, and Worland are the largest towns, each having a population of over 5,000. All but Worland showed moderate to large population gains during the past decade. For the period 1940 to 1970 urban areas showed a steady growth in population numbers, while rural farm population declined throughout the period. Rural nonfarm population showed some growth during the period but declined slightly from 1960 to 1970 (Table I-2).

Fremont and Hot Springs Counties contain the Wind River Reservation, the only Indian reservation in Wyoming. At the present time about 5.9 percent of the total Basin population and about 11.5 percent of the total rural people are Indian. The number of Indians increased from 3,517 in 1960 to 4,044 in 1970. Nearly 90 percent of the Indians have rural status.




# Figure I-2

## TRANSPORTATION SYSTEMS MAP

**STATE OF**

**WYOMING**

PREPARED BY THE

WYOMING HIGHWAY DEPARTMENT

PLANNING AND RESEARCH DIVISION

IN COOPERATION WITH THE

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

BUREAU OF PUBLIC ROADS

SCALE

1957

Revised to January 1, 1970

TABLE I-2 -- Population by Rural and Urban Categories
Bighorn River Basin

| Category | 1940 | 1950 | 1960 | 1970 |
|---|---|---|---|---|
| Urban | 10,380 | 24,747 | 30,366 | 33,206 |
| Rural Farm | 22,283 | 18,759 | 14,032 | 10,612 |
| Rural Nonfarm | 17,784 | 16,934 | 25,790 | 24,609 |
| Total | 50,447 | 60,440 | 70,188 | 68,427 |

Source: U. S. Census of Population.

## LAND OWNERSHIP

Figure I-3 is a land status map showing land ownership within the Basin. The Federal Government owns about 60.1 percent of the land within the Basin. Lands within the Basin administered by Federal agencies are: Forest Service 23.0 percent, Bureau of Land Management 33.6 percent, Bureau of Reclamation 3.1 percent, and other Federal agencies 0.4 percent. About 4.6 percent of the Basin area is in State ownership. Private lands are about 20.5 percent of the Basin and the Indian Reservation is about 14.8 percent of the Basin area (Table I-3).

TABLE I-3 -- Land Ownership and Administration in the Bighorn River Basin by Subbasin

Ownership Current to 10-1-71

| Subbasin | Wind River Acres | Bighorn Acres | Clarks Fork Acres | Little Bighorn Acres | Total Acres | Percent |
|---|---|---|---|---|---|---|
| Federal Lands | | | | | | |
| Department of Agriculture National Forest | 871,178 | 1,514,609 | 496,581 | 143,230 | 3,025,598 | 23.0 |
| Department of Interior | | | | | | |
| Bureau of Land Management | 1,307,877 | 3,004,850 | 113,137 | 285 | 4,426,149 | 33.6 |
| Bureau of Reclamation | 163,215 | 228,049 | 21,080 | -- | 412,344 | 3.1 |
| Other Federal | 10,520 | 44,210 | -- | 160 | 54,890 | .4 |
| Total Federal Lands | 2,352,790 | 4,791,718 | 630,798 | 143,675 | 7,918,981 | 60.1 |
| State Lands | | | | | | |
| Other State | 189,704 | 370,720 | 19,780 | 4,145 | 584,349 | 4.4 |
| State Game and Fish | 11,360 | 2,200 | 1,600 | 4,800 | 19,960 | .2 |
| Total State | 201,064 | 372,920 | 21,380 | 8,945 | 604,309 | 4.6 |
| Private and Indian Reservation Lands | | | | | | |
| Private | 735,815 | 1,781,394 | 144,392 | 41,050 | 2,702,651 | 20.5 |
| Indian Reservation | 1,703,074 | 250,030 | | | 1,953,104 | 14.8 |
| TOTAL AREA | 4,992,743 | 7,196,062 | 796,570 | 193,670 | 13,179,045 | 100.0 |

Source: Soil Conservation Service Type IV Study

There are 13,179,045 acres of land and water area in the Basin. Areas of water were not tabulated by county, but there are about 79,038 acres of water surface area in the Basin. Land ownership can be compared with surface areas in the Basin by referring to Tables I-3 and I-4. Lands are used principally for human habitation, livestock grazing, hayland, cash crops, feed grains, forests, recreation, mining, and petroleum production.

TABLE I-4 -- Total Area by County, Bighorn River Basin

| Political Subdivision | Square Miles | Acres |
|---|---|---|
| Big Horn | 3,127.1 | 2,001,317 |
| Fremont | 7,231.4 | 4,628,089 |
| Hot Springs | 2,089.2 | 1,337,108 |
| Johnson | 56.9 | 36,419 |
| Natrona | 532.0 | 340,479 |
| Park | 4,978.5 | 3,186,259 |
| Sheridan | 302.6 | 193,670 |
| Sublette | 13.0 | 8,294 |
| Teton | 4.0 | 2,560 |
| Washakie | 2,229.1 | 1,426,600 |
| Yellowstone National Park | 28.5 | 18,250 |
| Total | 20,592.3 | 13,179,045 |

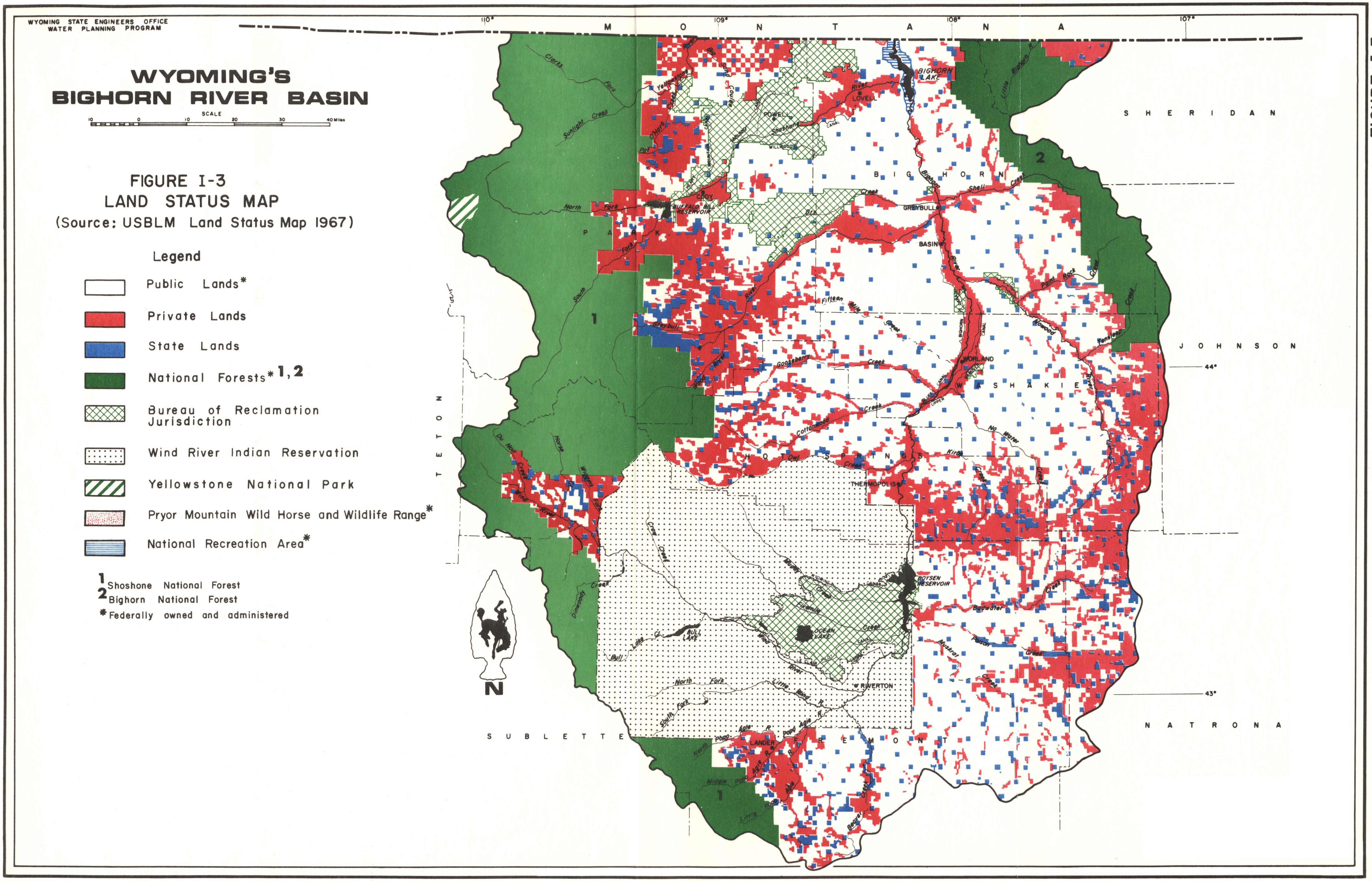
Source: Soil Conservation Service Type IV Study.

## PHYSIOGRAPHY

The report area is bounded by the Big Horn Mountains on the east and the Beartooth Mountains, Absaroka Range, and Wind River Range on the west. The Beaver Divide is a southern boundary, and the Wyoming-Montana State line is the northern boundary (see Figure I-1, Location Map). A portion of the western boundary separates the Bighorn River Basin area from the Yellowstone National Park. The drainage area of Middle Creek (not shown on the Location Map) which is tributary to the North Fork of the Shoshone River, is in the Yellowstone National Park (see Figure I-3). The Owl Creek Mountains and the Bridger (Copper) Mountains are interior mountains, along the legal boundary separating Fremont and Hot Springs Counties.

### Topography

The general topography consists of two large basinal areas separated by interior mountains. The northern basin is the Bighorn Basin, comprised of the Bighorn River and Clarks Fork Study Areas, and the southern one is the Wind River Basin (or Study Area). The small area on the east flank of the Big Horn Mountains drained by the Little Bighorn River consists of relatively steep uplands (the Little Bighorn River Study Area).



WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM
WYOMING'S
BIGHORN RIVER BASIN
SCALE
10 0 10 20 30 40 Miles
FIGURE I-3
LAND STATUS MAP
(Source: USBLM Land Status Map 1967)
Legend
Public Lands*
Private Lands
State Lands
National Forests*1,2
Bureau of Reclamation Jurisdiction
Wind River Indian Reservation
Yellowstone National Park
Pryor Mountain Wild Horse and Wildlife Range*
National Recreation Area*
1 Shoshone National Forest
2 Bighorn National Forest
* Federally owned and administered
M O N T A N A
110°
109°
108°
107°
44°
43°
S H E R I D A N
J O H N S O N
N A T R O N A
S U B L E T T E
T E T O N
P A R K
B I G H O R N
W A S H A K I E
H O T S P R I N G S
F R E M O N T
BIGHORN LAKE
LOVELL
POWELL
CODY
BUFFALO BILL RESERVOIR
GREYBULL
BASIN
WORLAND
THERMOPOLIS
BOYSEN RESERVOIR
OCEAN LAKE
BULL LAKE
RIVERTON
LANDER
Clarks Fork
Sunlight Creek
North Fork
South Fork
Greybull
Shoshone
Shell Creek
Paint Rock Creek
Nowood
Tensleep Creek
Fifteen Mile Creek
Gooseberry Creek
Cottonwood Creek
Owl Creek
No Water
Kirby Creek
Badwater
Poison Creek
Muskrat Creek
Wind River
Little Wind R.
Popo Agie R.
Beaver Creek
Dinwoody Creek
Du Noir Creek
Bull Lake Cr.
N


FIGURE I-3

Within the Bighorn Basin broad river valleys and narrow terraces, plains, rolling hills, badlands, and steep canyons are found. The rims of the basin are the foothills and steep mountain slopes. The highest elevation is 13,165 feet, at the top of Cloud Peak, on the crest of the Big Horn Mountains. The lowest is about 3,500 feet, where the Bighorn River leaves Wyoming (water surface of Bighorn Lake). Most of the high mountain country exceeds elevations of 10,000 feet above sea level.

The Wind River Basin, although smaller, is of similar topographic expression: rolling plains, river valleys, and badlands comprising a lowland rimmed by foothills and high mountains. The highest point in the Wind River Range (and in Wyoming) is Gannett Peak, with an elevation of 13,785 feet above sea level. Elevations along Beaver Divide are between 6,000 and 8,000 feet. The interior mountains are from 7,000 to 9,000 feet in elevation.

### Drainage System

The Wind River heads in the Absaroka and Wind River Mountains. Many of the major tributaries to the Wind River originate at high elevations in the Wind River and Absaroka Ranges. Others orginate in the Owl Creek Mountains. The mountain streams drop into gorges or narrow canyons at the foot of the mountains, then flow across the plains to join the main stem of the Wind River. According to some authorities, the Bighorn River begins near Riverton, below the confluence of the Little Wind with the Wind River (see Figure I-1). Others designate the Bighorn River as beginning below Boysen Reservoir at the Wedding of the Waters, on the basis of common historical usage. In this report, terminology is used which conforms to the major subdivision of the basin: the Wind River is south of the divide in the interior mountains, and the Bighorn River is north of the divide.

Western tributaries to the Bighorn River originate in the Absaroka Range and the Owl Creek Mountains, and flow in a northeasterly direction to join the main stem. Eastern tributaries originate in the Big Horn Mountains. A few start in the interior mountains. The Little Bighorn River starts on the east side of the crest of the Big Horn Mountains, and flows northward into Montana before joining the main stem. The Clarks Fork of the Yellowstone rises in the Beartooth Mountains in Montana and flows southeastward into Wyoming. After the river emerges from the Clarks Fork Canyon it curves northeastward and flows across the plains and into Montana again.

Table I-5 lists the streams shown on the Location Map (Figure I-1) by major drainage area (Bighorn River, Wind River, Clarks Fork of the Yellowstone, all in the Missouri River drainage system) and indicates by indentation the tributary rank. Rivers and creeks are listed by higher to lower tributary rank, and in upstream to downstream order.

## GEOLOGY

Events associated with the geologic development of the Rocky Mountain region greatly influenced the evolution of the report area. Structural deformation and patterns of deposition, uplift, and erosion of sedimentary formations have significantly influenced both surface and subsurface hydrology.

TABLE I-5 -- Streams Shown on Figure I-1 by Tributary Rank and Downstream Order

- (MISSOURI RIVER)
  - (Yellowstone River)
    - Clarks Fork Yellowstone River
      - Sunlight Creek
      - Pat O'Hara Creek
      - Big Sand Coulee
    - Bighorn River
      - Owl Creek
      - Kirby Creek
      - Cottonwood Creek
      - Gooseberry Creek
      - No Water Creek
      - Fifteen Mile Creek
      - Nowood River
        - Tensleep Creek
        - Paint Rock Creek
      - Greybull River
        - Wood River
      - Dry Creek
      - Shell Creek
      - Shoshone River
        - North Fork
        - South Fork
      - Little Bighorn River
    - Wind River[1]
      - Du Noir Creek
      - Horse Creek
      - Wiggins Fork
      - Dinwoody Creek
      - Crow Creek
      - Bull Lake Creek
      - Little Wind River
        - North Fork
        - South Fork
        - Popo Agie River or Middle Popo Agie River
          - North Popo Agie River
          - Little Popo Agie River
        - Beaver Creek
      - Muskrat Creek
      - Fivemile Creek
      - Poison Creek
      - Badwater Creek
      - Muddy Creek

[1] The Wind-Bighorn is one river system. A separation is made in this table for the reader's convenience.

## Basin Evolution

The Basin evolved geologically through many milleniums of sediment accumulation, structural deformation, and erosion. The granites and associated rocks now exposed in the cores of the Big Horn, Wind, Beartooth, and other mountains resulted from long periods of igneous activity, metamorphism, folding, and subsequent erosion, which began billions of years ago (Precambrian time). The igneous rocks exposed in the Absaroka Mountain Range are much younger in age (Tertiary), and are products of a past geologic environment best represented in nearby Yellowstone National Park.

Following the very early igneous activity, periods of submergence and deposition alternating with periods of emergence and erosion resulted in the accumulation of indurated sediments thousands of feet thick (Cambrian through Cretaceous in age). The mountain building that took place during late Cretaceous and early Tertiary times intensified the basin configuration of the report area. Formations from ground level to thousands of feet below the land surface were broken and contorted. At the front of the mountains' igneous cores, the sedimentary formations were broken and lifted into steeply inclined positions. Thick sequences of rock formations were exposed to the atmosphere and became conduits for recharge to underground reservoirs. Precipitation and surface runoff were able to enter the pore spaces in the exposed rock, and recharge the permeable aquifers at great depths.

During Tertiary time (from 2 to 60 million years ago) erosion of the uplifted areas brought much debris and sediment into basinal areas. The water which carried the earth material deposited it as sheets or channel fill. Before the end of Tertiary time the low areas were filled and low-lying parts of the interior highlands were covered. Erosion apparently overcame deposition in late Tertiary time and became the enduring dominant geologic process in the report area.

## Evolution of the Drainage System

An ancestral drainage system probably was in existence about the time mountain building and basin-fill deposition were dominant processes. This is the system that fed the extensive lakes that are thought to have existed in Tertiary time in the geologic Wind River and Bighorn basins.

The present drainage system came intc being about the end of Tertiary time. Basic factors that could have been responsible for changing the system between middle and late Tertiary times are regional uplift or tilting, climate, stream piracy, and erosion and deposition. The courses of some of the rivers in the report area at places are through deep steep-walled canyons cut into granite and other relatively hard rock. It appears that the courses originally were in softer sediments overlying the present host rocks. As uplift progressed, the rivers and streams eroded the softer sedimentary cover and entrenched themselves in the underlying harder material.

Within the basinal areas the erosive action of major streams and earth movements (and perhaps climatic changes as well) resulted in repeated cycles of downcutting and valley widening. Testimony to this past activity is given in part by the stream terraces found in the report area.

# SOILS [2]

The wide variety of soils in the Bighorn River Basin is due basically to the kinds and orgins of the parent materials and to variations in climatic conditions.

## Mountain Soils

The soils in mountain areas of the Basin are in three land resource areas: Semiarid Rocky Mountain, Northern Rocky Mountain, and Alpine Meadow and Rockland. The Semiarid Rocky Mountain land resource area, which comprises about 7 percent of the total Basin area, is largely used for grazing. Desert shrubs, midgrasses, and mountain shrubs cover most of the area. Small areas in isolated valleys are irrigated and used for producing hay and grain. Elevations range from 6,000 feet to more than 8,000 feet. The average annual precipitation is 12 to 16 inches. Most of the soils are shallow to deep, well drained, dark colored loamy soils which formed in materials weathered from sandstone, limestone, and dolomite on steep, strongly dissected mountain fronts with many rock outcrops and some steep canyons. Also included are some deep and shallow, well drained, light colored loamy soils which formed in materials weathered from interbedded shale and sandstone or dissected to rough broken uplands.

The Northern Rocky Mountain land resource area comprises about 27 percent of the total Basin area. It is largely public land with heavy forest cover. Elevations range from 6,000 to 12,000 feet. The average annual precipitation is 20 to 50 inches. Most of the soils are shallow to deep, well drained, dark colored loamy soils which formed in materials weathered from volcanic rocks, granite, gneiss, and schist. There are many rock outcrops. In the narrow valleys the soils are deep, well to poorly drained, dark colored, gravelly, cobbly, and stony and occupy narrow floodplains, stream terraces, and alluvial fans.

The Alpine Meadow and Rockland land resource area comprises about 3 percent of the total Basin area. It is mostly public land and the vegetation consists of alpine grasses, herbaceous plants, and shrubs. Elevations are 10,000 feet or more. The average annual precipitation is 20 to 40 inches. The soils are shallow to deep, well drained, dark colored loamy soils. Fifty percent or more of the area is rock outcrop.

## Foothill Soils

The Northern Rocky Mountain Foothills land resource area comprises about 13 percent of the total Basin area. Some of the alluvial soils in the small valleys are irrigated and are used to produce grain and forage for livestock, but the area is used primarily for grazing. The native vegetation consists of short and midgrasses and shrubs. Some of the highest areas are in forest. Elevations range from 5,000 to 7,500 feet. The average annual precipitation is 12 to 20 inches. The soils are: (1) deep, well to poorly drained, dark colored loamy soils which formed in alluvium on floodplains, stream terraces, and alluvial fans; (2) deep, well drained, dark colored, gravelly, cobbly, and stony soils on rolling to steep glacial moraines and outwash fans and terraces; (3) deep to shallow, well drained, light colored loamy and clayey soils which formed in material weathered from interbedded sandstone and shale on strongly dissected, rolling to steep uplands with

[2] Contributed by the USDA Soil Conservation Service.

some rock outcrops; and (4) deep and shallow, well drained, light colored loamy soils which formed in materials weathered from red beds, limestone, and sandy shales on rolling to steep, strongly dissected uplands with many rock outcrops.

## Desertic Soils

The Northern Intermountain Desertic Basin land resource area comprises about 32 percent of the total Basin area. Much of the land is used for grazing, but most of the irrigated land in the Bighorn River Basin is in this land resource area, and is used to produce hay, grain, and row crops. The native vegetation consists primarily of desert shrubs and brush, but short and midgrasses grow on the more favorable sites. Elevations are 3,800 to 6,000 feet. The average annual precipitation is 5 to 14 inches. Most of the soils in irrigated parts of the Bighorn River Basin are deep, well to poorly drained, light colored loamy and clayey soils which formed in alluvium on floodplains, stream terraces, and alluvial fans. The soils are moderately to strongly alkaline and some are moderately to strongly saline. Most of the soils in the Riverton Project area are shallow to deep, well drained, light colored loamy soils which formed in alluvium or residuum from interbedded shale and sandstone on gently sloping to sloping alluvial fans, stream terraces, and uplands. These soils are moderately to strongly alkaline and some of them are moderately to strongly saline. In the nonirrigated parts of this land resource area the soils are: (1) deep, well drained, light colored, moderately alkaline, loamy soils which formed in alluvial deposits on nearly level to sloping high terraces; (2) shallow to deep, well drained, light colored, moderately to strongly alkaline, loamy and clayey soils which formed in material weathered from shale on nearly level to sloping uplands; and (3) deep to shallow, well drained, light colored, moderately to strongly alkaline, loamy to clayey soils which formed in material weathered from interbedded sandstone and shale on undulating to rolling uplands and strongly dissected, steep uplands.

The Central Desertic Basin Mountain and Plateau land resource area comprises about 18 percent of the total Basin area. It is used mostly for cattle and sheep grazing. The native vegetation is sagebrush, greasewood, other desert shrubs, and short and midgrasses. Small areas along the larger streams are irrigated and used to produce hay and pasture. Elevations range from 4,500 to 7,500 feet. The average annual precipitation is 7 to 12 inches. Most of the soils in this land resource area are deep to shallow, well drained, light colored, moderately to strongly alkaline, loamy to clayey soils which formed in material weathered from interbedded sandstone and shale on rolling uplands and dissected, rough and broken uplands. There are some deep to shallow, well drained, moderately alkaline loamy soils which formed in material weathered from redbeds and thin interbedded sandstone and limestone on rolling to steep dissected uplands. There are also some deep, excessively drained, light colored, sandy soils which formed in deep loose sands on gently sloping to dune-like uplands; and deep, well to poorly drained, light colored loamy soils which formed in alluvium on floodplains and stream terraces. These two latter may be moderately to strongly alkaline or moderately to strongly saline.

## CLIMATE [3]

The climate of the Basin is a product of its latitude, elevation, and topography. The plains are semiarid as a result of their distance and isolation from moisture sources. This area is in the latitudes of the prevailing westerlies with

[3] Contributed by John Alyea, NOAA Climatologist for Wyoming.

a dominance of maritime Pacific air. This air, however, is modified by the several mountain ranges which are between the west coast and the Basin and which cause low level moisture to precipitate before reaching the Basin. Moisture in the Basin ranges from less than 6 inches annually in the north end of the Bighorn Basin to over 40 inches of moisture in the higher mountains bordering the Wind River and Bighorn Basins. Most of the plains in the Basin normally receive from 6 to 11 inches annual moisture.

While the predominant air mass is maritime Pacific, continental air masses from Canada regularly invade the drainage. The shallow, cold air masses which do not have too strong a southerly push often do not cross the Big Horn Mountains but move eastward. When the deeper cold Canadian air invades the Basin, very cold temperatures can persist for several days. Upon rare occasions, continental tropical air from Mexico invades the area during the summer with resultant high temperatures and very low relative humidities. The plains in the Wind River drainage are around 1,000 feet higher in elevation than those in the Bighorn Basin, and consequently mean temperatures are cooler and growing seasons shorter.

## Precipitation

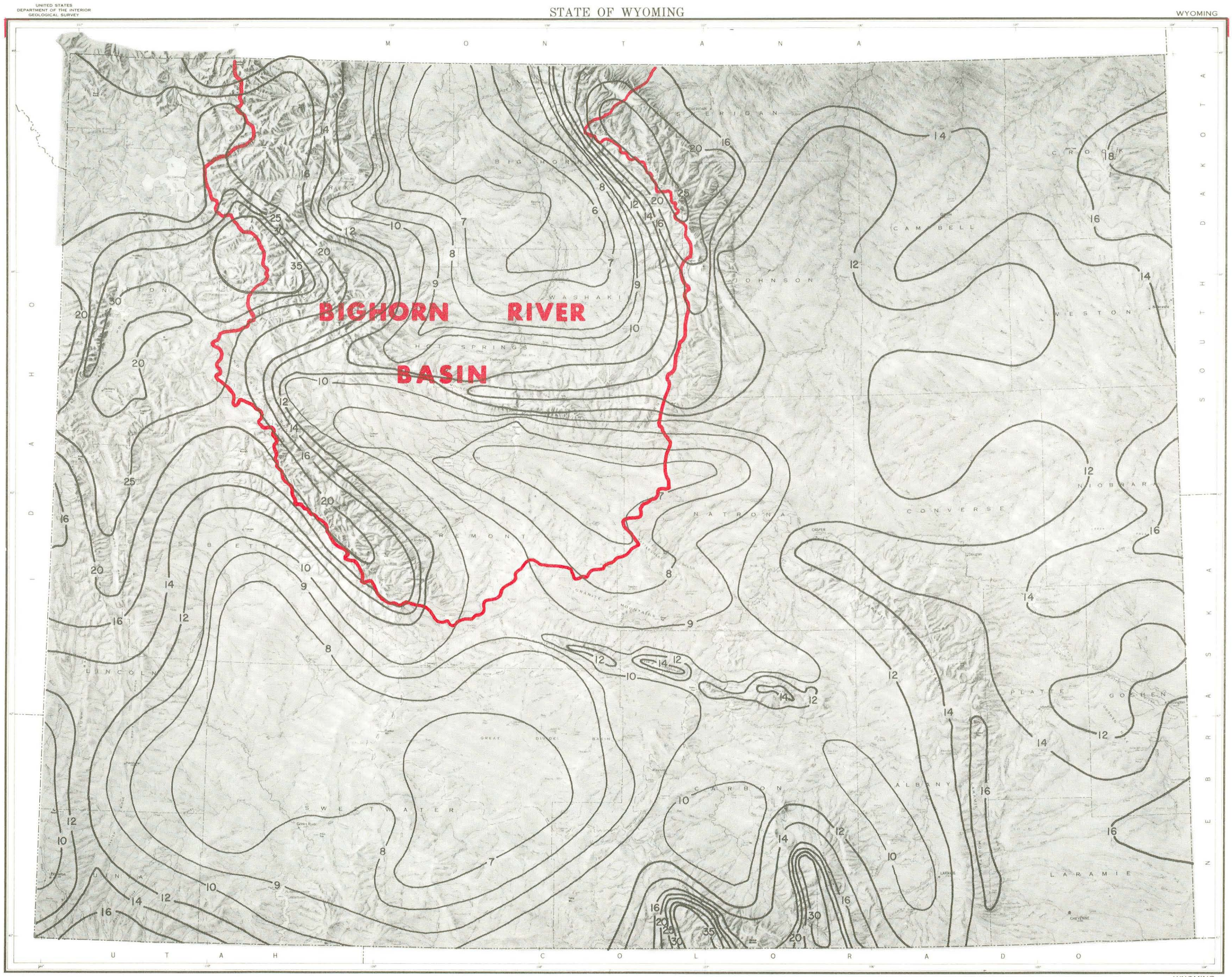
The precipitation map, Figure I-4, shows the variation of mean annual precipitation over the State and the Basin. The average monthly precipitation and temperature are illustrated in Figure I-5, which shows normals for representative climate stations in the Basin. Summertime precipitation is usually in the form of showers with occasional cloudbursts. Fall and winter snows are normally light, while springtime brings wet snows and rains. Annual snowfall averages from 14 to 40 inches over most of the plains, up to 90 inches over the southern Wind River plains, and much higher over the mountains. Normally, sunshine and wind keep great snow depths from accumulating on the plains, while in the mountains, accumulations of several feet occur.

Water supplies of the area bear a direct relationship to the precipitation. The streams with dependable flow rise in the mountains and derive most of their annual runoff from the spring and early summer snowmelt.

## Temperature

Basin temperature variations are also shown in Figure I-5. The relatively high elevation of the Basin combined with the advent of both warm and cold air masses result in large annual and daily temperature ranges. The highest recorded summer temperature of 114° F (Fahrenheit), highest for both State and Basin, occurred at the town of Basin, elevation 3,837 feet on July 12, 1900, but even Dubois at 6,917 feet has recorded 98° F. The coldest official winter temperature of 51° F below zero was recorded at Basin, Lovell, and Worland.

The growing seasons of the plains areas of the Basin are elevation oriented, i.e., the higher the elevation, the shorter the season. For alfalfa and grass the growing season is assumed to be the period when mean daily temperatures are above 40° F. The growing seasons for other crops have been estimated with the assistance of specialists in the College of Agriculture, University of Wyoming and are measured from planting dates to harvest. A planting date was estimated to be a specified number of days before or after the date when the mean daily temperature rises to 40° F, depending upon the crop. Average 40° growing seasons for forage crops, as well as 32° freeze-free periods at selected stations in the Basin are shown in Table I-6.




Prepared by the Wyoming Water Planning Program in cooperation with E.S.S.A. Weather Bureau State Climatologist Wyoming.

MEAN ANNUAL PRECIPITATION
AS OF 1965
(IN INCHES)

FIGURE I-4

Important Note:
Caution should be used in interpolating on this map, particularly in mountainous areas, which receive higher amounts than indicated.

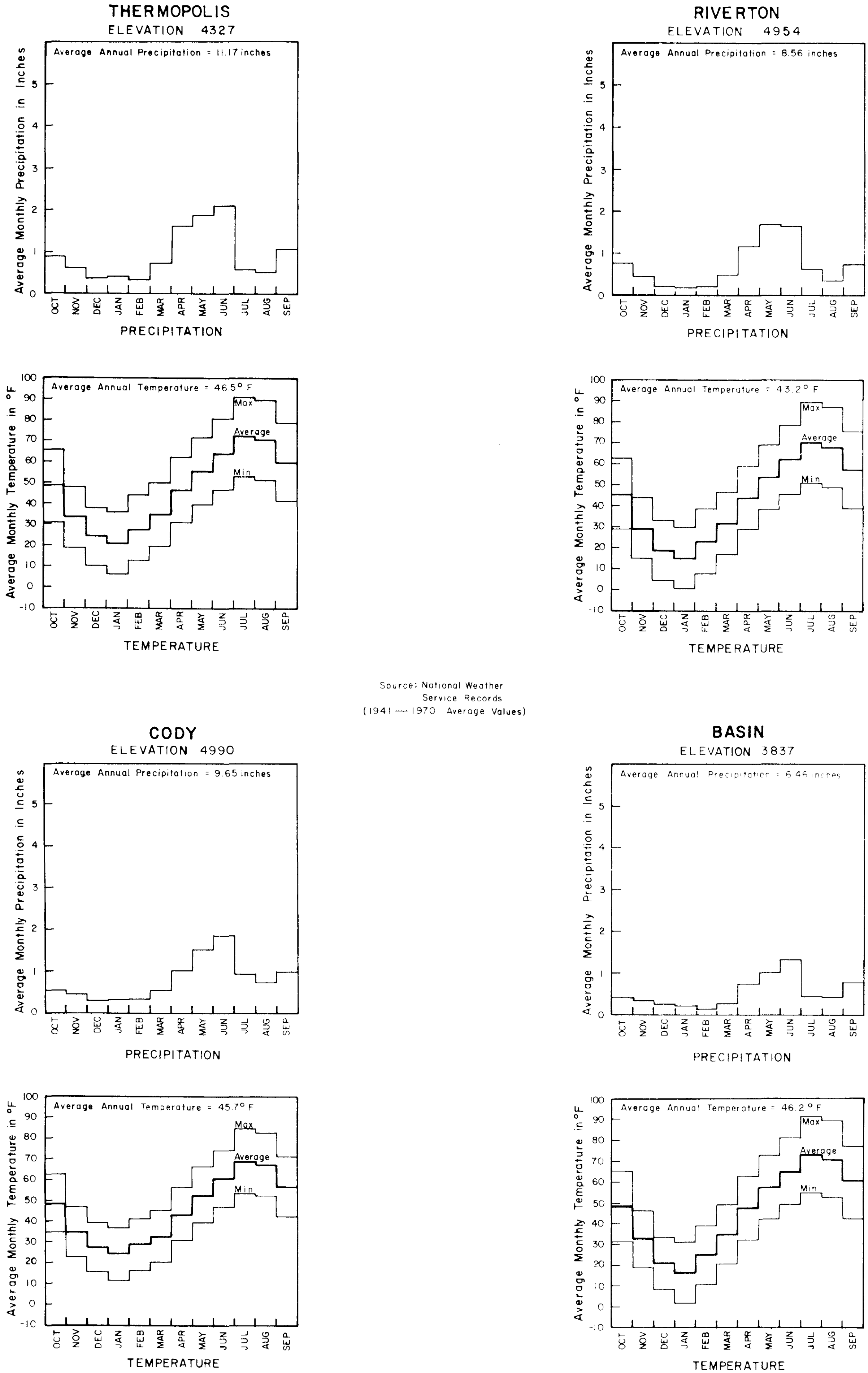



Figure I-5 Average Monthly Precipitation & Temperature
At Selected Stations in the Bighorn River Basin

TABLE I-6 — Average 40° Growing Seasons and Average Freeze-Free Periods at Selected Basin Climate Stations

| Station | County | Normal Date of 40° Mean Daily Temperature | | Length of Growing Season (Days) | Normal Date of 32° Occurrence | | Length of 32° Freeze-Free Period (Days) |
|---|---|---|---|---|---|---|---|
| | | Spring | Fall | | Spring | Fall | |
| Basin | Big Horn | 3-27 | 11-3 | 221 | 5-12 | 9-25 | 136 |
| Cody | Park | 4-4 | 11-5 | 215 | 5-22 | 9-19 | 120 |
| Diversion Dam | Fremont | 4-7 | 10-30 | 206 | 5-24 | 9-18 | 117 |
| Dubois | Fremont | 4-21 | 10-24 | 186 | - - - No dependable freeze-free period - - - - | | |
| Ft. Washakie | Fremont | 4-5 | 10-29 | 207 | 6-6 | 9-11 | 97 |
| Lander | Fremont | 4-7 | 10-30 | 206 | 5-20 | 9-23 | 126 |
| Lovell | Big Horn | 4-4 | 10-31 | 210 | 5-14 | 9-21 | 129 |
| Powell | Park | 4-3 | 11-1 | 212 | 5-18 | 9-24 | 129 |
| Thermopolis | Hot Springs | 3-31 | 10-31 | 214 | 5-22 | 9-17 | 118 |
| Worland | Washakie | 3-31 | 10-27 | 210 | 5-13 | 9-23 | 133 |

The predominant crops grown in the Basin are grasses and alfalfa in the higher elevations and fodder and row crops in the lower elevations.

## Sunshine, Relative Humidity, and Winds

Sunshine is estimated to average about 65-70 percent of possible daytime hours on an annual basis, ranging from about 55-60 percent during the winter and spring to about 75-80 percent during the summer and fall.

Relative humidity over most of the area is estimated to average about 55 percent annually, ranging from 35 to 40 percent for July and August, and 70 to 75 percent during winter. Considerable variation in relative humidity is recorded daily throughout the year.

Winds are relatively moderate over the area and, as is typical of semiarid to arid climate, the strongest winds occur during daytime hours. Winds average around 10 miles per hour annually, a little stronger over the eastern two-thirds of the Wind River drainage, with 13 mph winds in the winter and spring and 5 to 8 mph winds in the summer. Strong winds of 25 to 35 mph with higher gusts can prevail for a few hours or days, and occasional periods occur with very light winds. During particular storms, winds can uncommonly gust to as high as 100 mph.

# C H A P T E R  I I

# S U R F A C E  W A T E R  R E S O U R C E S

# S U R F A C E   W A T E R   R E S O U R C E S

The water resources of the region are its lakes, streams, groundwater, and the precipitation that creates the water supplies. The streams of the Wind-Bighorn, Clarks Fork, and Little Bighorn River systems provide water supplies for irrigation and municipal and industrial uses as well as for fish and wildlife habitat and water-based recreation.

## WATER SUPPLIES AND STREAMFLOW CHARACTERISTICS

Streams of the Basin discharge a major portion of their annual runoff in the spring and early summer months. The late summer, fall, and winter flows are derived primarily from groundwater effuent, mostly from the alluvial aquifers associated with the streams. These alluvial aquifers are recharged by spring runoff and irrigation.

Surface water flows are measured by stream gages maintained through cooperative agreements between the Wyoming State Engineer, the U. S. Geological Survey (USGS), and others. Figure II-1 shows the location of selected stream gages in the Basin. Water years 1948 through 1968 have been used as the base period because the period is reasonably current and most of the selected stream gages have continuous records during this time. The water year begins October 1st and ends September 30th of each year. The base period includes the year of critically low runoff as well as near average and high runoff years.

Hydrographs of the average monthly runoff (see Figures II-2 and II-3) show the monthly variation of streamflow at selected gaging stations in the Basin. The hydrographs in Figure II-2 illustrate the variation in the monthly streamflow distribution along the Wind-Bighorn River. The Wind River near Dubois is essentially an uncontrolled river, whereas near Crowheart upstream irrigation and natural lake and reservoir storage have regulated streamflow somewhat. Below Boysen Reservoir the monthly distribution is nearly uniform due to the regulation by Boysen Reservoir, but by the time the Bighorn River reaches the gaging station at Kane, the monthly distribution has been changed to reflect upstream effects of irrigation return flow and tributary inflow as well as reservoir regulation. Figure II-3 shows the distribution of streamflow on three unregulated streams--Wood River, Little Bighorn River, and Medicine Lodge Creek--and the Shoshone River at Byron which has been modified from natural conditions by regulation in Buffalo Bill Reservoir and by irrigation diversions and return flows.

Crop irrigation demands are the greatest during July and August. Lands irrigated from uncontrolled streams require reservoir storage to provide a full season irrigation demand. Lands irrigated by regulated streams such as the Bighorn River and the Shoshone River generally receive the required irrigation demand.

Annual variation (Figure II-4) in streamflow also presents a problem to water users in the Basin. During dry years such as 1960 and 1961, insufficient water supplies are available; whereas during wet years excess water flows downstream undiverted. With the aid of reservoir carry-over storage, the annual variation in streamflow can be lessened to provide a more uniform and dependable water supply.

The major river in the Basin is the Wind-Bighorn River which flows 318 miles through Wyoming from its headwaters near Togwotee Pass to the Wyoming-Montana

State line. Figure II-5 shows average streamflows along the river. Throughout this reach the water is used for recreation, wildlife habitat, hydropower production, irrigation, and municipal and industrial purposes. As the Wind River flows the first 77 miles from the headwaters to the diversion into the Wyoming Canal, it accrues a large volume of tributary inflow. The Wyoming Canal diverts an average of 393,100 acre-feet per year for power production at Pilot Butte Reservoir and irrigation on the Riverton Project. From the Wyoming Canal diversion the Wind River flows 37 miles to the confluence of Little Wind River, which contributes 396,900 acre-feet per year. Irrigation diversions in this reach are offset by irrigation return flows and waste water from the Pilot Butte Reservoir. In the 37 miles between the Little Wind River and Boysen Reservoir, river gains are contributed primarily by irrigation return flows and also by several small streams that empty into the Wind River or Boysen Reservoir. Above Boysen Reservoir 195,769 acres are irrigated.

The streamflow of the Bighorn River in the 83 mile reach from Boysen Reservoir to the Nowood River is mainly influenced by irrigation diversions to the Hanover, Bluff, and Bighorn Canals, and return flow from irrigation. However, several minor tributaries drain into the river in this reach. The Bighorn River receives 252,000 acre-feet from the Nowood River, flows 23 miles picking up irrigation return flow mainly from the Bighorn Canal to the Greybull River, and then flows 4 miles to Shell Creek. From Shell Creek the Bighorn River flows 32 miles to the gaging station at Kane, 0.5 miles upstream of the high-water line of Bighorn Lake. The river gains little tributary inflow in this reach. The Shoshone River empties 847,800 acre-feet per year into Bighorn Lake 11 miles downstream from Kane. Little tributary inflow enters Bighorn Lake in the next 14 miles to the Wyoming-Montana State line. The State-line flow of the Bighorn River is 2,422,400 acre-feet per year. From Boysen Reservoir to the State line, 329,503 acres are irrigated, of which 148,724 acres are in the Shoshone River Basin. The total irrigated acreage in the Wind River and Bighorn River Study Areas is 525,272 acres.

The major stream in the Clarks Fork Study Area (Figure II-6) is the Clarks Fork of the Yellowstone River which flows southward into Wyoming from Montana. After the river emerges from the Clarks Fork Canyon it curves northeastward and returns to Montana near Chance. The average annual discharge at Chance, Montana is 689,600 acre-feet. The Clarks Fork Study Area has 11,119 irrigated acres.

The Little Bighorn River Study Area (Figure II-6) has four primary streams leaving the State including the Little Bighorn River and Lodge Grass, Twin, and Pass Creeks. These streams have an estimated combined average annual State-line flow of 133,900 acre-feet, three-fourths of which is contributed by the Little Bighorn River. There are 2,441 irrigated acres in the Little Bighorn River Study Area.

The total streamflow originating in Wyoming within the four major study areas shown on Figure II-6 was estimated. The streamflow depletions caused by man's activities were added to each area's calculated water yield. Man's depletions include reservoir and stock pond evaporation, and irrigation, municipal and industrial consumptive uses. Table II-1 summarizes the natural streamflow originating within each study area, and man's streamflow depletions. The estimated streamflow originating in the Basin under natural conditions is about 4,237,280 acre-feet per year. Adding the estimated streamflow entering the State from Montana, the average natural discharge leaving Wyoming would be 4,384,620 acre-feet per year. In Wyoming 1,028,500 acre-feet of surface water per year are consumptively used by irrigation; 105,300 acre-feet by reservoir and stock pond evaporation,

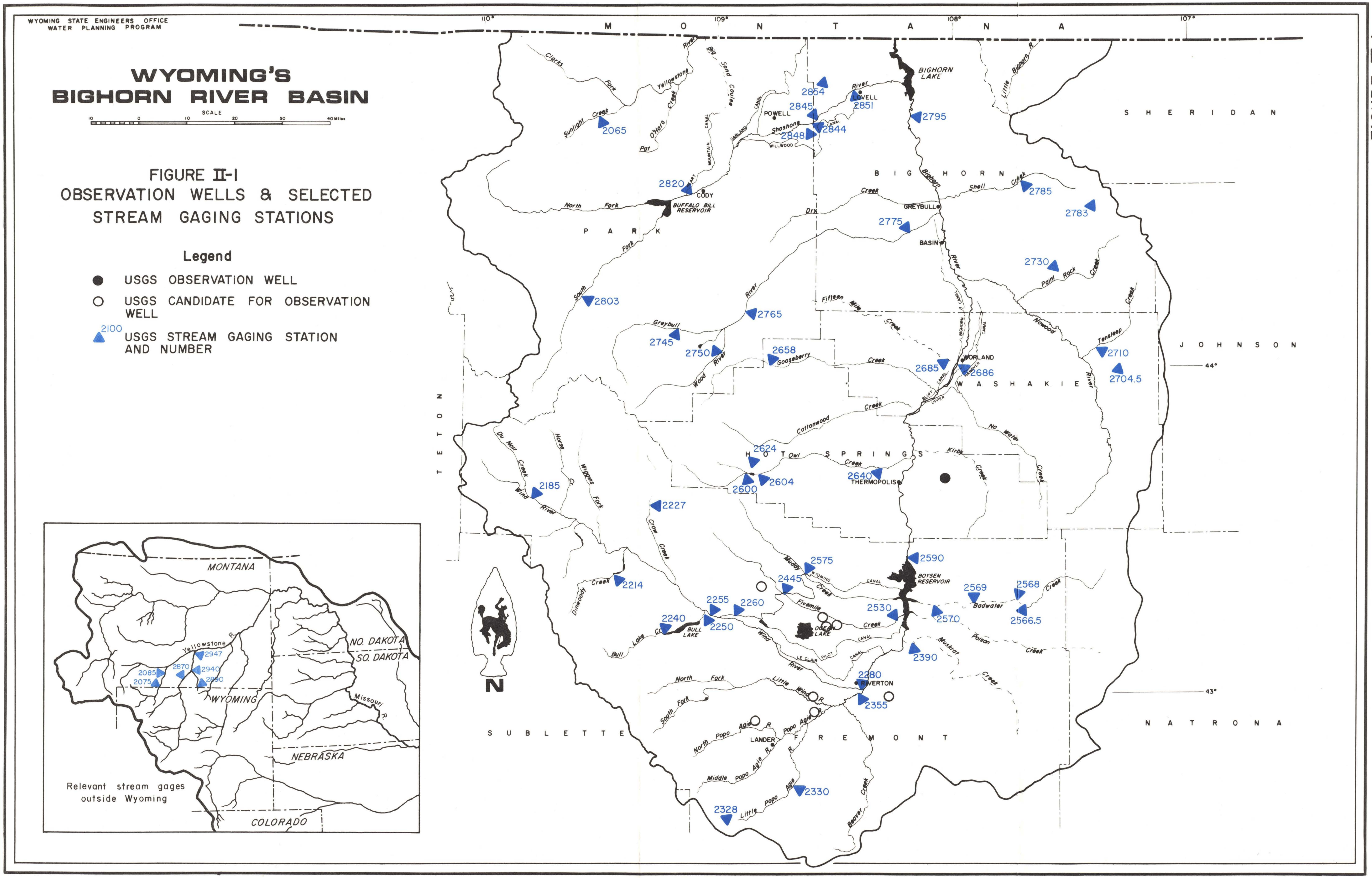



FIGURE II-1
OBSERVATION WELLS & SELECTED STREAM GAGING STATIONS

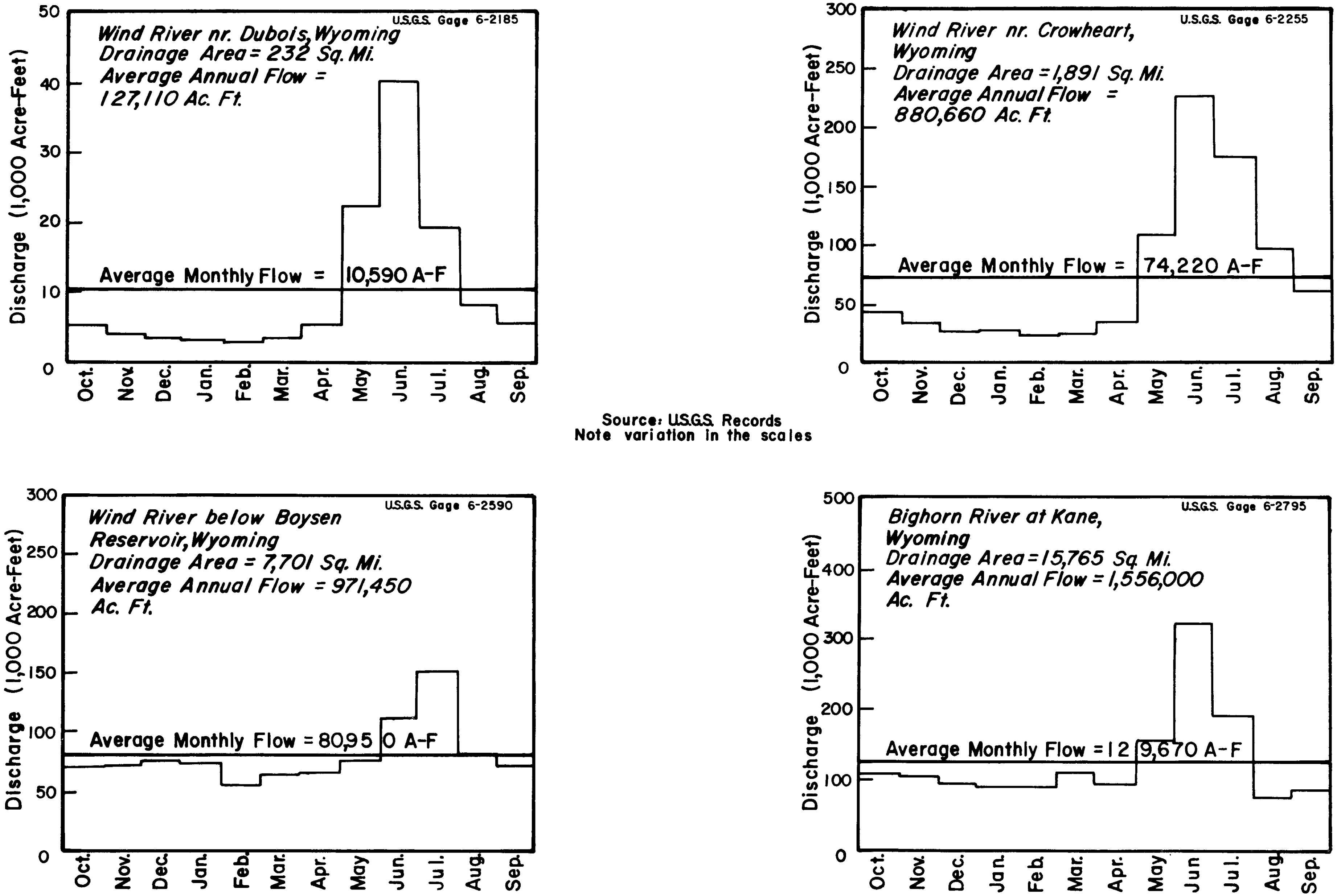
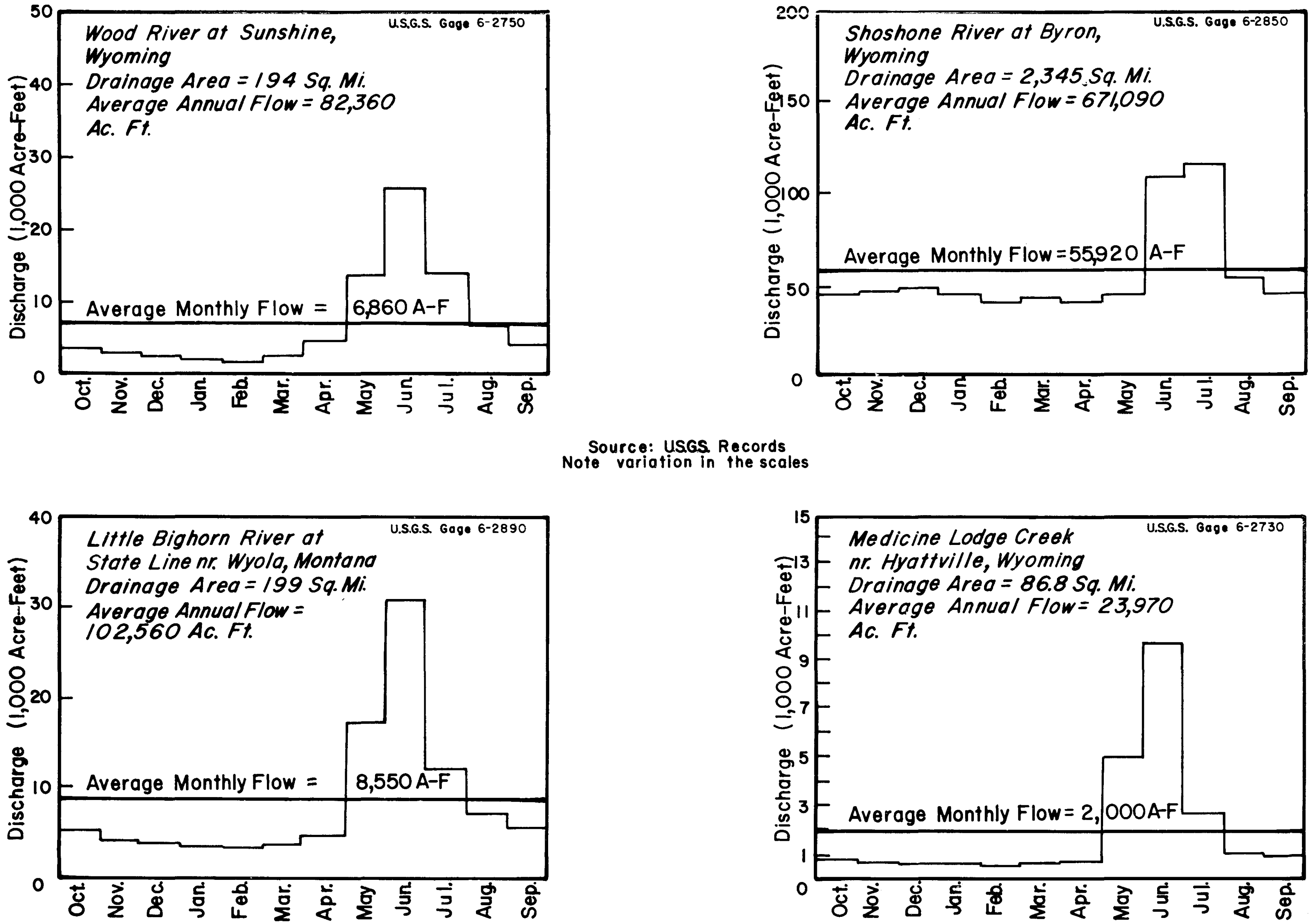



**Figure II-2**

**Monthly Flow of Selected Streams in the Bighorn River Basin**




Source: U.S.G.S. Records
Note variation in the scales

Figure II-3

**Monthly Flow of Selected Streams in the Bighorn River Basin**

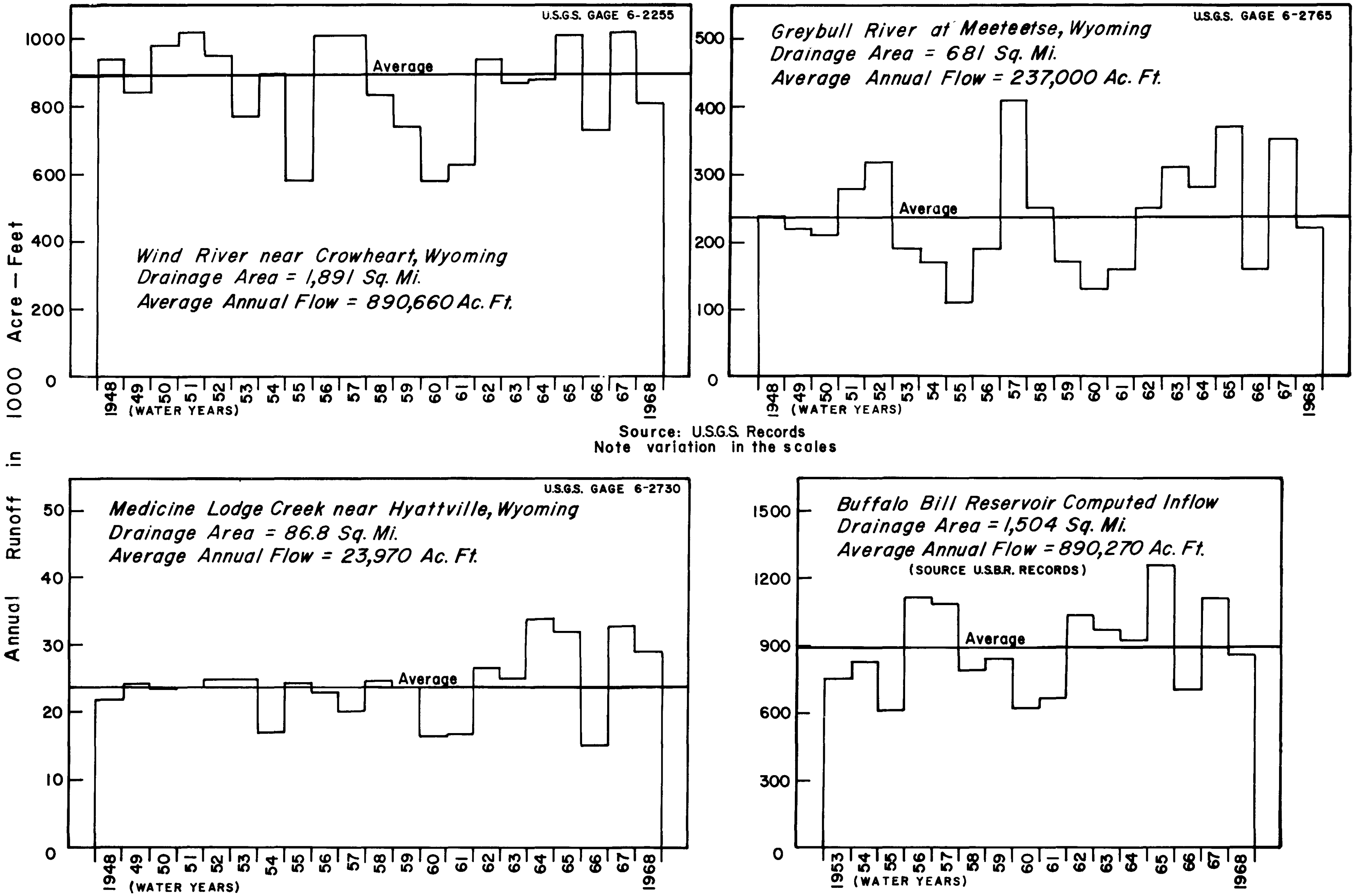
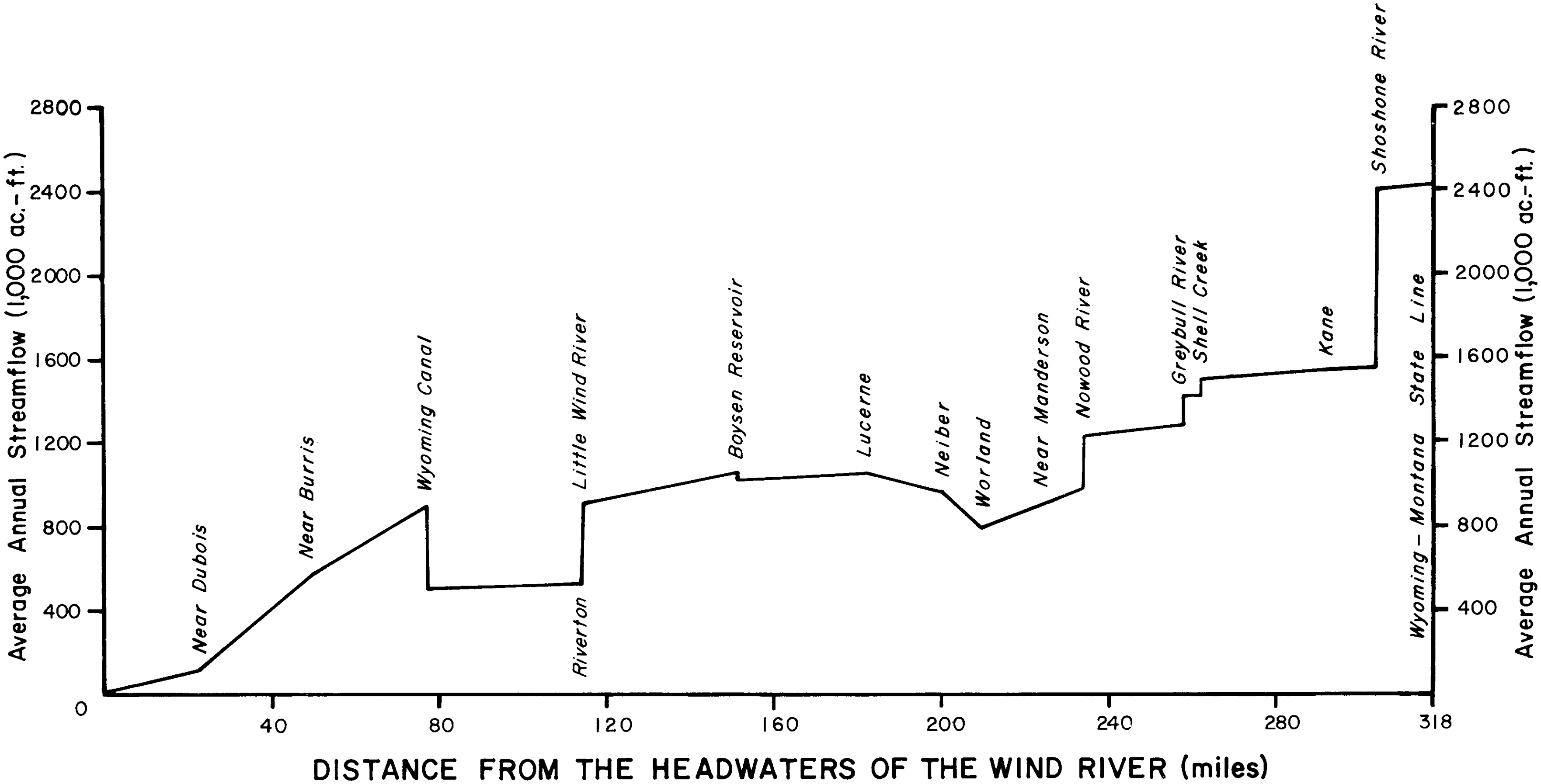



Figure II - 4

Annual Flow of Selected Streams in the Bighorn River Basin




# FIGURE II-5

## AVERAGE ANNUAL STREAMFLOW OF THE WIND-BIGHORN RIVER

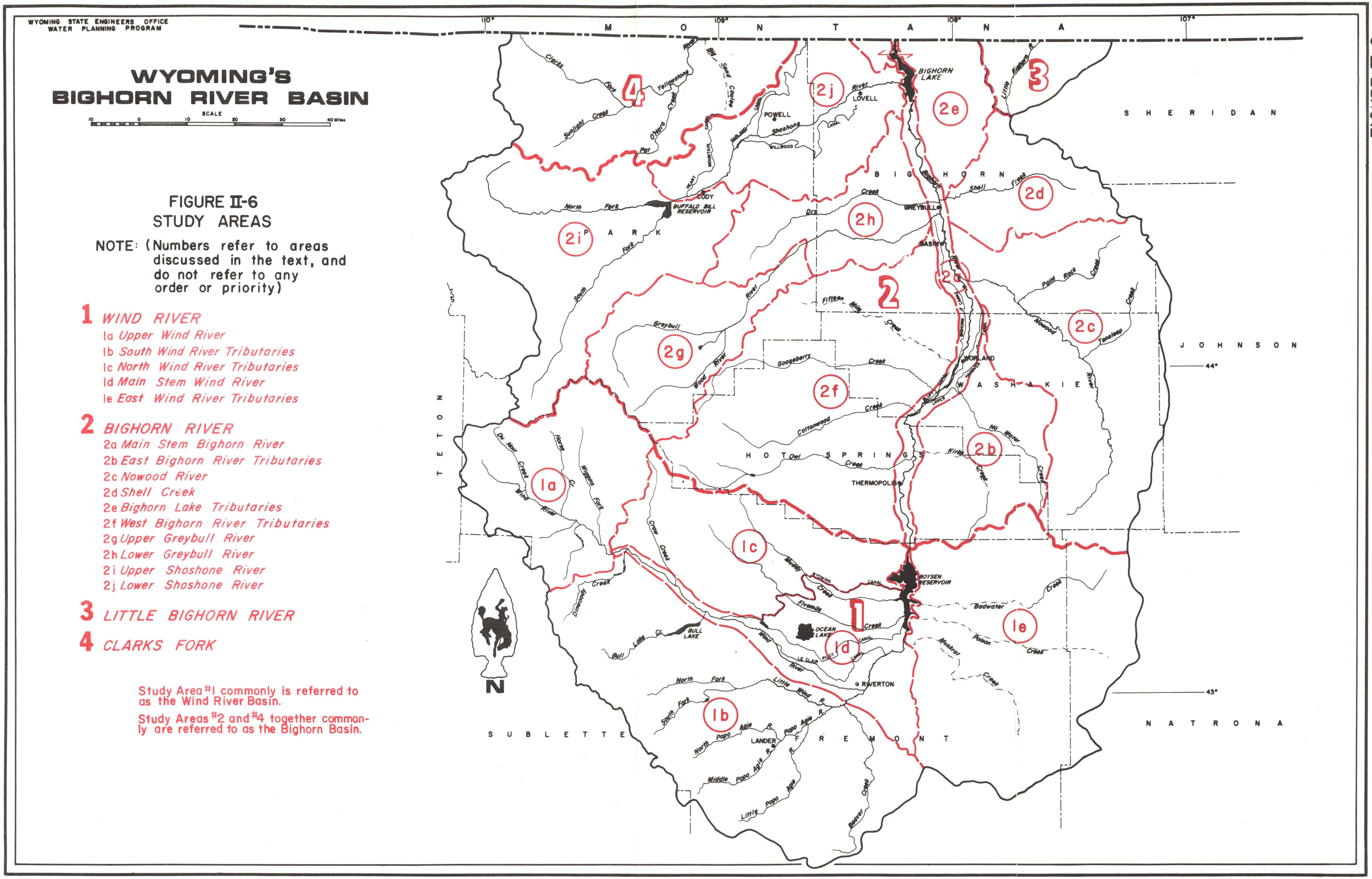

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM
WYOMING'S
BIGHORN RIVER BASIN
SCALE
10 0 10 20 30 40 Miles
FIGURE II-6
STUDY AREAS
NOTE: (Numbers refer to areas discussed in the text, and do not refer to any order or priority)
1 WIND RIVER
1a Upper Wind River
1b South Wind River Tributaries
1c North Wind River Tributaries
1d Main Stem Wind River
1e East Wind River Tributaries
2 BIGHORN RIVER
2a Main Stem Bighorn River
2b East Bighorn River Tributaries
2c Nowood River
2d Shell Creek
2e Bighorn Lake Tributaries
2f West Bighorn River Tributaries
2g Upper Greybull River
2h Lower Greybull River
2i Upper Shoshone River
2j Lower Shoshone River
3 LITTLE BIGHORN RIVER
4 CLARKS FORK
Study Area #1 commonly is referred to as the Wind River Basin.
Study Areas #2 and #4 together commonly are referred to as the Bighorn Basin.
M O N T A N A
110° 109° 108° 107°
S H E R I D A N
J O H N S O N
N A T R O N A
F R E M O N T
S U B L E T T E
T E T O N
P A R K
B I G H O R N
W A S H A K I E
H O T S P R I N G S
BIGHORN LAKE
LOVELL
POWELL
CODY
BUFFALO BILL RESERVOIR
GREYBULL
BASIN
WORLAND
THERMOPOLIS
BOYSEN RESERVOIR
OCEAN LAKE
BULL LAKE
RIVERTON
LANDER
44°
43°
N

FIGURE II-6

TABLE II-1 -- Estimated Average Annual Streamflows and Water Uses of the Bighorn River Basin
Streamflow Base Period 1948-1968
(Figures in Acre-Feet)

| Study Area | Inflow From Other Study Areas | Water Yield Within Study Area | Outflow Under Natural Conditions | Man's Depletions of Streamflow | | | | | Depleted Outflow |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Irrigation | Municipal | Industrial | Reservoir Evaporation [1] | Total | |
| | (1) | (2) | (7)=(1)+(2) | (4) | (5) | (6) | (7) | (8) | (9)=(3)-(8) |
| WIND RIVER | | | | | | | | | |
| 1a. Upper Wind River | 0 | 517,110 | 517,110 | 11,000 | 0 | 10 | 100 | 11,110 | 506,000 |
| 1b. South Wind River Tributaries | 0 | 881,960 | 881,960 | 103,600 | 750 | 10 | 9,900 | 114,260 | 767,700 |
| 1c. North Wind River Tributaries | 0 | 31,400 | 31,400 | 4,400 | 0 | 0 | 900 | 5,300 | 26,100 |
| 1d. Main Stem Wind River | (1,317,400) [2] | -26,080 | -26,080 | 212,900 | 0 | 520 | 61,600 | 275,020 | -301,100 |
| 1e. East Wind River Tributaries | 0 | 21,900 | 21,900 | 2,500 | 0 | 0 | 1,800 | 4,300 | 17,600 |
| 1. Wind River Total | 0 | 1,426,290 | 1,426,290 | 334,400 | 750 | 540 | 74,300 | 409,990 | 1,016,300 |
| BIGHORN RIVER | | | | | | | | | |
| 2a. Main Stem Bighorn River | (2,454,100) [3] | 109,970 | 109,970 | 140,000 | 1,150 | 520 | 0 [4] | 141,670 | -31,700 |
| 2b. East Bighorn River Tributaries | 0 | 23,800 | 23,800 | 300 | 0 | 0 | 600 | 900 | 22,900 |
| 2c. Nowood River | 0 | 286,410 | 286,410 | 33,100 | 0 | 10 | 1,200 | 34,310 | 252,100 |
| 2d. Shell Creek | 0 | 107,910 | 107,910 | 17,700 | 0 | 10 | 500 | 18,210 | 89,700 |
| 2e. Bighorn Lake Tributaries | 0 | 21,200 | 21,200 | 2,500 | 0 | 0 | 100 | 2,600 | 18,600 |
| 2f. West Bighorn River Tributaries | 0 | 104,500 | 104,500 | 17,700 | 0 | 0 | 3,800 | 21,500 | 83,000 |
| 2g&h. Greybull River | 0 | 258,260 | 258,260 | 128,600 | 50 | 10 | 5,900 | 134,560 | 123,700 |
| 2i&j. Shoshone River | 0 | 1,198,060 | 1,198,060 | 330,200 | 760 | 1,100 | 18,200 | 350,260 | 847,800 |
| 2. Bighorn River Total | 0 | 2,110,110 | 2,110,110 | 670,100 | 1,960 | 1,650 | 30,300 | 704,010 | 1,406,100 |
| BIGHORN RIVER BASIN | | | | | | | | | |
| 1.&2. Wind-Bighorn River [5] | 0 | 3,536,400 | 3,536,400 [6] | 1,004,500 | 2,710 | 2,190 | 104,600 | 1,114,000 | 2,422,400 [7] |
| 3. Little Bighorn River | 0 | 137,010 | 137,010 [6] | 2,900 | 0 | 10 | 200 | 3,110 | 133,900 [7] |
| 4. Clarks Fork | 146,800 [8] | 564,410 | 711,210 [6] | 21,100 | 0 | 10 | 500 | 21,610 | 689,600 [7] |
| Total | 146,800 [8] | 4,237,820 | 4,384,620 | 1,028,500 | 2,710 | 2,210 | 105,300 | 1,138,720 | 3,245,900 |

[1] Includes stock pond evaporation.
[2] Includes inflow from the other Wind River study areas; nonadditive in this table.
[3] Includes inflow from the Wind River and the other Bighorn River study areas; nonadditive in this table.
[4] Excludes Bighorn Lake evaporation.
[5] Summation of the Wind and Bighorn River study areas.
[6] Approximate streamflow which would be leaving Wyoming under natural conditions.
[7] State-line streamflow.
[8] Inflow from Montana.

excluding Bighorn Lake evaporation; 2,210 acre-feet by industry; and 2,710 acre-feet by minicipal and domestic uses. The total consumptive use in the Bighorn River Basin is about 1,138,720 acre-feet per year. Thus, the annual depleted streamflow leaving the State of Wyoming is 3,245,900 acre-feet per year.

Streamflow may be artifically augmented in the future. Potential sources of increased water supplies are improved watershed management, importation of water from other river basins, and augmentation of precipitation (weather modification). The U. S. Bureau of Reclamation is conducting extensive research on weather modification including augmenting summer and winter precipitation and associated problems such as instrumentation requirements and ecological, social, and institutional problems. This research is carried out for the Bureau by several concerns, including the University of Wyoming, Department of Atmospheric Research. The State of Wyoming is participating in this research by having the University investigate possibilities for operational weather modification. Areas showing a potential for such operations are the Wind River, Big Horn, Absaroka, Beartooth, and other mountains where snowpack might be increased. Operational areas, costs, resulting water supplies, and other factors have not been determined at this time, and it is premature to estimate water supply increases from this source.

## FLOODS [1]

Damaging floods have occurred on many of the streams of the Basin. Some flood damage usually occurs annually from high spring runoff, occasional summer rainstorms, or ice jams. The flood damage is generally restricted to agricultural developments and machinery, roads, railroad crossings, wildlife habitat, and farm buildings and urban development built on the floodplain. In irrigated areas diversion structures, canals, and laterals frequently experience flood damage, usually caused by snowmelt runoff coupled with local rainstorms. Anchor, Buffalo Bill, Boysen, and other dams have helped control floods.

In 1923 a heavy rainstorm covered most of the Basin causing serious basin-wide flooding. Recently, in the years 1962, 1963, 1965, and 1967, serious floods have occurred on several streams in the Basin. Most of the principal tributaries of the Wind-Bighorn River have had a serious flood at one time or another.

Above Boysen Reservoir Crow Creek, Beaver Creek, Badwater Creek, and the Popo Agie River have been identified as having flood problems.

In mid-June of 1965 heavy snowmelt runoff coupled with a series of three cloudbursts caused serious damage to irrigation diversion structures, canals, fences, farmsteads, roads, and crops on Crow Creek, a tributary of the Wind River. The flood damage during the 1965 flood was estimated to be $40,000. A flood of this magnitude has a 10-percent-chance of occurring in any given year. Floods of lesser magnitude cause damage nearly every year along the lower portions of Crow Creek. The estimated annual flood damage is about $9,750.

Beaver Creek, a tributary of the Popo Agie River, has received flood damages to crops, canals, fences, and irrigation structures. The largest recent flood occurred in June 1969. The estimated average annual flood and sediment damages are $1,600.

[1] Data summarized from information supplied by the Soil Conservation Service from the Wind-Bighorn - Clarks Fork River Basin Survey.

Summer thunderstorms have caused flood damage along Badwater Creek below Sioux Creek nearly every year, primarily to agricultural property. The largest flood since the 1923 Basin-wide event occurred in 1968 and caused an estimated $8,200 of damage. A flood of the magnitude of the 1968 event on Badwater Creek has a 3-percent-chance of occurring in any year. The estimated annual flood damage in the Badwater drainage is $1,430.

The Popo Agie River system has had serious flood damage to agricultural properties and to urban developments in the towns of Hudson and Lander. Flooding is a problem along the Little Popo Agie River from Twin Creek to the Popo Agie River. It has been especially serious in Lyons Valley where floods have damaged crops, farm buildings, irrigation structures, livestock and pheasant habitat. Below the confluence of the Little Popo Agie and Popo Agie Rivers, floods have damaged homes, roads, and commercial property in the town of Hudson. Several floods have occurred on the Middle Fork of the Popo Agie River, which flows through the town of Lander. The most damaging and recent flood was a 1-percent-chance flood in 1963. It caused considerable damage to businesses, residences, streets, and water supply and sewage systems. Since 1963 the town of Lander has initiated a street and channel improvement program and constructed several dikes to prevent flooding.

The LeClair-Riverton and Riverton Valley Irrigation Districts have annual flood damages from sedimentation and floodwaters to cropland, canals, and irrigation systems. The annual damages are estimated at $15,000.

Below Boysen Reservoir most of the principal tributaries of the Bighorn River have had serious floods. The streams that have been identified as having flood damages are Nowood River, Greybull River, Shoshone River, and Shell Creek.

Serious flood damages have occurred along the main stem of the Nowood River and its tributaries. Nowood River tributaries are less susceptible to flooding, but some damage has occurred on Canyon, Tensleep, and Paint Rock Creeks. Spring snowmelt runoff, summer rainstorms or ice jams cause some flood damage nearly every year. The floods frequently cause damage to crops, irrigation structures, roads, bridges, fences, and to urban property in the town of Manderson. The most serious floods occurred in 1917, 1918, 1923, 1935, 1962, 1967, and 1970. The 1970 flood caused an estimated $135,000 of damage due to a combination of snowmelt runoff and a rainstorm in a portion of the Basin. The average annual flood and sediment damages on the Nowood River are estimated to be $105,000. The flood damages for four sections of the Nowood River have been estimated to be: $19,500 above Tensleep Creek, $26,500 between Tensleep and Paint Rock Creeks, $19,500 from Paint Rock Creek to Manderson, and $39,500 to the town of Manderson. About 60 percent of the damage in Manderson was caused by the Nowood River and 40 percent by the Bighorn River.

The entire Greybull River is subject to flooding; however, the most serious damage has occurred in the lower reaches. The damages have been restricted to croplands, irrigation structures, farmsteads, roads, and bridges. The most serious floods occurred in 1937, 1957, 1963, 1965, and 1967. The most damaging flood occurred in 1963, and caused several hundred thousand dollars worth of damages. Damaging floods can be expected along the Greybull River 2 out of 10 years. The estimated average flood damage along the Greybull River is $50,000 per year.

Buffalo Bill Reservoir has reduced the flood damages along the Shoshone River; however, some flood damages still occur, especially in the vicinity of Lovell. The majority of this flooding is due to ice jams. The flood damages in the lower reaches of the Shoshone River have been to agricultural properties and wildlife habitat. Above Buffalo Bill Reservoir serious flooding occurs along the North and South Forks of the Shoshone River. Most of the damage on the North Fork drainage occurs on the tributaries to irrigation structures, crops, homes, commercial properties, and roads. Along the South Fork flood waters have damaged crops, farm buildings, irrigation structures, and wildlife habitat. Some flood damage occurs nearly every year on the North and South Forks of the Shoshone River. Serious recent floods on the Shoshone River occurred in 1961, 1962, 1963, 1965, and 1967.

Shell Creek has had serious flood problems. The worst flooding occurs on Trapper and Beaver Creeks, tributaries of Shell Creek. Since 1960, serious flooding has occurred in 1961, 1962, 1963, 1965, and 1968; and moderate flooding has occurred in 1964, 1967, 1969, and 1970. The flood waters have damaged crops, irrigation structures, wildlife habitat, and aesthetic quality.

The town of Thermopolis has had serious flooding from Candy Jack Creek in 1960, 1962, 1963, and 1967. The Soil Conservation Service has recently completed a project to help alleviate the flood damage to the town. The estimated annual flood damage before the SCS project was $38,740.

## WATER QUALITY [2]

Quality of water refers to its physical and chemical characteristics and biological and radiological content. The goal of water quality management is to maintain water of adequate quality for multiple uses, both for present and future needs. Two water quality factors should be considered in every water development project. First, the water must be of adequate quality for the use for which it is intended. Second, if the water is not 100-percent consumptively used, the return flow quality must be considered.

### Water Quality Standards

The Federal Water Quality Act of 1965 required that the states adopt water quality standards for all interstate waters. The water quality standards approved by the Wyoming State Board of Health were accepted and approved by the Federal Water Pollution Control Administration of the Department of the Interior (now the Water Quality Office of the Environmental Protection Agency or EPA) in November of 1968. The purpose of the Interstate Water Quality Standards is to insure that all multiple use demands are met. This means that recreation and fish and wildlife propagation and overall aesthetic values are met, while at the same time municipal, industrial, and agricultural demands are met. These latter demands call for both a source of usable water and for an assimilative receptacle for the discharge or return flows of waste waters. A further criterion for quality levels in streams is to hold quality at such levels that conventional treatment techniques, such as sedimentation, filtration, and chlorination, would be the maximum treatment needed to enhance the quality to potable condition.

Within the Basin, the following streams are designated as interstate waters for which water quality standards have been established: Section 1 -- Clarks Fork

[2] Contributed by the Sanitary Engineering Division of the State Department of Health and Social Services.

River and tributaries, including the main stem Clarks Fork, Glacier Lake - Rock Creek, Bear Tooth Creek - Lonesome Lake, Lake Creek - Granite Lake, Big Moose Creek - Crazy Creek, Line Creek, Haydan Creek, Republic Creek and Gilbert Creek; Section 2 -- Porcupine, Trout, Crooked, and Sage Creeks, including the main stem Shoshone River from the mouth of Sage Creek to is confluence with the Bighorn River; Section 3 -- Wind-Bighorn River, Stretch I, consisting of the main stem Wind River from its headwaters downstream to the outlet of Boysen Reservoir; Section 4 -- Wind-Bighorn River, Stretch II, consisting of the main stem of the Bighorn River from the outlet of Boysen Reservoir downstream to the Wyoming-Montana State line; and Section 5 -- including the Little Bighorn River, Lodge Grass Creek, West Pass Creek, and East Pass Creek above the Wyoming-Montana State line.

The water quality standards established for interstate streams are based on physical and chemical characteristics and biological and radiological content. Water quality standards for intrastate streams have not been established. Generally, the quality of interstate waters in the Wind-Bighorn and Clarks Fork River Basins is within the limits of established standards.

Based on water use and existing conditions, ten basic standards and five variable standards have evolved. The following list of basic standards is summarized from "Water Quality Standards for Interstate Waters in Wyoming," published by the Wyoming Department of Public Health (now the Department of Health and Social Services):

1. Physical: Water should be essentially free of obvious and/or offensive pollutants such as particulates, taste, odor, and color, and the temperature should permit natural aquatic life.

2. Chemical: Water should be free of toxic materials, and the dissolved oxygen and pH (measure of acidity or alkalinity) should permit natural aquatic life.

3. Bacteriological: The concentration of fecal coliform bacteria in water should be within the most probable number (MPN) limit set for the particular stream.

4. Radiological: Water should have a level of radioactivity below the limit set in the U. S. Public Health Service Drinking Water Standards of 1962.

Salinity (total dissolved solids) in water is becoming a controversial issue due to unknowns and variables affecting its degree of concentration. Where salinity increase can be attributed to specific discharges capable of control, specific control measures shall be instituted and a specific numerical standard may be adopted. Where salinity increase is due to widespread irrigation or to natural accumulation of salts, the control is beyond present technology and a numerical standard has no meaning. Where control remains beyond present technology, an interim approach with the following provisions is recommended:

1. A routine monitoring program should be implemented to determine any unreasonable increases that might be attributable to new specific sources capable of control.

2. An educational program should be established through the Agricultural Extension Service and the Soil and Water Conservation Districts as to the proper control and use of water and implementation of improved control methods as they are developed.

In addition to the above basic standards which apply to all Wyoming interstate waters, special water quality standards have been established for some of the designated interstate streams within the Basin:

A. Clarks Fork River and tributaries: The basic water quality standards applying to all interstate waters in Wyoming are the only standards applicable to these waters at this time.

B. Porcupine, Trout, Crooked, and Sage Creeks: For Sage Creek, the control of salinity will be carried out in accordance with the general salinity policy outlined above.

C. Wind-Bighorn, Stretch I: Wastes or substances of other than natural orgin shall not be discharged into these waters in amounts which will cause organisms of the fecal coliform group to exceed 240 per 100 ml (MPN) as a geometric mean of the last five consecutive samples, nor exceed 750 per 100 ml in any one sample. This standard applies only to the waters of Boysen Reservoir. Also, the control of salinity will be carried out in accordance with the general salinity policy outlined above.

D. Wind-Bighorn River, Stretch II: Wastes or substances of other than natural origin shall not be discharged into these waters in amounts which (1) will cause organisms of the fecal coliform group to exceed 2,000 per 100 ml (MPN) as a geometric mean of the last five consecutive samples, except that within the confines of Yellowstone Reservoir (Bighorn Lake) organisms of the fecal coliform group shall not exceed 240 per 100 ml (MPN) as a geometric mean of the last five consecutive samples during the period May 1 through September 30; or (2) will result in a pH of the waters of less than 7.0 or greater than 8.5. Also, control of salinity will be carried out in accordance with the general salinity policy outlined above.

E. Little Bighorn River, Lodge Grass Creek, West Pass Creek, and East Pass Creek: The basic water quality standards applying to all interstate waters in Wyoming are the only standards applicable to these waters at this time.

## Historical Water Quality Data in the Bighorn River Basin

An informal cooperative program of physical and chemical monitoring in the Basin has been carried out since the inception of Wyoming's water pollution control program in 1956. The agencies involved in this program are the Wyoming State Engineer's Office, the Wyoming Game and Fish Commission, the State Department of Agriculture, the State Department of Health and Social Services, and the U. S. Geological Survey.

The State Department of Agriculture carries out the basic chemical quality-of-water program in cooperation with the USGS and the State Engineer's Office. Currently 20 chemical-quality stations, seven sediment stations, and two combined chemical-sediment stations are being maintained in the Basin.

Personnel of the Game and Fish Commission play a very important role in the monitoring of streams within the State. Fishery management crews maintain a personal and continuous supervision of Wyoming waters and are aware of all conditions that may affect fisheries. In addition, the Game and Fish Commission has two men assigned statewide as pollution analysts, who are responsible for detailed study of water quality problems.

The State Department of Health and Social Services is responsible for the supervision of municipal and industrial waste water facilities and for the necessary bacteriological monitoring to determine compliance with the proposed standards. Bacteriological monitoring is done at the following locations:

(1) Boysen Reservoir
(2) Bighorn River below Thermopolis
(3) Bighorn River at Worland
(4) Bighorn River at Basin
(5) Bighorn Lake

Due to a lack of funding, radiological monitoring sites are no longer maintained; however, samples are still taken on a problem-oriented basis.

## Existing and Potential Water Quality Problems

The available data indicate that the water quality of the interstate streams of the Basin is in general agreement with adopted interstate standards.

### Municipal

Table II-2 is an inventory of all municipalities in the Basin. Generally, the communities that discharge waste to the waters cited are considered to have adequate treatment facilities so far as waste effects on water quality of interstate streams and subsequent uses are concerned. The one exception to this is the town of Thermopolis, including Hot Springs State Park. At the present time Thermopolis has wastewater treatment consisting of preaeration, sedimentation, and separate sludge digestion. Hot Springs State Park has a separate waste water treatment system which consists of a single Imhoff tank. The effluent from these two systems causes constant violation of the fecal coliform section of Wyoming's Interstate Water Quality Standards. A plan to correct this problem by providing a single post-chlorination plant to treat effluents from both the town of Thermopolis and Hot Springs State Park has been written by the Wyoming Department of Health and Social Services. Under this plan, a Federal grant will be made available in the amount of $35,000 for the construction of facilities. The use of this new facility, projected for the fall of 1972, will bring the receiving water quality at this point into compliance with interstate standards.

Table II-2 shows the estimated amounts of BOD (biochemical oxygen demand, TDS (total dissolved solids), and P (phosphorus) added to receiving streams by municipalities in the Basin. The BOD is a measure of the oxygen depleting capacity of organic wastes, TDS indicates the quantity of mineral salts present in the municipal discharge, and P is an important nutrient contributing to eutrophication and is nearly exclusive to municipal waste waters.

### Industrial

Table II-3 indicates all known waste-water-producing industries in the Basin.

In addition to the petroleum refineries listed in Table II-3, there are some 2,760 oil and gas producing wells in the Basin. In many of the production wells highly mineralized waters are brought to the surface with crude oil. The oil and water are separated, and in many cases these produced waters are a valuable resource in a generally arid region. Livestock and wildlife are often solely dependent on these discharges as a source of water, and in some cases this water is also used for irrigation.

TABLE II-2 -- Municipal Waste Water Treatment

| Municipality | Study Area [1] | 1970 Population | Type of Treatment | Receiving Water | Discharge Volume (gpd--est.) | Estimated Load to Stream (tons/year) [2] | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | BOD | TDS | P | |
| Dubois | 1a | 898 | 3.5-acre Stabilization Pond | Wind River | 45,000 | 6 | 62 | 1 | Community is planning pond expansion |
| Lander | 1b | 7,125 | Two Stabilization Ponds, total 44 acres | Middle Fork Popo Agie River | 475,000 | 44 | 494 | 9 | |
| Arapahoe Industrial Park | 1b | -- | Two Stabilization Ponds- 1 acre each | Little Wind River | Var. to 5,000 | -- | -- | -- | |
| Arapahoe Community | 1b | -- | -- | -- | -- | -- | -- | -- | |
| Hudson | 1b | 381 | Stabilization Pond | Popo Agie River | 15,000 | 2 | 26 | -- | Aeration planned |
| State Training School - Lander | 1b | -- | 7-acre Stabilization Pond | Middle Fork Popo Agie River | 50,000 | | | | |
| Fort Washakie | 1b | 300 | Stabilization Pond, 2 acres Primary, 1 acre Polishing | Little Wind River | 10,000 | 2 | 21 | -- | Current design effort to relocate and expand facilities |
| Ethete | 1b | 50 | Individual Septic Tanks | None | None | -- | -- | -- | |
| Riverton | 1d | 7,995 | Conventional with Trickling Filter | Wind River | 700,000 | 50 | 554 | 10 | |
| Pavillion | 1d | 181 | Stabilization Pond | Pavillion Main Irrigation Lateral | 10,000 | 1 | 13 | -- | |
| Shoshoni | 1e | 562 | Four Anaerobic Lagoons | Poison Creek | 35,000 | 4 | 39 | 1 | |
| Thermopolis | 2a | 3,063 | Preaeration, Sedimentation, Separate Sludge Digestion | Bighorn River | 900,000 | 19 | 212 | 4 | Post-chlorination plant under planning |
| Hot Springs State Park | 2a | -- | Imhoff Tank | Bighorn River | Var. to 10,000 | -- | -- | -- | Being considered for connection to Thermopolis system |
| Worland | 2a | 5,055 | Two Stabilization Ponds, 40 acres total | Bighorn River | 420,000 | 31 | 351 | 6 | |
| Wyoming Industrial Institute | 2a | -- | Stabilization Pond | Bighorn River | Var. to 10,000 | -- | -- | -- | |
| Manderson | 2a | 117 | Septic Tank and Soil Absorption | Bighorn River | No discharge | 1 | 8 | -- | Serves two small schools, five residences |
| Basin | 2a | 1,145 | 20-acre Stabilization Pond | Bighorn River | 90,000 | 7 | 79 | 1 | |
| Greybull | 2a | 1,953 | 20-acre Stabilization Pond | Bighorn River | 160,000 | 12 | 135 | 2 | |
| Tensleep | 2c | 320 | Stabilization Pond, Leach | Nowood River | 24,000 | 2 | 22 | -- | |
| Meadowlark | 2c | -- | Oxidation Ditch | Nowood River | 5,000 | | | | |
| Meeteetse | 2g | 459 | Septic Tank | Greybull River | 50,000 | 3 | 32 | 1 | |
| Lovell | 2j | 2,371 | Two Stabilization Ponds, 20 acres total | Shoshone River | 170,000 | 15 | 164 | 3 | |
| Byron | 2j | 397 | 3-acre Stabilization Pond | Shoshone River | 26,000 | 3 | 28 | | |
| Powell | 2j | 4,807 | 30-acre Stabilization Pond | Shoshone River | 375,000 | 30 | 333 | 6 | |
| Deaver | 2j | 112 | Stabilization Pond | Polecat Creek | 8,000 | 1 | 8 | -- | |
| Frannie | 2j | 139 | Stabilization Pond | Sage Creek | 10,000 | 1 | 10 | -- | |
| Cody | 2i | 5,161 | 35-acre Stabilization Pond | Shoshone River | 360,000 | 32 | 358 | 6 | |
| Total | | | | | | 266 | 2,949 | 50 | |

[1] Numbers in this column refer to study areas shown in Figure II-2.

[2] Basis of estimate: BOD 62 lbs. per person per year with 80% removal.
TDS 146 lbs. per person per year with 5% removal.
P 3 lbs. per person per year with 20% removal.

Oil spills and pipeline breaks do occasionally produce pollution problems. The 1970 Amendments to the Water Pollution Control Act required the development of a National Contingency Plan for Spills of Oils and Other Hazardous Materials. The person in charge of a facility from which a spill or pipeline break occurs is now required to immediately notify the Regional Office of the Environmental Protection Agency. Failure to do so is punishable by fine or imprisonment. This procedure has effectively reduced the pollution problems originating from the spills of oil and hazardous materials.

In summary, water quality problems related to industrial discharges are minor in the Bighorn River Basin.

## Agricultural

Health Department records indicate a total of 66 cattle and 14 sheep feedlots in the Lovell-Deaver-Cowley area of the Big Horn County. There are 14 feedlots in the Riverton area and a small number in the Basin-Greybull area. Guidelines for

TABLE II-3 -- Industrial Waste Water Treatment

| Name and Location | Receiving Water | Type of Treatment | Effect on Receiving Water |
|---|---|---|---|
| Cowboy Timber Treating, Inc.--Manderson | None | Retention | None |
| Federal-American Partners Uranium Mills--Fremont County | None | Retention | None |
| Great Western Sugar Refinery-Lovell | Shoshone River | Chemical wastes retained, only screened flumed water discharged | BOD, Turbidity, Coliform, and Solids |
| Holly Sugar Company Refinery--Worland | Bighorn River | Clarified flume water with 90% suspended solids removed | Minor BOD, Turbidity and Coliform |
| Husky Oil Refinery--Cody | Shoshone River | A.P.I. separator system with associated cooling | None |
| Montana-Dakota Utilities--Worland | None | Retention and periodic removal | None |
| Sage Creek Refinery-Cowley | Sage Creek | Small overflow pond capability | None |
| Chemgas Company--Worland | Bighorn River | Boiler blowdown discharge | None |
| Union Oil Company of California--Worland | Bighorn River | Intake water is aerated, flocculated and settled, once through cooling and boiler blowdown use. No known degradation. | None |
| Utah Construction Company Uranium Mine--Fremont County | None | Retention | None |
| Union Carbide Uranium Mine Sites--Fremont County | None | Retention | None |
| Miscellaneous uranium mine Sites--Fremont County | Muskrat Creek | Retention and Absorption | None |
| Triangle Packing Plant--Worland | Bighorn River | Normal operation is retention in two section aerobic ponds; bypass possible. | None |
| Stanolind Oil Company | Elk Basin Dry Drainage | Retention | None |

the control of pollution from livestock feeding operations have been developed by the Health Department, Agricultural Extension Service, and the State Department of Agriculture. All feedlot operators are being urged to adopt the provisions contained in these guidelines.

It is recognized that irrigation return flows can, by virtue of the soil characteristics of the irrigated land, carry significant amounts of sediments and total dissolved solids (TDS or salinity) into the receiving stream. An extensive program of education in regard to proper irrigation practices is being carried on in the State through the University Extension Service, Farm Bureau, Irrigation Districts, and Soil and Water Conservation Districts. This is resulting in many improvements such as lined canals, buried pipelines, and improved irrigation practices, all of which will help improve water quality. Salinity is not measured in enough places in the Basin to adequately differentiate natural salinity increases from those resulting from irrigation. Figure II-7 is a schematic diagram of streamflows and total dissolved solids at USGS stream gages.

The contribution by agriculture to water pollution in the Basin is not specifically known at this time.

Natural

A large natural source of salinity exists in the Basin. The many hot springs that flow in the Thermopolis area contribute millions of gallons of mineralized water per day to the drainage system. These waters contain about 3,500 ppm total dissolved solids and account for approximately 20 percent of the average annual pick-up in salt load between Boysen Reservoir and the Kane gaging station.

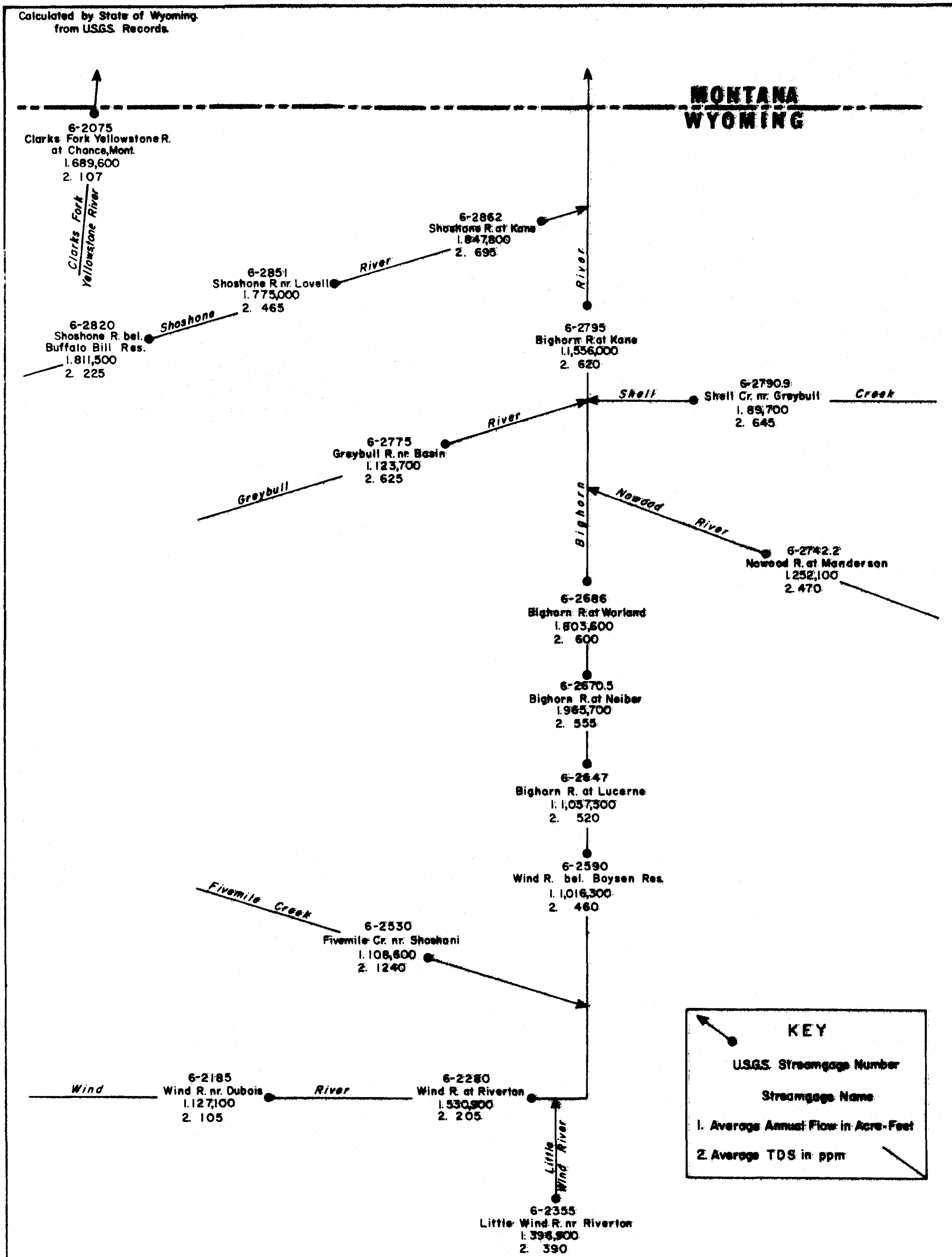



Figure II-7 Schematic Diagram of Bighorn River Basin Streams Showing Streamflow and Total Dissolved Solids

Heavy overgrazing in early years has produced miniature badlands, and the water courses carry heavy silt loads at times of runoff. In areas of salty soils, salinity increases can occur by the same process.

### Training of Waste-Water-Treatment Plant Operators

The State of Wyoming is now conducting a voluntary training course for operators of municipal and industrial waste water facilities. An operator certification system will be implemented in the near future.

## WATER RIGHTS

The Wyoming Constitution declares that the waters of all natural streams, springs, lakes, or other collections of still water within the boundaries of the State are the property of the State. Constitutional provisions allow the appropriation of water for beneficial uses, and establish the office of State Engineer and the Board of Control to supervise such appropriations. The Board of Control consists of the State Engineer, who is president, and the Superintendents of each of the four administrative water divisions of the State. The State Engineer has "general supervision of the distribution of waters of the State and of the officers connected with its distribution."

State statutes establish the procedure for the appropriation of water for beneficial use. First, a permit to use water must be obtained from the State Engineer. After the water has been put to use and proof of beneficial use is made to the Board of Control, the Board will adjudicate the water right. Priority of appropriation is based upon the relative dates on which applications for permits were accepted in the State Engineer's Office. "First in time is first in right," is the basis of Wyoming water law.

Water Division Number 3 includes the Clarks Fork Study Area and the Wind-Bighorn River and its tributaries. The Little Bighorn River Basin is in Water Division Number 2. Table II-4 presents a tabulation of irrigation water rights for the entire study area in both water divisions. The tabulation is by study area, and is current as of January, 1972.

TABLE II-4--Tabulation of Adjudicated Acres and Permits in Good Standing as of January 1972

| Study Area (1) | Adjudicated Acres (2) | Permits in Good Standing (3) | Total (2) & (3) (4) |
|---|---|---|---|
| 1. Wind River | 96,520 | 327,400 | 423,920 |
| 2. Bighorn River | 464,970 | 41,470 | 506,440 |
| 3. Little Bighorn River | 8,040 | -- | 8,040 |
| 4. Clarks Fork | 21,710 | 2,240 | 23,950 |
| Total | 591,240 | 371,110 | 962,350 |

Total irrigated acreage in the Bighorn River Basin was determined by the staffs of the Wyoming Water Planning Program and the Soil Conservation Service during the summer of 1969. The irrigated lands were identified by field examination and mapped on aerial photographs. The irrigated lands total 538,830 acres, some 423,520 acres less than existing water rights. No attempt was made in this inventory phase of work to compare irrigated lands with water rights. The existance of more water rights than irrigated land is not unique to the Bighorn River Basin; a similar situation exists throughout the State.

There are also water rights for other uses such as municipal, domestic, stock, industrial, and fish and wildlife purposes. These rights involve relatively minor quantities of water when compared with irrigation and are not summarized in this report.

Water rights for storage involve a considerable amount of water in the Basin. Existing reservoirs over 1,000 acre-feet are shown on Figure IV-2 and reservoir capacities and uses are given in Table IV-10 (pages 111 and 113).

A conflict between State and Federal water rights could affect water resources development in the Bighorn River Basin. The "reserved water rights doctrine," or "reservation doctrine," had its conceptual beginnings in 1908, when the United States Supreme Court in the Winters case stated that the United States, in setting aside an Indian reservation, necessarily reserved the water without which the lands would be valueless. In subsequent decisions the Supreme Court held that the doctrine applied to other reservations or withdrawls of the public domain as well. The 1963 decision in Arizona v. California was the first case to actually allocate water for types of reservations other than Indian reservations. The Court quantified the Indian rights, finding that the only feasible and fair way to measure them was by fixing the amount of water needed to irrigate all of the practicably irrigable land. The Court also asserted that the United States had intended to reserve sufficient water for the future requirements of a national recreation area, two wildlife refuges, and a national forest (9).

The reservation doctrine is not easily analyzed or interpreted, and there are numerous questions that arise relative to its basis and application. The foundation of the doctrine is the property clause of the United States Constitution. The basic elements of the reservation doctrine are as follows (9).

"If the United States, by treaty, act of Congress, or executive order, reserves a portion of the public domain for a Federal purpose which will ultimately require water, and if at the same time the government intends to reserve unappropriated water for that purpose; then sufficient water to fulfill that purpose is reserved from appropriation by private users. The effect of the doctrine is twofold: (1) when the water is eventually put to use the right of the United States will be superior to private rights in the source of water acquired after the date of the reservation; hence such private rights may be impaired or destroyed without compensation by exercise of the reserved right, and (2) the Federal use is not subject to state laws regulating appropriation and use of water."

It is evident that a new water use under the reservation doctrine could take water without compensation from an appropriator with a priority under state law established subsequent to the reservation.

In addition to possible damage to existing water users, Federal claims to substantial and ill-defined rights to use water would undeniably be a deterrent to further non-Federal development. Unrecorded and unquantified reserved water rights whether presently developed, or planned for future development, cause uncertainty in water management, regulation, and development, and can cause injury to water users who have no knowledge of such claims. For example, there are those who claim that the reservation of water for Indian reservations should not be limited to the amount required for the practicably irrigable lands, but should also include water for mineral and industrial development. Some strong advocates of Indian rights even go so far as to maintain that Indian rights may be marketable and transferable to places of use outside Indian reservations.

Federal legislation has been proposed which would require Federal recognition of state water laws. A recent proposal calls for a "National Water Rights Procedures Act" (9), which would foster a cooperative spirit between the states and the Federal Government in accommodating the water needs of Federal lands with those of the western states. The basic policy of Federal-state cooperation in water appropriation and administration is to be accomplished by legislation . . ."which, without surrendering any power of the United States relating to Federal water programs, projects, and uses will adopt a policy of recognizing and utilizing the laws of the states relating to creation, administration, and protection of water rights, (1) by establishing, recording, and quantifying Federal water rights in conformity with such state laws as are consistent with and appropriate to the Federal purposes, (2) by protecting and preserving vested water rights held under state law through the elimination of the no compensation features of the reservation doctrine and the navigation servitude, and (3) by providing new Federal procedures for the condemnation of water rights and the settlement of legal disputes." (9).

Enactment of this type of legislation by Congress, if properly framed, would clarify the Federal-state dispute, and would enable water appropriation and administration on a consistent basis for all water users. A most important feature of the proposal is the payment of compensation to holders of rights junior to a reservation who are injured by a Federal reserved water use. The quantification of Federal water rights under a National Water Rights Procedures Act may require a test in the courts before the extent of defining such rights is finalized.

Federal reservations in the Bighorn River Basin of Wyoming and Montana include two Indian reservations and three national forests. In Wyoming the Wind River Indian Reservation was made in 1868, the Shoshone National Forest in 1891, and the Bighorn National Forest in 1897. The Land Status Map, Figure I-3, shows the locations of these reservations. The Crow Indian Reservation was made in Montana in 1868, and the Custer National Forest was established in 1907. The Indian reservations predate all water rights in Water Division 3, and the national forests predate most of the existing water rights in the area. Uses of water on the Federal reservations have not significantly affected other water users, although a few water developments may not have been undertaken because of a fear of conflict with reserved water rights. The potential for damage to private water uses does exist, especially if expanded and new water uses are developed on the reservations.

In this report, water uses in national forests are assumed not to expand past recreational uses such as presently exist. Indian water uses are treated in the same manner as other water uses so far as projections and planning are concerned. Since development of new Indian water uses affects the economies of the local areas and the states as well as the Indians, future new Indian water uses are assumed to be a part of the compact allocation of the state in which the uses are made. This assumption is supported by the language of Arizona v. California.

## INTERSTATE COMPACTS

As irrigation developed in the Bighorn and other river basins, it became apparent that agreements were necessary between Wyoming and downstream states for allocating water uses. The State of Wyoming learned from United States Supreme Court cases concerning the Laramie and North Platte Rivers that obtaining divisions of interstate waters on the basis of court decrees is a lengthy and costly process that should be avoided if possible. Agreements, or interstate compacts, which divide water uses between states usually provide better, more amiable, and more equitable solutions to interstate water problems. The waters of the Clarks Fork and the Bighorn River, except the Little Bighorn River, are allocated by the Yellowstone River Compact.

### Yellowstone River Compact

The Yellowstone River Compact provides a basis for dividing the waters of the Yellowstone River between the States of Wyoming, Montana, and North Dakota. The Yellowstone River Compact was negotiated in 1950 and ratified by the three states and the Federal Government in 1951. The compact establishes a commission composed of one representative each from Montana, Wyoming, and the U. S. Geological Survey to administer its provisions. Article V provides for a division of water on the following basis:

A. Water rights to beneficial uses of the water of the Yellowstone River system existing as of January 1, 1950, shall remain unimpaired by the terms of the compact.

B. Of the unused and unappropriated waters of the interstate tributaries of the Yellowstone River, each of the signatory states is allocated sufficient water to provide supplemental water supplies to all rights existing as of January 1, 1950. The remaining unused and unappropriated water of the interstate tributaries of the Yellowstone River is allocated to Wyoming and Montana as follows:

Clarks Fork of the Yellowstone River:

Wyoming . . . . . . . . . . 60%
Montana . . . . . . . . . . 40%

Bighorn River (exclusive of the Little Bighorn River):

Wyoming . . . . . . . . . . 80%
Montana . . . . . . . . . . 20%

Tongue River:

Wyoming . . . . . . . . . . 40%
Montana . . . . . . . . . . 60%

Powder River:

Wyoming . . . . . . . . . . 42%
Montana . . . . . . . . . . 58%

Figure II-8 shows the drainage areas, compact percentages, and stream gages used to determine compact water supplies. Lands in Montana and North Dakota below Intake, Montana, are entitled to beneficial use of the flow of the Yellowstone River on a proportionate basis of acreage irrigated.

C. Existing and future domestic and stock water uses including stock water reservoirs up to a capacity of 20 acre-feet are exempted from the provisions of the compact.

D. The Commission is to re-examine the water allocations from "time to time" considering among other factors: "priorities of water rights, acreage irrigated, acreage irrigable under existing works, and potentially irrigable lands."

Other provisions of the compact which affect the division of the use of Yellowstone River water include:

1. Article VI--"Nothing contained in this Compact shall be so 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."

2. The water of a lower signatory State may be stored and diverted in an upper State and vice versa, and the right to acquire water rights and rights-of-way in one State for use of water in another is provided (Articles VII, VIII, and IX).

3. Article X provides: "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."

## AVAILABLE WATER RESOURCES

In estimating the surface water supplies that might be available in the Basin, several factors must be considered. These include the physically available streamflow, its variability and dependability, and legal factors of water rights and interstate compacts. The overriding constraint in determining the water supplies is the Yellowstone River Compact. This interstate compact must be interpreted, and assumptions concerning existing water rights must be made to estimate the appropriated and unappropriated water supplies available to Wyoming. As previously noted, irrigation water right acreage far exceeds the acreage actually irrigated. Therefore, analysis of water physically available to existing water rights must accompany any water supply study to ascertain water supplies available to existing water rights and water supplies available for new uses.

Streamflow records for the water years 1948 through 1968 (21 years) were used as the base period for this report. The base period is believed to provide a conservative estimate of average conditions, and it contains the critical drought of the early 1960's for analysis. The amount of water available for use in Wyoming was estimated for the Bighorn River and Clarks Fork under the allocations of the Yellowstone River Compact, and for the Little Bighorn River which is not allocated by an interstate stream compact.

## Bighorn River

The Yellowstone River Compact provides a formula for allocating water between Wyoming and Montana. Stream gage records at the compact gages shown on Figure II-8 must be corrected for the effects of full use of pre-1950 water rights to estimate the unused and unappropriated water. Then supplemental water supply depletions must be estimated, and the remaing unused and unappropriated water of the Bighorn River is allocated 80 percent to Wyoming and 20 percent to Montana.

The compact allocations of the Bighorn River were determined as follows:

1. The recorded streamflows of the Bighorn River at Bighorn, Montana for the period 1948-1968 were used. Corrections were made for developments that affected streamflows for only a portion of the study period such as Boysen Reservoir and Bighorn Lake filling. The average flow from the Little Bighorn River was deducted.

2. The unused and unappropriated water was determined by deducting uses of pre-1950 water rights that have not yet materialized, such as the Riverton Project extensions and other minor scattered irrigation developments and industrial use of Boysen Reservoir water. Assumptions regarding future Wind River Indian Reservation water uses and the future operation of Boysen Reservoir were required. These are discussed in Chapter V. The total unused and unappropriated water was determined to average 2.2. to 2.4 million acre-feet per year.

3. Depletions from potential supplemental water supplies for pre-1950 were deducted to determine the remaining unused and unappropriated water subject to the compact percentage allocation. Supplemental irrigation depletions would vary from 67,700 acre-feet per year to about 98,800 acre-feet per year depending upon intra-basin transfers (see Table IV-12). The remaining unused and unappropriated water is 2.1 to 2.3 million acre-feet per year. Wyoming's 80 percent allocation is 1.8 million acre-feet per year, more or less.

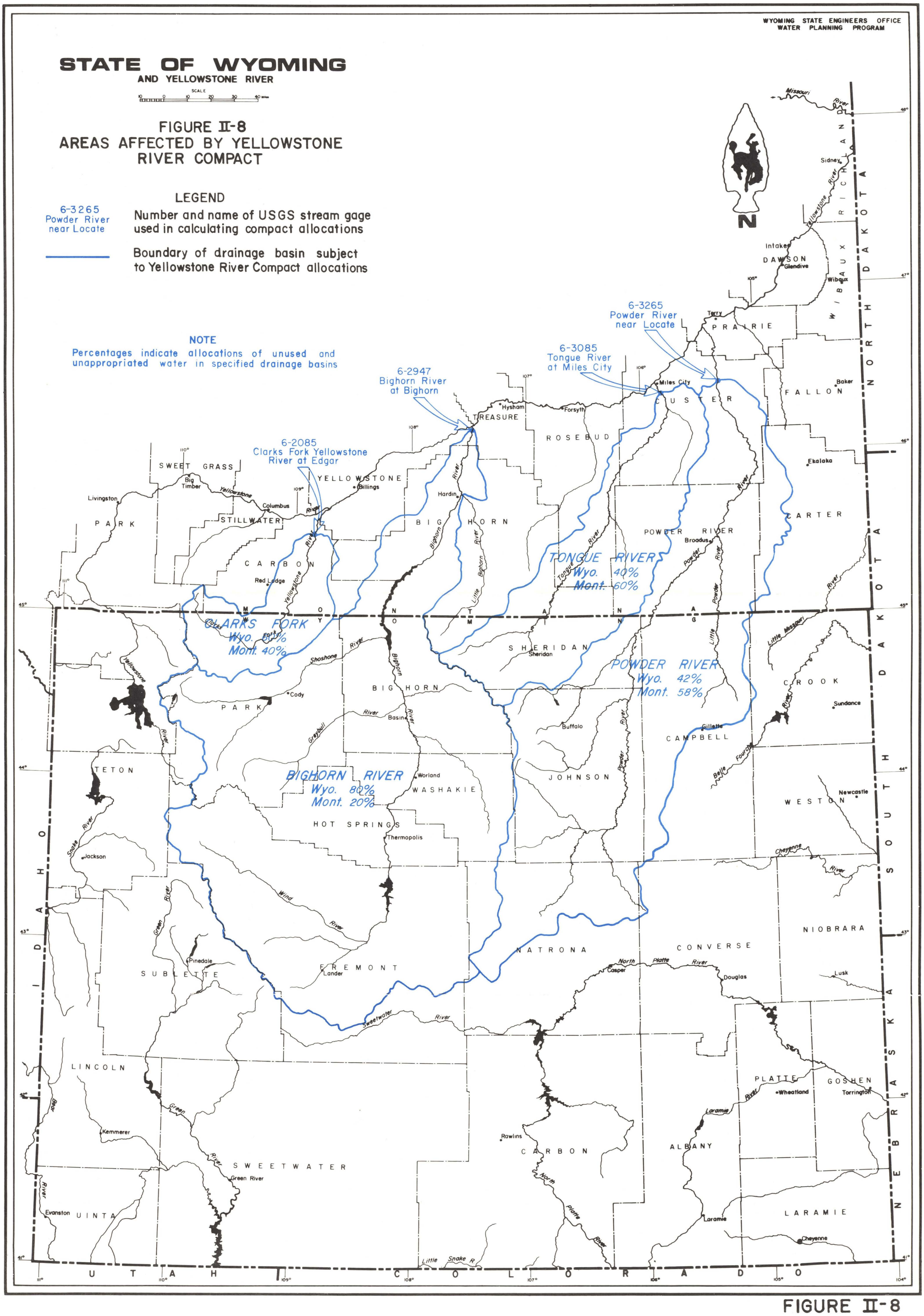
There are minor uses of compact water in Wyoming at the present time. Analysis of adjudicated water rights indicates that about 7,200 acres of adjudicated irrigation water rights are dated after January 1, 1950.

Additional reservoir capacity is required for Wyoming to use the compact water on a firm basis. Bighorn Lake could provide a part of the water supply regulation if water uses can be from the reservoir or from the river below the dam.

## Clarks Fork

The Clarks Fork of the Yellowstone River is also included in the Yellowstone River Compact (see Figure II-8). The assumptions required to estimate water supplies allocable under the compact include: (a) the continued use of, and development of supplemental water supplies for pre-1950 water rights in Wyoming and (b) interpretation of Montana's water rights and provisions for supplemental water supplies.

The Wyoming Water Planning Program has estimated the average depletable unused and unappropriated water in the Clarks Fork Study Area to be 714,000 acre-feet per year. Of this, Wyoming's 60-percent share is 429,000 acre-feet per year.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STATE OF WYOMING
AND YELLOWSTONE RIVER
SCALE
FIGURE II-8
AREAS AFFECTED BY YELLOWSTONE
RIVER COMPACT
LEGEND
6-3265
Powder River
near Locate
Number and name of USGS stream gage
used in calculating compact allocations
Boundary of drainage basin subject
to Yellowstone River Compact allocations
NOTE
Percentages indicate allocations of unused and
unappropriated water in specified drainage basins
6-3265
Powder River
near Locate
6-3085
Tongue River
at Miles City
6-2947
Bighorn River
at Bighorn
6-2085
Clarks Fork Yellowstone
River at Edgar
TONGUE RIVER
Wyo. 40%
Mont. 60%
POWDER RIVER
Wyo. 42%
Mont. 58%
BIGHORN RIVER
Wyo. 80%
Mont. 20%
CLARKS FORK
N
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
IDAHO
UTAH
COLORADO
RICHLAND
DAWSON
WIBAUX
PRAIRIE
FALLON
CUSTER
ROSEBUD
TREASURE
CARTER
POWDER RIVER
BIG HORN
YELLOWSTONE
SWEET GRASS
STILLWATER
CARBON
PARK
SHERIDAN
CROOK
CAMPBELL
JOHNSON
WASHAKIE
HOT SPRINGS
TETON
WESTON
NIOBRARA
CONVERSE
NATRONA
FREMONT
SUBLETTE
LINCOLN
SWEETWATER
UINTA
ALBANY
PLATTE
GOSHEN
LARAMIE
Sidney
Intake
Glendive
Wibaux
Terry
Miles City
Baker
Hysham
Forsyth
Ekalaka
Billings
Hardin
Big Timber
Livingston
Columbus
Red Lodge
Broadus
Sheridan
Sundance
Cody
Basin
Buffalo
Gillette
Worland
Newcastle
Thermopolis
Jackson
Pinedale
Lander
Casper
Douglas
Lusk
Wheatland
Torrington
Kemmerer
Rawlins
Green River
Evanston
Laramie
Cheyenne
Missouri River
Yellowstone River
Powder River
Little Powder River
Tongue River
Little Bighorn River
Bighorn River
Shoshone River
Greybull River
Wind River
Sweetwater River
North Platte River
Laramie River
Little Snake R
Green River
Snake River
Belle Fourche River
Cheyenne River
Little Missouri River

FIGURE II-8

Storage is required to develop Wyoming's annual compact share. During a drought period such as 1960, without reservoir storage Wyoming's compact uses would be limited to 295,600 acre-feet or about 70 percent of the average compact allocation. There is currently a small Wyoming use of compact water as indicated by about 368 adjudicated acres of irrigation water rights.

## Little Bighorn River

The Little Bighorn River and its tributaries are excluded from the Yellowstone River Compact and there is no other basis for allocation. Thus, Wyoming's development is limited to the dependable water supply in Wyoming over and above existing uses. The average flow leaving the State of Wyoming is estimated to be 133,900 acre-feet per year; 102,600 acre-feet from the Little Bighorn River and the remainder from the Little Bighorn River tributaries. Wyoming could probably develop most of this water if such development would not adversely affect existing water rights in Montana; however, storage will be required to develop a dependable supply for any new uses. The average annual flow of the Little Bighorn River near Hardin, Montana, one-half mile upstream from the mouth, is 197,200 acre-feet.

# CHAPTER III

# GROUNDWATER RESOURCES

# G R O U N D W A T E R   R E S O U R C E S

## OCCURRENCE

The primary sources of groundwater are precipitation and the infiltration of surface water. The amount and distribution of underground storage space (porosity), the ability of the rock unit to transmit water (permeability), the depth to water, and the hydraulic gradient are characteristics which for the most part have been determined by past geologic environment.

Groundwater usually occurs as fluid filling the very small pore spaces in the sediment or rock. Sometimes it occurs as large enclosed pools below the water table, in solution cavities in limestone. If enough of the water-filled pores or cavities are interconnected, the saturated portion of the rock or sediment is an aquifer. Fractures can create excellent aquifers in rocks which otherwise would not effectively transmit water.

Figure III-1 is a map showing the generalized surface distribution of Quaternary, Tertiary, Cretaceous, and pre-Cretaceous (and the Cloverly) rock units. Also shown is the distribution of Precambrian rocks which make up the cores of the various mountain ranges bounding and transecting the report area. The Bighorn River Basin consists of several geologic basins. Figure III-2 shows the geologic basins referred to in this report.

Quaternary sediments (the youngest in geologic age) are the unconsolidated floodplain alluvium and terrace gravels found in stream valleys, sand dunes on the plains and foothills, glacial deposits at mountain elevations, and other deposits. Tertiary formations are consolidated sandstones and shales, and volcanics and associated rocks. The sandstones and shales make up the bulk of the basin floors between the major mountain ranges. The volcanics are at higher elevations and are found on the western limb of the drainage basin, north of the Owl Creek Mountains.

Older rocks (Cretaceous and pre-Cretaceous) flank the Tertiary cover east and south of the volcanics. Pre-Cretaceous formations are exposed between the Cretaceous rocks and the Precambrian mountain cores, and along the axes of breached and eroded anticlines (see Figure III-1).

The physical characteristics of the geologic formations or units are not consistent from one part of the report area to another. Table III-1 is a correlation of the geologic formations and rock units in the report area, based on subdivisions shown on Figure III-2. The geologic subdivisions used are Bighorn basin, Wind River basin, and Powder River basin. For the Cretaceous units, the Bighorn basin is subdivided into "North" and "South" in order to accommodate the regional geologic nomenclature as influenced by the petroleum industry. The drainage basin of the Little Bighorn River is in the geologic Powder River basin. Table III-2 lists the formation names, lithologies, and regional groundwater potentials of all the rock units identified in this report. The names are listed in alphabetical order. Figure III-3 shows the geologic basins and study areas superimposed on a physiographic map.

Figures III-1 and III-3 show the distribution of Tertiary volcanic rocks in the western part of the Bighorn basin. Little, if anything, is known about the groundwater potential of these rocks. The nature of these volcanic rocks reportedly is basic breccia, which suggests poor regional groundwater potential.

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WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE 10 0 10 20 30 40 Miles

## FIGURE III-1 SURFACE GEOLOGY MAP ILLUSTRATING REGIONAL GROUNDWATER POTENTIAL

(Generalized From the Geologic Map of Wyoming, 1955)

(1) NUMBERS REFER TO STUDY AREAS

Quaternary sediments – sand dunes, and glacial and landslide deposits [dotted pattern] are not considered to be reliable aquifers. Floodplain alluvium and terrace gravels [red] yield up to 2000+gpm from depths to 100+feet.

Tertiary formations – consolidated sandstones [blue diagonal lines] may yield up to 600+gpm from depths to 1,000+feet. The potential of volcanic and associated rocks [black diagonal lines] is not known.

Cretaceous formations [green dots] include sandstones which may yield up to ±350gpm from depths to 5,000+feet.

The Cloverly and pre-Cretaceous formations [blue brick pattern] include sandstone and limestone aquifers which may yield up to 3250+gpm from depths to 5,000+feet. Flowing artesian wells are possible.

Precambrian igneous rocks [> < pattern] are not normally aquifers.

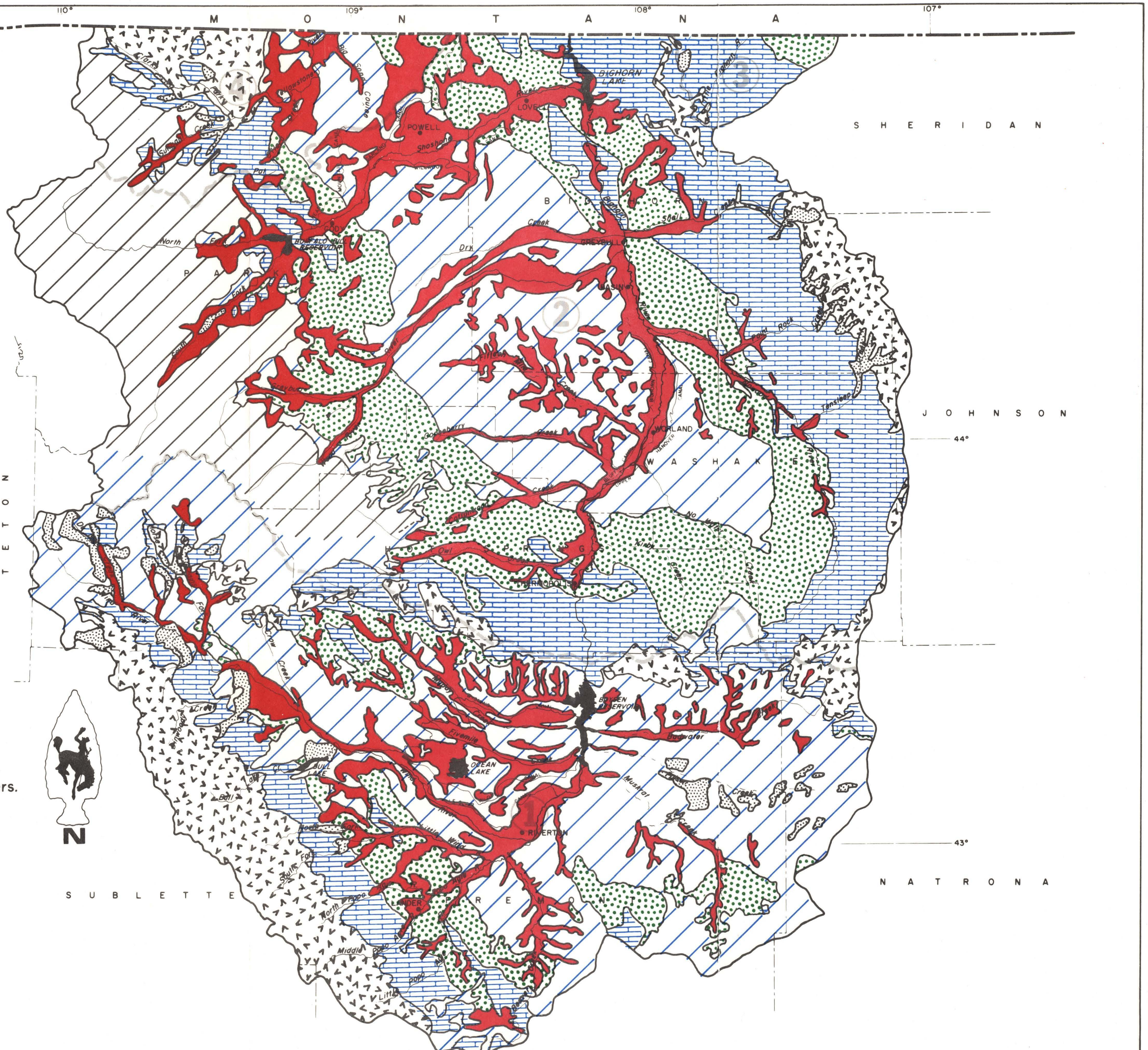


FIGURE III-1

TABLE III-1

Correlation and Thicknesses of Geologic Formations or Stratigraphic Units in the Bighorn River Basin
(The drainages of the Wind-Bighorn, Little Bighorn, and Clarks Fork Rivers)

Number in parenthesis refers to the reported maximum thickness of the unit, and is subject to revision.

| Time-Rock System | Time-Rock Series | Lithologic Unit or Formation: Bighorn Basin | Wind River Basin | Powder River Basin (Little Bighorn River drainage) |
|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | Floodplain alluvium, terrace deposits, glacial deposits, slope wash. (100) | Floodplain alluvium, terrace deposits, glacial deposits, windblown sand, travertine deposits. (65) | Floodplain alluvium, terrace deposits, landslide deposits. |
| Tertiary | Pliocene | Absent or unreported | Moonstone formation | Absent or unreported |
| | Miocene | Absent or unreported | Arikaree formation | Absent or unreported |
| | Oligocene | Volcanics and associated rocks; Wiggins formation (1,000+) | Wiggins formation (1,000+); White River formation | Absent or unreported (a/u) |
| | Eocene | Pitchfork formation; Wasatch formation: Tatman formation (870), Willwood formation (2,500) | Tepee Trail formation (1,500); Unnamed tuff (300+); Aycross formation (1,000+); Wagon Bed formation (700); Wind River formation (5,000): Lost Cabin member (300+), Lysite member (600+); Indian Meadows formation (3,000) | |
| | Paleocene | Polecat Bench formation (Fort Union formation) (1,500) [1] | Fort Union formation (7,000±): Shotgun member (2,800+), Waltman shale member (2,000+), Lower member | |

| Time-Rock System | Time-Rock Series | Bighorn Basin: North | Bighorn Basin: South | Wind River Basin | Powder River Basin |
|---|---|---|---|---|---|
| Cretaceous | Upper Cretaceous | Hell Creek formation (1,400) | Lance formation (1,800) | Lance formation (6,000) | Lance formation |
| | | Lennep (300); Bearpaw (1,000); Meeteetse formation | Meeteetse formation (1,150) | Meeteetse formation (1,300+); Lewis shale (550) | Fox Hills (500+); Bearpaw shale (900±) |
| | | Mesaverde group: Judith River (600); Parkman (300); Claggett shale (675); Eagle (250); Virgelle (140); Telegraph Creek (300); Elk Basin (50) | Mesaverde formation (1,400); Cody shale (3,500) | Mesaverde formation (1,575); Cody shale (5,000) [2] | Mesaverde: Teapot sandstone (50±), Parkman sandstone (500+); Sussex sandstone (40±); Shannon sandstone (200±); Steele shale; Cody shale (3,750) |
| | | Cody shale (1,500) | | Niobrara shale | Niobrara shale (985±) |
| | | Torchlight sandstone (50±); Frontier formation (500+); Peay sandstone | Frontier formation (450+): Torchlight (25+); Peay sandstone (60) | Carlile shale; Frontier formation (1,000+) | Carlile shale; Frontier formation (900): "1st", "2nd", "3rd Wall Creek sand" |
| | Lower Cretaceous | Mowry shale (1,000) [3] | Mowry shale (400); Shell Creek shale | Mowry shale (700+) | Mowry shale (525) |
| | | Muddy sandstone | Muddy sandstone (100) | Muddy sandstone (100) | Muddy sandstone (100) |
| | | Thermopolis shale | Thermopolis shale (575) [4] | Thermopolis shale (250) [4] | Thermopolis shale (250) |
| | | Cloverly: Dakota; Greybull; Greybull (50); Fuson (Kootenai); Lakota sandstone (100) | ? Rusty beds; Cloverly formation (300) [5] | Cloverly formation (700) [6] | Cloverly: Fall River (200); Fuson shale (100); Lakota (300) — Inyan Kara |

TABLE III-1 -- continued

| Time-Rock System | Lithologic Unit or Formation: Bighorn Basin, North | Bighorn Basin, South | Wind River Basin | Powder River Basin (Little Bighorn River drainage) |
|---|---|---|---|---|
| Jurassic | Morrison formation | | Morrison formation | Morrison formation (235) |
| | Sundance (375): Upper Sundance | | Sundance (435): Upper Sundance | Sundance (350+): Upper Sundance |
| | Lower Sundance | | Lower Sundance | Lower Sundance |
| | Gypsum Spring (200) | | Gypsum Spring (230) | Gypsum Spring (150) |
| | Absent or unreported | Nugget sandstone (10) | Nugget sandstone (425) | Absent or unreported |
| Triassic | Chugwater (600±) | Chugwater: Popo Agie (200) [7] | Chugwater group (1,300): Popo Agie | Chugwater group (1,000): Popo Agie (150) |
| | | Crow Mountain | Crow Mountain | Crow Mountain (100) |
| | | Alcova (3) | Alcova | Alcova (20) |
| | | Red Peak shale (1,000) | Red Peak shale | Red Peak shale (1,250) |
| | Embar formation (250): Dinwoody formation (75) | | Dinwoody formation (155) | Goose Egg (250) [8]: Ervay |
| Permian | Phosphoria (Park City) formation | Phosphoria formation / Park City formation | Park City / Phosphoria (300); Goose Egg formation (300) | Forelle limestone |
| | | | | Glendo shale |
| | | | | Minnekahta limestone |
| | | | | Opeche shale |
| Pennsylvanian | Tensleep sandstone (380) | | Tensleep sandstone (Casper formation) (900) [9] | Tensleep sandstone (400+) |
| | Amsden formation (350) [10] | | Amsden formation | Amsden formation (300) |
| | Darwin sandstone | | Darwin sandstone | Darwin sandstone |
| Mississippian | Madison limestone (1,000) | | Madison limestone (700) | Madison limestone (1,100±) |
| Devonian | Three Forks | Three Forks (100) | Darby formation (300) | Darby formation (200) |
| | Duperow (Jefferson) | Jefferson (25) | | |
| | ? | | | ? |
| | Beartooth Butte | Absent or unreported | | Beartooth Butte |
| Silurian | Absent or unreported | | Absent or unreported | Absent or unreported |
| Ordovician | Leigh dolomite | | Bighorn dolomite (200) | Bighorn dolomite (450+) |
| | Bighorn dolomite (425) [11] | | | Lander sandstone (10) |
| | Lander sandstone | | | Harding sandstone (40+) |
| Cambrian | Gallatin group (200+) | Boysen: Grove Creek; Snowy Range; Maurice — Deadwood formation (1,275+) | Gallatin (Grove Creek) limestone (1,200) [12] | Gallatin limestone (1,100) [12] |
| | Gros Ventre (600+) | Depass: Gros Ventre | Gros Ventre formation | Gros Ventre formation |
| | Flathead (400 +) | Flathead | Flathead sandstone | Flathead sandstone |
| Precambrian | | | | |

1 The Fort Union reportedly attains a thickness of 8,500 feet in the Montana portion of the Bighorn basin.

2 Probably includes thicknesses of the Carlile and Niobrara shales.

3 Includes thicknesses of the Muddy sandstone and the Thermopolis shale.

4 Includes the thickness of the Muddy sandstone.

5 Reportedly includes the thicknesses of the Rusty beds and the Morrison formation.

6 Includes the thickness of the Morrison formation.

7 May include the thickness of the Crow Mountain sandstone.

8 The Goose Egg thickness refers to the Permian-age part of the unit.

9 Includes thicknesses of the Amsden formation and the Darwin sandstone.

10 Includes the thickness of the Darwin sandstone.

11 Thickness of the entire Ordovician interval.

12 Thickness of the entire Cambrian interval.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE
10 0 10 20 30 40 Miles

## FIGURE III-2
## GEOLOGIC BASINS & STUDY AREAS

NUMBERS REFER TO STUDY AREAS

**1** *WIND RIVER*
- 1a *Upper Wind River*
- 1b *South Wind River Tributaries*
- 1c *North Wind River Tributaries*
- 1d *Main Stem Wind River*
- 1e *East Wind River Tributaries*

**2** *BIGHORN RIVER*
- 2a *Main Stem Bighorn River*
- 2b *East Bighorn River Tributaries*
- 2c *Nowood River*
- 2d *Shell Creek*
- 2e *Bighorn Lake Tributaries*
- 2f *West Bighorn River Tributaries*
- 2g *Upper Greybull River*
- 2h *Lower Greybull River*
- 2i *Upper Shoshone River*
- 2j *Lower Shoshone River*

**3** *LITTLE BIGHORN RIVER*

**4** *CLARKS FORK*

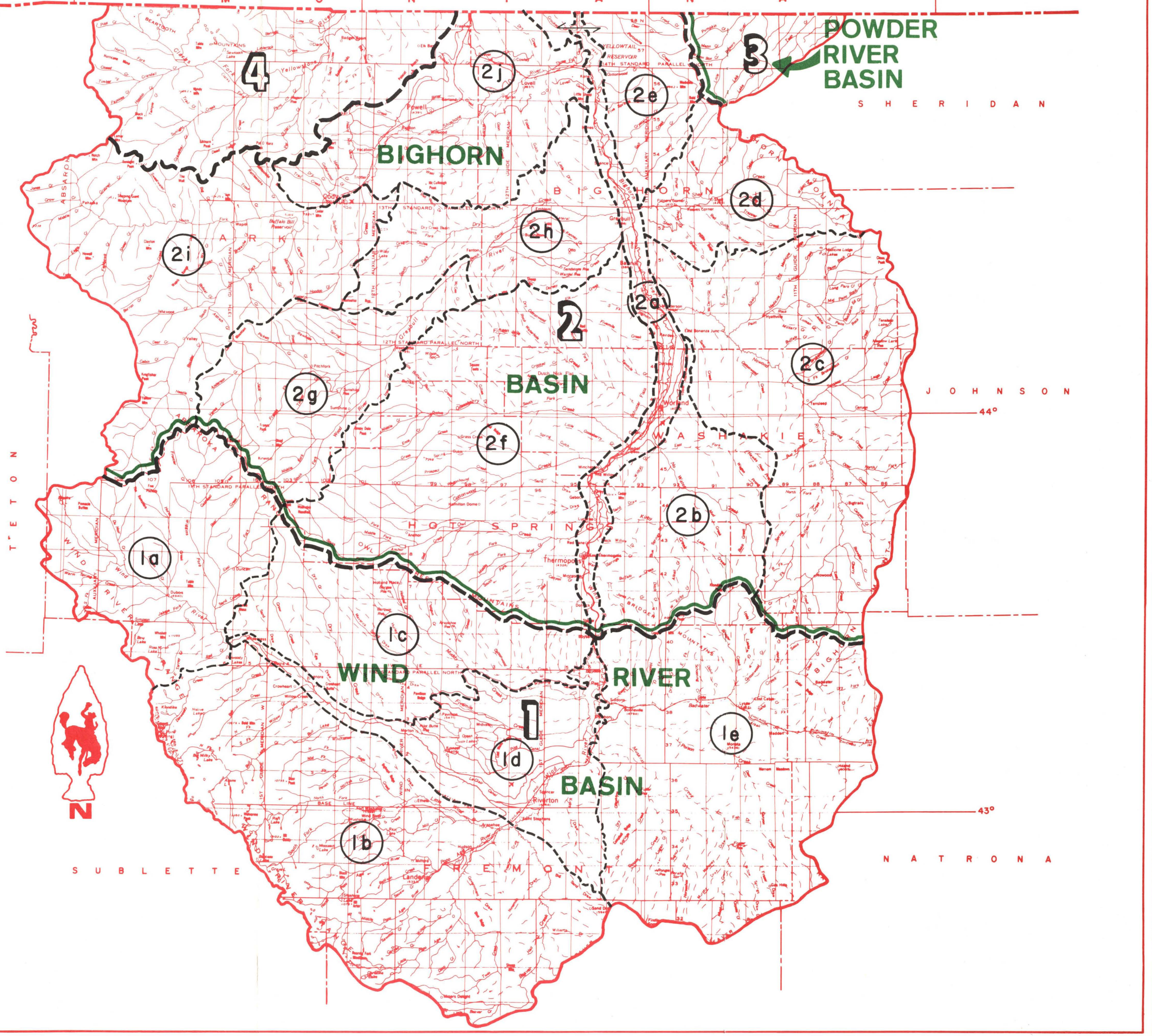


FIGURE III-2

TABLE III-2 -- Alphabetical Listing of Formations and Rock Units Correlated and/or Mentioned in the Report

| Formation or Unit | Age | Lithology[1] | Groundwater Potential[2] |
|---|---|---|---|
| Alcova limestone member | Triassic | Cream to gray limestone. | Probably poor. |
| Alluvium | Recent and Pleistocene | Unconsolidated sand, silt, clay, and gravel, found in stream valleys (floodplains) and on terraces; includes glacial deposits, slope wash, landslide deposits, and windblown sand. | Floodplain alluvium and terrace deposits yield water to wells; yields are in the range 10-1,200 gpm. |
| Amsden formation | Pennsylvanian | Red shales, white limestones, cherty and sandy limestones, and dolomitic sandstones. | May yield small to moderate supplies. |
| Arikaree formation | Miocene | Tuffaceous sandstone and conglomerate. If present, found only in the vicinity of the Beaver Divide. | Normally a significant aquifer; not significant here due to its very limited extent (or absence). |
| Aycross formation | Eocene | Volcanic conglomerate, tuffaceous sandstone and claystone, present in northwestern part of the Wind River basin. | Unknown potential, but probably would yield water to wells. |
| Bearpaw shale | Upper Cretaceous | Dark clay shale with many calcareous concretions. | Not normally an aquifer. |
| Beartooth Butte formation | Devonian | Reportedly "channel fill" deposits in older formations. | Unknown, but probably poor. |
| Bighorn dolomite | Ordovician | Light gray massive dolomite and limestone. | Moderate yields reported near the Big Horn Mountains. |
| Boysen formation | Cambrian | Mostly green and gray shales and limestones with some intraformational conglomerates. | Unknown; similar to potential of Gallatin limestone. |
| Carlile shale | Upper Cretaceous | Gray shale, sometimes having a thin purplish limestone or a thicker yellow sandstone at the top. | Not normally an aquifer. |
| Casper formation | Pennsylvanian | In part of the Wind River basin, equivalent to the Tensleep sandstone; light colored sandstone. | Same as Tensleep sandstone-may yield large supplies to wells. |
| Chugwater formation or group | Triassic | Red siltstone and red sandy shale, with red sandstone, gypsum, and persistent thin Alcova limestone at top. | Sandstone may yield water to wells. Across State line, in Montana, Chugwater hosts large-yield springs and wells. |
| Claggett shale | Upper Cretaceous | Light gray shale and sandstone. | Not normally an aquifer, but sandstone within the formation may yield water. |
| Cloverly formation or group | Lower Cretaceous | Sandstone, siltstone, and shale. | May yield small to moderate supplies to wells. |
| Cody shale | Upper Cretaceous | Gray and dark gray shale with sandstone beds and lenses. | The shale is not normally an aquifer, although small yields may be possible from the sandstone. |
| Crow Mountain sandstone | Triassic | Sandstone, gray to orange and reddish brown, poorly sorted. | Probably would yield small amounts water to wells. |
| Dakota sandstone | Lower Cretaceous | Light colored fine grained sandstone approximately equivalent to the Fall River sandstone. | May yield small amounts of water to wells. |
| Darby formation | Devonian | Varicolored shale, dolomitic limestone, and sandstone. | Unknown. |
| Darwin sandstone | Pennsylvanian | Cream colored sandstone at the base of the Amsden formation. | Probably would yield small to moderate amounts of water to wells. |
| Deadwood formation | Cambrian | Equivalent to entire sequence of Cambrian rocks. | Probably would yield water to wells locally; large flowing yields possible. |
| Depass formation | Cambrian | The interfingering sandstones of the Flathead and shales of the Gros Ventre considered as one unit. | Flathead sandstones probably would yield water locally. |
| Dinwoody formation | Triassic | Predominantly red shale with numerous thin plates of dense calcareous sandstone or argillaceous dolomite. | Not normally an aquifer. |
| Duperow formation | Devonian | Equivalent to dolomitic limestone interval of the Darby formation. | Probably poor to fair potential. |
| Eagle sandstone or formation | Upper Cretaceous | Shaly sandstone, and buff colored massive sandstone at top, a tan or white medial soft sandstone, and a basal unit consisting of a massive gray-white sandstone or thinly laminated sandstone. | Locally capable of small to moderate yields; yields in excess of 300 gpm have been reported in Montana. |
| Elk Basin sandstone | Upper Cretaceous | Local basal member of the Telegraph Creek formation. | Potential for small to moderate well yields. |
| Embar formation | Permian and Triassic | Limestone/dolomite, commonly cherty, anhydritic, with red and green shale. | Poor potential, if any (might yield small amounts of mineralized water). |
| Ervay limestone tongue | Permian | Thin bedded limestone. | Not normally an aquifer. |
| Fall River sandstone | Lower Cretaceous | Sandstone consisting almost wholly of quartz grains, interbedded with shale and containing iron concretions ("rusty beds"). | Locally has fair potential. |
| Flathead sandstone or member | Cambrian | Sandstone or quartzite. | Locally has a potential for small to large yields. |
| Forelle limestone tongue | Permian | Limestone, at times gypsiferous and thin bedded. | Not normally an aquifer. |
| Fort Union formation | Paleocene | Clay and sand, numerous beds and seams of coal and lignite. | Yields small supplies to wells; potential for yields of 100± gpm. |
| Fox Hills sandstone | Upper Cretaceous | Gray, yellow-tan sandstone with clay layers. | Yields water to wells elsewhere in Wyoming; yields generally are small. |
| Frontier formation | Upper Cretaceous | Alternating beds of "salt and pepper" sandstone and beds of dark gray shale. | Sandstones may be water bearing. |
| Fuson formation or shale | Lower Cretaceous | Massive shales and clays, variegated or black, with varying amounts of sandstone. | Sandstone within this unit may yield small to moderate amounts of water to wells. |

TABLE III-2 -- continued

| Formation or Unit | Age | Lithology[1] | Groundwater Potential[2] |
|---|---|---|---|
| Gallatin limestone or member | Cambrian | Brownish yellow pebbly limestone, red-pink shale, with shaly calcareous sandstone, mottled limestone and greenish shale. | Unreported, but may yield small amounts of water to wells. |
| Glendo shale | Permian | Red shale and gray brecciated limestone, with red, sandy shale. | Probably poor if any potential. |
| Goose Egg formation | Permian and Triassic | Red and ochre anhydritic sandy shale and siltstone, with thin limestone and dolomite members or tongues. | May yield small amounts of water from porous and permeable members. |
| Greybull sandstone or member | Lower Cretaceous | Light colored fine-to medium-grained sandstone. | Potential for small to moderate yields. |
| Gros Ventre formation or member | Cambrian | Greenish gray calcareous shale with gray stripes, and conglomeratic and oolitic limestone, partly glauconitic. | Unknown, but probably poor. |
| Grove Creek limestone or member | Cambrian | Equivalent to the Gallatin limestone. | Potential similar to that of the Gallatin limestone. |
| Gypsum Spring formation | Jurassic | Red shale and siltstone, massive gypsum and dolomite. | Unknown, but probably poor potential. |
| Harding sandstone | Ordovician | White, yellow, tan, medium-to coarse-grained sandstone, massive, limey at the top; and shale. | Unknown. |
| Hell Creek formation | Upper Cretaceous | Alternating sandstone and clay shale. | Small to moderate well yields possible. |
| Indian Meadows formation | Eocene | Sandstone and interbedded shale, siltstone, and clay. Sandstone is light colored, finer grained constituents are variegated. | Probably poor potential; wells not known to tap this unit, but yields up to 50 gpm may be possible (7). |
| Inyan Kara group | Lower Cretaceous | A variable group of discontinuous beds of sandstone, sandy shale, conglomerate, lignite, and variegated siltstone. | Potential for small to moderate well yields. |
| Jefferson limestone or dolomite | Devonian | Brown to dark gray to black crystalline limestone or dolomite. | Unknown; probably fair potential. |
| Judith River sandstone | Upper Cretaceous | Alternating beds of sandstone and shale. | Well yields of 1-40 gpm are reported across the State line in Montana. |
| Kootenai formation | Lower Cretaceous | Varicolored shales, sandstone, and chert conglomerate; equivalent to Fuson. | Sandstone may yield water to wells. |
| Lakota sandstone or conglomerate | Lower Cretaceous | Massive, coarse-grained, cross-bedded sandstone, often conglomerate and containing chert pebbles and iron concretions. Lateral continuity not persistent. | Usually yields moderate, sometimes large, amounts of water to wells. |
| Lance formation | Upper Cretaceous | Thick-to thin-bedded gray to buff sandstone and gray to brown shale. | Small to moderate yields possible. |
| Lander sandstone | Ordovician | A thin, fine grained yellow sandstone at the base of the Bighorn dolomite. | Unknown. |
| Leigh dolomite | Ordovician | Light colored dolomite at the top of the Bighorn dolomite. | Unknown, but probably similar to potential of the Bighorn dolomite. |
| Lennep sandstone | Upper Cretaceous | Dark colored sandstone and interbedded shale. | Probably poor, but may yield small amounts of water to wells. |
| Lewis shale | Upper Cretaceous | Sandy shale and clay of gray or drab color. | Probably poor potential, if any. |
| Lost Cabin member | Eocene | Shale and sandstone, equivalent to the upper part of the Wind River formation. | Unknown, but probably fair potential. |
| Lower member | Paleocene | Refers to basal part of Fort Union formation. | Probably fair potential. |
| Lower Sundance | Jurassic | Fine-grained, pink to gray sandstone, oolitic limestone, and gray to green shale. | Sandstone may yield small amounts of water to wells. |
| Lysite member | Eocene | Yellowish and gray sandy shale and boulders, buff sandstone and red and blue-gray shale, and gypsum; equivalent to the lower part of the Wind River formation. | Sandstone may yield small to large amounts of water to wells. |
| Madison limestone | Mississippian | Nearly white to grayish brown, massive to thin bedded, partly cherty limestone and dolomite. | Potential varies; yields from 10 to 2,500 gpm are reported, some flowing. |
| Maurice member | Cambrian | Basal member of the Boysen formation (Gallatin limestone). | Unknown. |
| Meeteetse formation | Upper Cretaceous | Argillaceous sandstone, sandy shale, brown carbonaceous shale, and lenticular coal near top. | Sandstone may yield small water supplies to wells. |
| Mesaverde formation or group | Upper Cretaceous | Sandstone, gray to black carbonaceous shale and coal. | Sandstone may yield small water supplies to wells. |
| Minnekahta limestone | Permian | Thin-bedded gray limestone. | Not normally an aquifer, but may yield highly mineralized water. |
| Moonstone formation | Pliocene | Claystone, shale and tuffaceous sandstone; some conglomerate and limestone. If present, areal extent confined to vicinity of Beaver divide. | If present, reportedly can yield small supplies of good water to stock and domestic wells. |
| Morrison formation | Jurassic | Clay shale of mostly dull and drab colors, with lesser amounts of variegated shale. Sandstone, siltstone, and thin limestone are present. | Yields of 20 gpm are reported in the Wind River basin.[3] |
| Mowry shale | Lower Cretaceous | Dark gray siliceous shale and claystone, containing thin bentonite beds. | Not normally an aquifer, although known to yield water to wells elsewhere in Wyoming. |
| Muddy sandstone | Lower Cretaceous | White lenticular sandstone, sometimes glauconitic. | Yields to 20 gpm to wells elsewhere in Wyoming. |

TABLE III-2 -- continued

| Formation or Unit | Age | Lithology[1] | Groundwater Potential[2] |
|---|---|---|---|
| Niobrara shale | Upper Cretaceous | Gray shale and yellowish-white limestone. | Not normally an aquifer. |
| Nugget sandstone | Jurassic | Fine- to medium-grained sandstone, absent from much of the Basin. | Probably would yield small to moderate water supplies to wells. |
| Opeche shale | Permian | Red to deep purple shale, sandy shale, and local gypsum beds. | Not normally an aquifer. |
| Park City formation | Permian | Interbedded dolomite, chert, limestone, siltstone, and sandstone, with minor amount shale. | Might yield small supplies of mineralized water. |
| Parkman sandstone | Upper Cretaceous | Soft massive buff sandstone with harder, darker concretions. | Probably would yield small amounts of water to wells. |
| Peay sandstone | Upper Cretaceous | Light gray and light brown sandstone in the lower part of the Frontier formation. | Probably would yield small amounts of water to wells; water could be mineralized. |
| Phosphoria formation | Permian | Dolomite, chert, limestone, siltstone, sandstone, with phosphate beds or lenses. | Might yield small supplies of mineralized water. |
| Pitchfork formation | Eocene (and Oligocene?) | Equivalent in part to volcanics and associated rocks, and in part to the Wasatch formation. | Unknown. |
| Polecat Bench formation | Paleocene | Equivalent to the Fort Union formation. | Similar to the potential of the Fort Union formation. |
| Popo Agie member | Triassic | Interbedded red to ochre colored oolitic and dolomitic claystone, limestone pellet conglomerate and red to purple siltstone and shale. | Not normally an aquifer. |
| Precambrian | | Igneous and metamorphic rocks. | Recharge areas. |
| Red Peak shale | Triassic | Brick red shale, siltstone, and sandy siltstone with beds of white gypsum. | Not normally an aquifer. |
| Rusty beds | Lower Cretaceous | Eqivalent to Dakota or Fall River sandstone (may also include basal part of Thermopolis). | Potential similar to that of equivalent sandstones. |
| Shannon sandstone | Upper Cretaceous | Fine-grained sandstone, often with dark gray shale interbeds. | Probably would yield small amounts of water to wells. |
| Shell Creek shale | Lower Cretaceous | A soft shale at the base of the Mowry. | Not normally an aquifer. |
| Shotgun member | Paleocene | Equivalent to upper part of the Fort Union formation. (Approximate equivalent of the Tongue River sandstone.) | Potential for yields to 100+ gpm. |
| Snowy Range member | Cambrian | Middle member of the Boysen formation (Gallatin limestone). | Unknown. |
| Steele shale | Upper Cretaceous | Dark shale with thin beds of sandstone. | Sandstone beds within the shale may yield small amounts of water to wells. |
| Sundance formation | Jurassic | Sandstone, shale, and limestone. | May yield small amounts of water to wells. |
| Sussex sandstone | Upper Cretaceous | Light greenish-gray fine-grained sandstone. | Probably would yield small amounts of water to wells. |
| Tatman formation | Eocene | Yellow shale, yellow-brown and gray sandstone, much lignite. Equivalent to upper part of Wasatch formation. | May yield small amounts of water to wells, if not above the water table. (Not water-bearing in vicinity of Greybull River-Dry Creek area.) |
| Teapot sandstone | Upper Cretaceous | Gray sandstone and carbonaceous shale. | May yield small amounts of water to wells locally. |
| Telegraph Creek formation | Upper Cretaceous | Yellow sandy shale and basal sandstone. | Basal sandstone may yield small to moderate supplies to wells. |
| Tepee Trail formation | Eocene | Interbedded sandstone, conglomerate and tuff. Present in northwestern part of Wind River basin. | Would probably yield small amounts of water to wells. |
| Tensleep sandstone | Pennsylvanian | Massive, medium-grained, cross-bedded, tan to gray sandstone with interbedded thin, cherty, dolomite and limestone. | Yields of 20-1,000+ gpm reported. |
| Thermopolis shale | Lower Cretaceous | Dark colored shale containing one or more lenticular sandstones. Shale contains uranium minerals in the Gas Hills area. | Sandstone may yield small amounts of water to wells. |
| Three Forks shale | Devonian | Dark dolomitic shale and argillaceous dolomite. | Not normally an aquifer. |
| Torchlight sandstone | Upper Cretaceous | Light gray to white sandstone, often strongly cross-bedded, at the top of the Frontier formation. (The South Byron sandstone may be present above the Torchlight in the subsurface near the State line.) | Usually has sufficient porosity and permeability to be water-bearing or oil-bearing. |
| Travertine deposits | Recent and Pleistocene | Spring deposits associated with dissected high terraces west of Bull Lake along northeast slope of the Wind River Mountains (7). | Commonly associated with springs, and may yield water locally to springs (7). |
| Unnamed tuff | Eocene | Fine- to coarse-grained volcanic conglomerate, with some limestone, yellow-green, green, olive, and gray. Present along the north-central margin of the Wind River basin. This unit probably is contemporaneous in part to the Tepee Trail formation. | Largely drained because of topographic position. Where the unit contains water, yields of as much as 50 gpm may be possible (7). |
| Upper Sundance | Jurassic | Glauconitic greenish shale, calcareous sandstone, and thin limestone layers. | May yield small amounts of water to wells. |
| Virgelle sandstone | Upper Cretaceous | Gray coarse-grained massive sandstone, cross-bedded. | Yields small to moderate amounts of water to wells across the State line in Montana. |

TABLE III-2 -- continued

| Formation or Unit | Age | Lithology[1] | Groundwater Potential[2] |
|---|---|---|---|
| Volcanics and associated rocks | Oligocene (and Eocene?) | Pyroclastic rocks; volcanic conglomerate and tuffaceous claystone. | Reportedly do not yield water, or yield water sparingly. Fractures and joint cracks probably would yield water. |
| Wagon Bed formation | Eocene | Bentonitic mudstone, locally tuffaceous, sandstone, and volcanic sandstone and conglomerate. Present in south-eastern part of Wind River basin. | Would probably yield at least small, and possibly large supplies, from sandstone and conglomerate. |
| "Wall Creek sand" | Upper Cretaceous | One of several buff colored sandstones of the Frontier formation. | Sandstones yield small amounts of water (5-40 gpm) locally. |
| Waltman shale member | Paleocene | Middle member of the Fort Union formation. | Would not normally be considered an aquifer. |
| Wasatch formation | Eocene | Sandstone and claystone, locally conglomeratic. | Known to yield 5-40 gpm from the Willwood member. |
| White River formation | Oligocene | Bentonitic and tuffaceous mudstone; lenses of arkose and conglomerate; beds of tuff. Present along the Beaver Divide. | Known to yield water to many wells elsewhere in the State. Potential in subject area poor at best due to restricted distribution. |
| Wiggins formation | Oligocene | Tuffs interbedded with volcanic conglomerate. Present in northwestern part of Wind River basin. | Yields small supplies to wells. |
| Willwood formation or member | Eocene | Variegated shale, numerous beds of white and yellow sandstone and locally abundant beds of conglomerate. | Yields of 5-40 gpm reported. |
| Wind River formation | Eocene | Interbedded siltstone, sandstone and conglomerate. Hosts uranium minerals. | Yields up to 600 gpm reported. |

1 Taken from references listed in the bibliography.

2 The nomenclature commonly used by the U. S. Geological Survey is referred to: A small yield is up to 50 gpm; a moderate (fair) yield is 51 to 350 gpm; a large (good) yield is more than 350 gpm. Good potential means a large yield would be anticipated; fair potential means a moderate yield would be anticipated.

3 Some earlier reports list the Morrison as yielding large amounts of water. This usually indicates that the Morrison formation of those reports includes the Lakota sandstone.

## QUALITY OF GROUNDWATER

Groundwater generally is classified, as to chemical constituents, by the amount of total dissolved solids in parts per million (ppm).[1] The U. S. Geological Survey uses U. S. Public Health Service standards (1962) for interstate common carriers (3) as a guide for evaluating the suitability of domestic supplies. According to public health standards, good drinking water for humans contains no more than 500 ppm total dissolved solids. If no better water is available, not more than 1,000 ppm total dissolved solids is the upper limit for acceptable drinking water.

Animals reportedly can become accustomed to highly mineralized water. According to some investigators, water with less than 1,000 ppm total dissolved solids is considered good for stock; 1,000 to 3,000 ppm is fair, 3,000 to 5,000 ppm is poor but usable, 5,000 to 7,000 ppm is very poor and of questionable use, and more than 7,000 ppm is not advisable.

According to the 1962 standards, the following substances should not be present in humans' drinking water in amounts greater than those shown:

| Substance | Concentration (mg/l) | Substance | Concentration (mg/l) |
|---|---|---|---|
| Arsenic | 0.05 | Silver | 0.05 |
| Barium | 1.0 | Fluoride | 0.8-1.7 (upper limit, depending on annual average of maximum daily air temperatures, °F) |
| Cadmium | 0.01 | | |
| Chromium | 0.05 | | |
| Cyanide | 0.2 | | |
| Lead | 0.05 | | |
| Selenium | 0.01 | | |

An excessive amount of any of these is a basis for rejection of the supply.

1 More recently also in milligrams per liter (mg/l).

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE
10 0 10 20 30 40 Miles

## FIGURE III-3
## PHYSIOGRAPHY, GEOLOGIC BASINS AND STUDY AREAS

NUMBERS REFER TO STUDY AREAS

**1** *WIND RIVER*
- 1a *Upper Wind River*
- 1b *South Wind River Tributaries*
- 1c *North Wind River Tributaries*
- 1d *Main Stem Wind River*
- 1e *East Wind River Tributaries*

**2** *BIGHORN RIVER*
- 2a *Main Stem Bighorn River*
- 2b *East Bighorn River Tributaries*
- 2c *Nowood River*
- 2d *Shell Creek*
- 2e *Bighorn Lake Tributaries*
- 2f *West Bighorn River Tributaries*
- 2g *Upper Greybull River*
- 2h *Lower Greybull River*
- 2i *Upper Shoshone River*
- 2j *Lower Shoshone River*

**3** *LITTLE BIGHORN RIVER*

**4** *CLARKS FORK*

*Axis of deep or deepest part of basin*

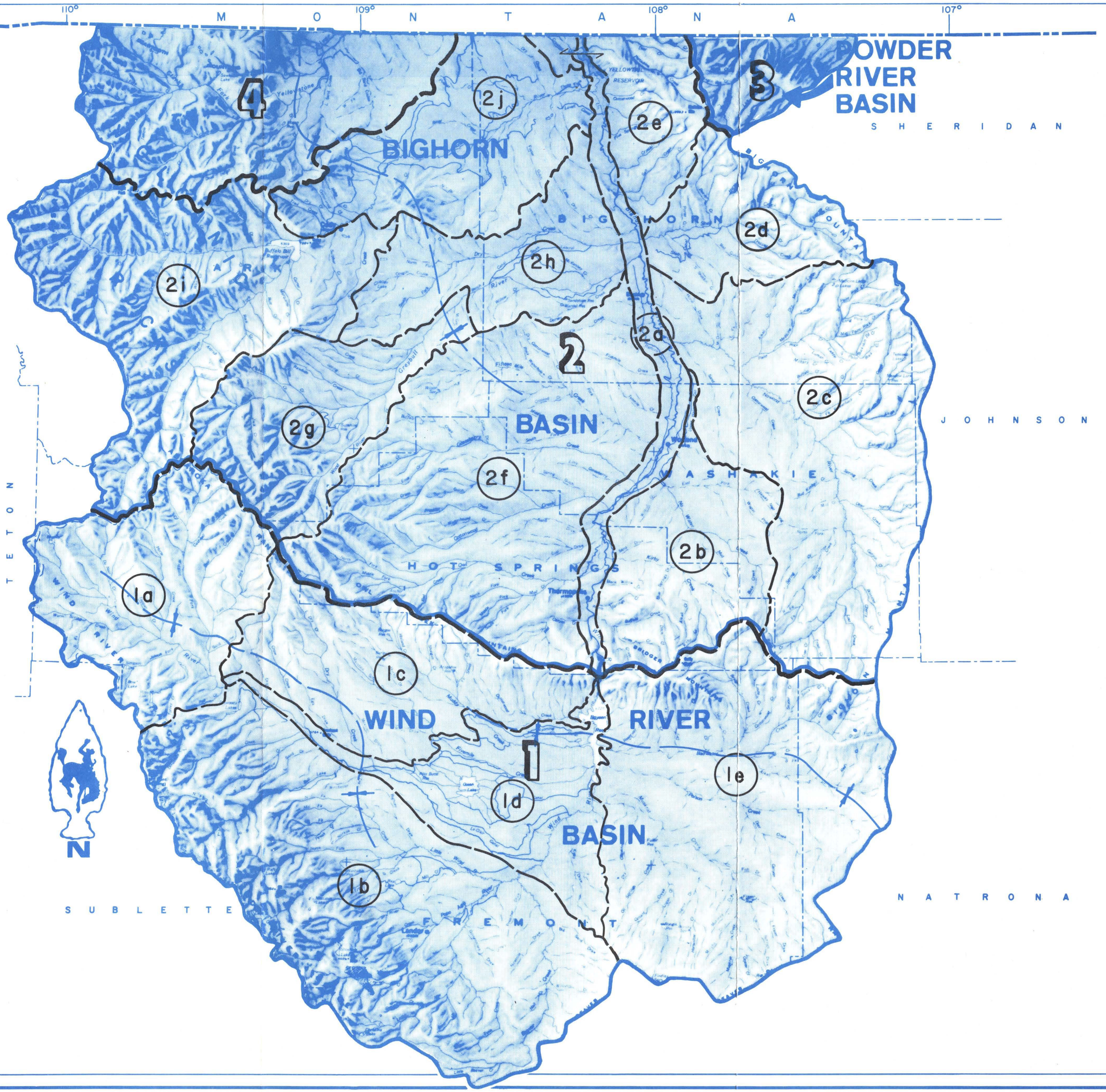


FIGURE III-3

If the water is acceptable on the basis of the preceding, a second set is considered. These are to be complied with unless no better supply is available (3):

| Substance | Concentration (mg/l) | Substance | Concentration (mg/l) |
|---|---|---|---|
| Alkyl benzene sulfonate (a synthetic detergent formerly in common use) | 0.5 | Iron | 0.3 |
| Arsenic | 0.01 | Manganese | 0.05 |
| Chloride | 250 | Nitrate | 45 |
| Copper | 1 | Phenols | 0.001 |
| Carbon chloroform extract (a measure of the total concentration of organic solutes) | 0.2 | Sulfate | 250 |
| Cyanide | 0.01 | TDS | 500 |
| | | Zinc | 5 |
| | | Fluoride | 0.7-1.2 (optimum, depending on temperature) |

The U. S. Salinity Laboratory classifies irrigation water according to its salinity and sodium hazard. As a rule, the higher the salinity, the less suitable the water is for irrigation, because the application of such water tends to add salts to the soil. Because salinity is directly related to its specific conductance, the following classification has been established (3):

| Salinity hazard | Specific conductance (micromhos per centimeter) |
|---|---|
| Low | 100-250 |
| Medium | 250-750 |
| High | 750-2,250 |
| Very High | greater than 2,250 |

Specific conductance is a measure of the ability of a solution to conduct electrical current. It is related to the amount of total dissolved solids. Water that is chemically pure has a very low conductance. As the concentration of dissolved material increases, the electrical resistance of the water decreases and the electrical conductance increases. Natural waters are not simple solutions and the conductance determination does not have a direct relationship to total dissolved solids (unless the water is a dilute solution of a single salt). Usually the ratio of dissolved solids in ppm (mg/l) to specific conductance in micromhos per centimeter at 25° C ranges from 0.55 to 0.75 (3). Because conductance is the reciprocal of resistance, the unit in which specific conductance is reported is the reciprocal ohm, or mho. Natural waters have specific conductances much less than 1 mho, and to avoid inconvenient decimals, data are reported in micromhos (mhos multiplied by a million).

The sodium hazard is directly related to the sodium adsorption ratio (SAR). For water whose specific conductance is 750, the following approximate relations between the SAR and sodium (alkali) hazard exist:

| SAR (approx.) | Sodium hazard |
|---|---|
| 0-10 | Low |
| 10-18 | Medium |
| 18-26 | High |
| more than 26 | Very high |

The sodium hazard increases as specific conductance increases, even though the SAR value remains constant. Water in which the percentage of sodium[2] is appreciably greater than 50 percent is of limited suitability for irrigation.

Hardness is a quality of water which influences the use of water for a specific purpose. Expressed as equivalent amounts of calcium carbonate, water that has less than 60 ppm is considered soft; 60 to 120 ppm is moderately hard; 120 to 200 ppm is hard; and more than 200 ppm is very hard.

Another quality consideration is the amount of sediment that is pumped with the water. Sand pumping reduces the efficiency of a well and causes premature abandonment, which results in excess water costs because of the necessity to replace wells. Unconsolidated aquifers and sandstones in some of the consolidated aquifers have loose sands that may result in the pumping of sand from wells. Sand pumping can be controlled by properly constructing wells with casings, gravel packs, and well screens when needed.

Chemical analyses given in Table III-3 show only chemical character and not sanitary quality. A discussion of the data is given in the next section of this chapter. Water quality (chemical) is attributed to the source of the groundwater, soluble minerals in the host material, the rate of percolation, and man's use of the land and the subsurface. The chemical nature of groundwater is influenced by many environmental factors. Climate and the composition of the soil and rock strata are two important factors influencing the quality of groundwater. Shales and clays may contribute large amounts of soluble minerals to water passing over or through the material, and groundwater that is withdrawn or discharges from aquifers in shales or clays usually has a very high amount of total dissolved solids. Other geologic factors, such as texture and porosity, and regional structure also influence the quality of the groundwater. A closely related factor is the proximity of the outcrop (recharge) area to the site of groundwater withdrawal or discharge.

Climate strongly influences the solution of minerals in the soil which eventually reach the water table, causes the concentration of dissolved minerals by evaporation, and greatly influences the natural movement of water, both into and out of aquifers, through resulting changes in natural surface water flows.

## AVAILABILITY OF GROUNDWATER

Sedimentary deposition and structural configuration control the occurrence of groundwater and therefore greatly influence its availability. Bedrock aquifers have much more water in storage than the unconsolidated aquifers. This is due to the great thicknesses and extent of the consolidated aquifers, compared to the relatively thin unconsolidated aquifers of limited extent. The unconsolidated aquifers, however, usually have greater porosities and permeabilities than consolidated aquifers, and yield water to wells and accept recharge more readily. Even so, the greatest well yields are reported from the Flathead formation, the Madison limestone, the Tensleep sandstone, and the Wind River formation. The availability of groundwater by major study areas is tabulated in Table III-4.

It is estimated that as much as 928,000 acre-feet of groundwater are available to wells from the unconsolidated floodplain alluvium in the report area. By major

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[2] Related to total concentration of calcium, magnesium, and sodium-potassium.

TABLE III-3 -- Chemical Analyses of Groundwater - Reported in Publications of the U. S. Geological Survey and in <u>Rocky Mountain Oil Field Waters</u> (by James G. Crawford, Chemical & Geological Laboratories of Casper, Wyo.)

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$: Calcium, Magnesium | Hardness as $CaCO_3$: Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALLUVIUM** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 34-1N-1E | 0-28 | 1b | 11/2/66 | -- | 15 | --- | -- | 157 | 63 | 223 | -- | 9.9 | 404 | 0 | 732 | 20 | 1.0 | 0.3 | 0.66 | 1,460 | 650 | 319 | -- | 3.8 | 1,860 | 7.8 |
| 3-1N-2E | 41 | 1d | 10/15/48 | 49 | 24 | 0.14 | -- | 48 | 11 | 28 | -- | 2 | 202 | 0 | 47 | 5 | .3 | .8 | .07 | 256 | 165 | 0 | -- | .9 | 435 | 8 |
| 35-1N-3E | 40 | 1d | 11/19/64 | -- | -- | -- | -- | 69 | 12 | 28 | -- | 1.5 | 238 | 0 | 99 | 9 | .2 | 10 | .04 | 354 | 223 | -- | -- | .8 | 541 | 7.6 |
| 31-1N-4E | 9 | 1d | 11/6/65 | 53 | 24 | .50 | 0.20 | 128 | 33 | 243 | -- | 3.9 | 488 | 0 | 495 | 64 | .6 | .1 | .17 | 1,270 | 456 | 56 | -- | 4.9 | 1,790 | 7.7 |
| 15-1N-5E | 29 | 1d | 9/28/65 | 51 | 12 | .80 | .54 | 42 | 8 | 461 | -- | 1.9 | 417 | 0 | 695 | 31 | 1.5 | .0 | .27 | 1,490 | 138 | 0 | -- | 17 | 2,140 | 8.2 |
| 13-2N-1E | 60 | 1d | 9/15/65 | -- | 13 | .10 | -- | 56 | 9.4 | 25 | -- | 1.6 | 188 | 0 | 68 | 6.2 | .2 | .0 | .02 | 284 | 178 | 24 | -- | .8 | 447 | 7.8 |
| 16-8N-4E | 50 | 2f | 7/23/46 | -- | -- | .05 | -- | 114 | 41 | -- | 445 | -- | 332 | -- | 1,060 | 30 | .8 | 1.6 | -- | 1,930 | 453 | 181 | -- | 9.1 | 2,440 | 8 |
| 35-9N-2E | 44 | 2f | 7/22/46 | -- | -- | .80 | -- | 285 | 121 | -- | 65 | -- | 300 | -- | 1,040 | 16 | .2 | .0 | -- | 1,960 | 1,210 | 964 | 11 | .8 | 2,010 | 7.3 |
| 8-4N-3W | 30 | 1d | 11/4/65 | 50 | 29 | .37 | .26 | 104 | 17 | 89 | -- | 3.6 | 526 | 0 | 84 | 10 | .3 | .3 | .02 | 601 | 331 | 0 | -- | 2.1 | 911 | 7.9 |
| 2-4N-4W | 21-33 | 1d | 10/26/66 | -- | 15 | -- | -- | 92 | 14 | 24 | -- | 2.8 | 286 | 0 | 103 | 3.4 | .1 | 1.4 | .06 | 378 | 286 | 51 | -- | .6 | 635 | 7.6 |
| 16-43N-95W | 42 | 2f | 7/23/46 | -- | -- | .20 | -- | 248 | 88 | -- | 287 | -- | 282 | -- | 1,270 | 28 | .4 | 8 | -- | 2,280 | 981 | 750 | 39 | -- | 2,540 | 7.5 |
| 14-50N-99W | Spring | 2g | 8/9/57 | 56 | 31 | -- | -- | 83 | 43 | 65 | -- | 8.1 | 447 | 0 | 153 | 3.5 | .6 | 2.7 | .1 | 605 | 384 | 17 | 26 | 1.4 | 921 | 7.5 |
| 2-51N-94W | 15 | 2h | 8/10/57 | 52 | 30 | .39 | -- | 188 | 50 | 380 | -- | 3 | 577 | 0 | 950 | 30 | .5 | 3.4 | .1 | 1,980 | 675 | 202 | 55 | 6.4 | 2,560 | 7.5 |
| 15-51N-95W | 24 | 2h | 8/10/57 | 55 | 30 | .02 | -- | 203 | 54 | 236 | -- | 3.7 | 516 | 0 | 770 | 30 | .3 | 4.1 | .02 | 1,600 | 730 | 307 | 41 | 3.8 | 2,050 | 7.8 |
| 3-51N-96W | 25 | 2h | 8/10/57 | 55 | 32 | .02 | -- | 85 | 19 | 115 | -- | 3.1 | 374 | 0 | 223 | 4.5 | .6 | 6.8 | .06 | 673 | 291 | 0 | 46 | 2.9 | 988 | 7.7 |
| | | | 4/11/58 | 55 | -- | -- | -- | -- | -- | -- | -- | -- | 370 | 0 | -- | -- | -- | -- | -- | -- | 294 | 0 | -- | -- | 960 | 7.8 |
| 12-51N-97W | 16 | 2h | 8/10/57 | 58 | 32 | .02 | -- | 96 | 25 | 70 | -- | 1.7 | 443 | 0 | 123 | .1 | .4 | 4.8 | .04 | 576 | 341 | 0 | 31 | 1.7 | 872 | 7.5 |
| 23-51N-98W | 9.2 | 2h | 8/9/57 | 54 | 28 | .23 | -- | 115 | 29 | 74 | -- | 11 | 464 | 0 | 186 | 4.5 | .4 | 1.2 | .04 | 679 | 408 | 28 | 28 | 1.6 | 1,020 | 7.2 |
| 24-52N-94W | 8 | 2h | 8/10/57 | -- | 29 | .06 | -- | 235 | 53 | 290 | -- | 5 | 614 | 0 | 880 | 36 | .4 | 5.5 | .7 | 1,930 | 804 | 301 | 44 | 4.4 | 2,390 | 7.4 |
| 4-1S-1W | 24 | 1b | 11/3/65 | -- | 10 | .0 | -- | 53 | 22 | 14 | -- | 3.1 | 220 | 0 | 63 | 5.7 | .3 | 1.2 | .10 | 292 | 222 | 42 | -- | .4 | 476 | 7.6 |
| 5-1S-1W | 42 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 36 | -- | -- | -- | -- | -- | -- | .28 | -- | -- | 420 | 209 | -- | -- | -- | -- | 7.9 |
| 6-1S-1W | 20-23 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 64 | -- | -- | -- | -- | -- | -- | .95 | -- | -- | 540 | 230 | -- | -- | -- | -- | 7.8 |
| 8-1S-1W | 3-12 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 7 | -- | -- | -- | -- | -- | -- | .82 | -- | -- | 550 | 347 | -- | -- | -- | -- | 7.4 |
| 9-1S-1W | 28-30 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 93 | -- | -- | -- | -- | -- | -- | .58 | -- | -- | 1,160 | 525 | -- | -- | -- | -- | 7.6 |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$: Calcium, Magnesium | Hardness as $CaCO_3$: Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALLUVIUM -- continued** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10-1S-1W | 33-40 | 1b | 11/3/65 | 47 | 7.9 | 1.3 | 0.16 | 40 | 18 | 200 | -- | 2.4 | 343 | 0 | 306 | 7.2 | 0.5 | 3.4 | 0.96 | 772 | 173 | 0 | -- | 6.6 | 1,170 | 7.8 |
| 18-1S-1W | 23-32 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 24 | -- | -- | -- | -- | -- | -- | .62 | -- | -- | 930 | 415 | -- | -- | -- | -- | 7.7 |
| 1-1S-2W | 20 | 1b | 5/10/63 | -- | -- | -- | -- | -- | -- | 72 | -- | -- | -- | -- | -- | -- | 1.32 | -- | -- | 450 | 195 | -- | -- | -- | -- | 7.7 |
| 15-1S-1E | 16-38 | 1b | 10/25/66 | 52 | 17 | -- | -- | 358 | 94 | 258 | -- | 5.4 | 342 | 0 | 1,470 | 21 | 1.4 | 8.5 | .44 | 2,540 | 1,280 | 1,000 | -- | 3.1 | 2,740 | 7.6 |
| 22-1S-1E | 19-21 | 1b | 10/5/65 | 53 | 19 | .45 | .45 | 227 | 156 | 316 | -- | 6 | 329 | 0 | 1,470 | 24 | .9 | 4 | .63 | 2,640 | 1,210 | 940 | -- | 4 | 2,890 | 8 |
| 31-1S-1E | 45 | 1b | 10/6/65 | 49 | 18 | .46 | .03 | 63 | 26 | 15 | -- | 2.3 | 284 | 0 | 59 | 1.9 | .9 | 1.4 | .08 | 329 | 264 | 31 | -- | .4 | 543 | 8.1 |
| 9-1S-2E | 20 | 1b | 11/3/65 | 54 | 20 | .01 | -- | 168 | 80 | 161 | -- | 4.6 | 395 | 0 | 694 | 18 | .9 | 3.6 | .32 | 1,450 | 746 | 422 | -- | 2.6 | 1,780 | 8.2 |
| 18-1S-3E | 12 | 1b | 11/3/65 | -- | 68 | .19 | -- | 162 | 58 | 226 | -- | 1 | 268 | 0 | 845 | 13 | 1.6 | 8.5 | .42 | 1,570 | 641 | 421 | -- | 3.9 | 1,930 | 7.7 |
| 24-1S-3E | 5-10 | 1b | 10/5/65 | 57 | 16 | .18 | .77 | 168 | 73 | 181 | -- | 3.9 | 344 | 0 | 736 | 28 | .6 | 2.7 | .20 | 1,500 | 720 | 438 | -- | 2.9 | 1,810 | 8.1 |
| 33-1S-4E | 20-22 | 1b | 9/28/65 | 52 | 18 | 1.3 | 1.1 | 184 | 48 | 169 | -- | 7.4 | 271 | 0 | 648 | 88 | 1 | .1 | .22 | 1,380 | 656 | 434 | -- | 2.9 | 1,780 | 8.1 |
| 11-1S-5E | 32-34 | 1d | 10/6/65 | 52 | 14 | .34 | .12 | 168 | 55 | 1,100 | -- | 4.7 | 409 | 0 | 2,450 | 95 | .8 | .1 | .49 | 4,600 | 646 | 311 | -- | 19 | 5,650 | 8.2 |
| **TERRACE DEPOSITS** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32-1N-4E | 12 | 1d | 10/15/48 | 54 | 38 | 0.34 | -- | 87 | 13 | 56 | -- | 6.4 | 368 | 0 | 86 | 7.0 | 1.2 | 0.6 | 0.16 | 494 | 270 | 0 | -- | 1.5 | 738 | 7.5 |
| 23-4N-4E | 11-19 | 1d | 6/26/51 | -- | -- | -- | -- | -- | -- | -- | 175 | -- | 334 | 7 | 122 | 17 | -- | 17 | -- | 606 | 68 | 0 | -- | -- | 897 | 8.4 |
| 32-4N-3W | 41 | 1d | 4/28/66 | -- | 30 | 0.04 | -- | 35 | 19 | 24 | -- | 1 | 223 | 0 | 20 | 5.3 | 0.6 | 1.9 | .04 | 268 | 165 | 0 | -- | .8 | 397 | 7.9 |
| 22-4N-4W | 21-33 | 1b | 10/26/66 | 50 | 31 | -- | -- | 64 | 12 | 86 | -- | 1.6 | 392 | 0 | 71 | 7.2 | 1.3 | .7 | .34 | 446 | 210 | 0 | -- | 2.6 | 705 | 7.6 |
| 8-43N-94W | 36 | 2a | 7/22/46 | -- | -- | .10 | -- | 275 | 155 | -- | 408 | -- | 472 | -- | 1,690 | 26 | 1 | 25 | -- | 3,120 | 1,320 | 933 | 40 | -- | 3,230 | 8 |
| 7-43N-96W | -- | 2f | 10/28/49 | -- | 32 | .10 | -- | 350 | 134 | 460 | -- | 5.6 | 442 | -- | 1,880 | 37 | 1.2 | 7.9 | .53 | 3,310 | 1,420 | 1,060 | 41 | -- | 3,620 | 7.4 |
| 18-43N-96W | 64 | 2f | 7/22/46 | -- | -- | .20 | -- | 235 | 108 | -- | 269 | -- | 444 | -- | 1,120 | 42 | 1.3 | 25 | -- | 2,270 | 1,030 | 666 | 36 | -- | 2,460 | 8 |
| 3-43N-97W | -- | 2f | 7/22/46 | -- | -- | .05 | -- | 183 | 81 | -- | 282 | -- | 573 | -- | 802 | 44 | 1.1 | 40 | -- | 1,830 | 790 | 320 | 44 | -- | 2,200 | 7.9 |
| 13-51N-98W | Spring | 2h | 8/9/57 | 52 | 23 | .01 | -- | 178 | 50 | -- | 74 | 4.4 | 392 | 0 | 468 | 5 | .9 | 13 | .01 | 1,080 | 648 | 327 | 20 | 1.3 | 1,340 | 7.6 |
| | | | 4/11/58 | 48 | -- | -- | -- | -- | -- | -- | -- | -- | 414 | -- | -- | -- | -- | -- | -- | -- | 686 | 347 | -- | -- | 1,370 | 7.8 |
| 5-52N-95W | 9 | 2h | 8/9/57 | 55 | 39 | .02 | -- | 185 | 38 | -- | 352 | 4.6 | 516 | 0 | 940 | 22 | 2.5 | 5.6 | .34 | 1,880 | 618 | 195 | 55 | 6.1 | 2,380 | 7.6 |
| 10-52N-95W | 27 | 2h | 8/8/57 | 55 | 35 | .19 | -- | 102 | 27 | -- | 232 | 3 | 386 | 0 | 515 | 14 | 1.9 | 18 | .19 | 1,130 | 366 | 49 | 58 | 5.3 | 1,580 | 7.7 |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$ Calcium, Magnesium | Hardness as $CaCO_3$ Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | TERRACE DEPOSITS -- continued | | | | | | | | | | | |
| 1-52N-96W | 19 | 2h | 8/9/57 | -- | 38 | 0.12 | -- | 114 | 41 | 272 | -- | 1.9 | 425 | 0 | 660 | 24 | 2.6 | 12 | .19 | 1,380 | 452 | 103 | 57 | 5.6 | 1,850 | 7.9 |
| 2-52N-96W | 26 | 2h | 8/8/57 | 49 | 37 | .22 | -- | 79 | 32 | 169 | -- | 2 | 376 | 0 | 355 | 8 | 3.1 | 16 | .07 | 882 | 330 | 22 | 53 | 4 | 1,260 | 7.8 |
| | | | 4/11/58 | 49 | -- | -- | -- | 101 | 41 | 188 | -- | -- | 426 | 0 | 425 | -- | -- | -- | -- | -- | 422 | 73 | 49 | 4 | 1,490 | 7.9 |
| 3-52N-96W | 36 | 2h | 8/8/57 | 53 | 44 | .20 | -- | 96 | 35 | 248 | -- | 1.7 | 428 | 0 | 550 | 9.5 | 4.2 | 15 | .22 | 1,210 | 384 | 33 | 58 | 5.5 | 1,660 | 7.7 |
| 8-52N-96W | 50 | 2h | 8/8/57 | 50 | 31 | .22 | -- | 140 | 126 | 336 | -- | 3.5 | 492 | 0 | 1,100 | 31 | 2.9 | 18 | .27 | 2,180 | 868 | 465 | 46 | 5 | 2,650 | 7.9 |
| | | | 4/11/58 | 46 | -- | -- | -- | 108 | 69 | 330 | -- | -- | 486 | 0 | 750 | -- | -- | -- | -- | -- | 552 | 153 | 57 | 6.1 | 2,190 | 7.9 |
| 9-52N-96W | 16 | 2h | 8/8/57 | 58 | 20 | .05 | -- | 35 | 11 | 35 | -- | 1.7 | 157 | 0 | 80 | .0 | .4 | .6 | .04 | 265 | 134 | 5 | 36 | 1.3 | 411 | 7.8 |
| 10-52N-96W | 57 | 2h | 8/8/57 | 56 | 30 | .13 | -- | 44 | 13 | 109 | -- | 3.2 | 246 | 0 | 180 | 4 | 1.2 | 5.9 | .16 | 508 | 164 | 0 | 59 | 3.7 | 761 | 7.9 |
| | | | 4/11/58 | 51 | -- | -- | -- | -- | -- | -- | -- | -- | 222 | 0 | -- | -- | -- | -- | -- | -- | 156 | -- | -- | -- | 733 | 8.1 |
| 16-52N-96W | 44 | 2h | 8/8/57 | 49 | 28 | .03 | -- | 128 | 36 | 143 | -- | 2.9 | 391 | 0 | 390 | 17 | 1 | 15 | .22 | 973 | 468 | 147 | 40 | 2.9 | 1,340 | 7.6 |
| 32-52N-96W | 30 | 2h | 8/9/57 | 53 | 28 | .05 | -- | 72 | 19 | 128 | -- | 3.9 | 334 | 0 | 238 | 6.4 | .7 | 13 | .11 | 670 | 258 | 0 | 51 | 3.5 | 982 | 7.7 |
| 33-52N-96W | 22 | 2h | 8/9/57 | 57 | 28 | .03 | -- | 59 | 18 | 130 | -- | 3.7 | 363 | 0 | 187 | 2.7 | .8 | 4.6 | .15 | 620 | 222 | 0 | 56 | 3.8 | 915 | 7.8 |
| 13-52N-97W | 16 | 2h | 8/8/57 | -- | 52 | .06 | -- | 95 | 54 | 99 | -- | 1.9 | 486 | 0 | 243 | 3.4 | 2.1 | 4.3 | .29 | 815 | 459 | 60 | 32 | 2 | 1,140 | 7.4 |
| 25-52N-97W | 19 | 2h | 8/9/57 | 49 | 31 | .11 | -- | 50 | 14 | 247 | -- | 3.7 | 386 | 0 | 355 | 6.8 | 2 | 34 | .17 | 940 | 184 | 0 | 74 | 7.9 | 1,360 | 7.8 |
| | | | | -- | 31 | .05 | -- | 102 | 26 | 130 | -- | 2.9 | 439 | 0 | 268 | 5.8 | 1.4 | 3.4 | .18 | 795 | 362 | 2 | 44 | 3 | 1,140 | 7.6 |
| 26-52N-97W | 16 | 2h | 4/11/58 | 47 | -- | -- | -- | 122 | 37 | 176 | -- | -- | 388 | 0 | 482 | 11 | -- | 3.6 | -- | -- | 458 | 140 | 46 | 3.6 | 1,470 | 7.7 |
| | | | | | | | | | | | | | | | GLACIAL DEPOSITS | | | | | | | | | | | |
| 17-3N-2W | 45 | 1d | 11/4/65 | -- | 19 | .10 | -- | 46 | 10 | 18 | -- | 2.4 | 170 | 0 | 52 | 4 | 0.2 | 0.2 | 0.03 | 240 | 157 | 18 | -- | 0.6 | 380 | 7.7 |
| | | | | | | | | | | | | | | | WIND RIVER FORMATION | | | | | | | | | | | |
| 3-1N-1E | 559-579 | 1d | 8/31/66 | 53 | 1.8 | -- | -- | 16 | 9.7 | 96 | -- | 2.5 | 204 | 0 | 103 | 20 | 0.6 | 0.2 | 0.19 | 358 | 100 | 0 | -- | 4.7 | 610 | 8.0 |
| 16-1N-3E | 103 | 1d | 10/19/48 | 50 | 15 | .02 | -- | 81 | 8.2 | 171 | -- | 4 | 157 | 0 | 426 | 17 | .3 | 1.2 | .12 | 830 | 236 | 107 | -- | 4.8 | 1,200 | 7.5 |
| 17-1N-3E | 246-280 | 1d | 11/8/65 | -- | 11 | .36 | .08 | 4.2 | .4 | 148 | -- | .4 | 52 | 2 | 251 | 15 | 2.4 | 0 | .33 | 474 | 12 | 0 | -- | 19 | 743 | 8.4 |
| 12-1N-4E | 64 | 1d | 10/21/48 | 51 | 19 | .32 | -- | 42 | 14 | 21 | -- | .8 | 145 | 3.9 | 68 | 20 | .4 | .5 | .30 | 247 | 162 | 37 | -- | .7 | 385 | 8.3 |
| 27-1N-4E (Riverton city well) | 255-645 | 1d | 10/21/60 | 57 | 13 | .13 | -- | 1.6 | 1 | 126 | -- | 1.6 | 184 | 10 | 107 | 9 | .6 | .6 | -- | 335 | 8 | 0 | -- | 19 | 574 | 8.5 |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (°F) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180°C) | Hardness as $CaCO_3$: Calcium, Magnesium | Hardness as $CaCO_3$: Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | W I N D R I V E R F O R M A T I O N -- continued | | | | | | | | | | | | | | | | | | |
| 34- 1N-4E (Riverton city well) | 460-660 | 1d | 10/26/51 | -- | 12 | 0.06 | -- | 23 | 1.1 | 125 | -- | 0.7 | 191 | 8 | 96 | 10 | 0.6 | 0.5 | 0.24 | 355 | 10 | 0 | -- | 6.9 | 562 | 8.6 |
| 24- 2N-1E | 180 | 1d | 9/15/65 | 55 | 26 | .13 | .06 | 94 | 14 | 15 | -- | 3.1 | 334 | 0 | 47 | 3 | .4 | 1.7 | .05 | 373 | 293 | 19 | -- | .4 | 586 | 8 |
| 17- 2N-2E | 486-500 | 1d | 10/18/48 | 50 | 25 | 2.8 | -- | 34 | 1.5 | 148 | -- | 1.2 | 186 | 0 | 232 | 6.5 | .5 | .0 | .12 | 548 | 91 | 0 | -- | 6.7 | 825 | 7.7 |
| 19- 2N-3E | 202-228 | 1d | 9/17/49 | 50 | 10 | 2 | -- | 14 | .6 | 235 | -- | 4 | 35 | 0 | 456 | 41 | 1.2 | .6 | .48 | 800 | 38 | 9 | -- | 17 | 1,130 | 7.3 |
| 10- 2N-4E | 330-350 | 1d | 9/17/49 | 52 | 10 | .54 | -- | 16 | .4 | 260 | -- | 4.8 | 34 | 0 | 456 | 92 | 1.2 | .3 | .46 | 878 | 42 | 14 | -- | 15 | 1,280 | 6.8 |
| 2- 2N-5E | 275-300 | 1d | 10/20/48 | 50 | 16 | .16 | -- | 14 | 1.5 | 261 | -- | .8 | 34 | 0 | 444 | 97 | 2.8 | .2 | .43 | 872 | 41 | 13 | -- | 18 | 1,360 | 7.7 |
| 30- 2N-5E | 165-167 | 1d | 10/21/48 | 52 | 10 | 1.9 | -- | 10 | .1 | 248 | -- | .4 | 163 | 0 | 376 | 28 | 1.2 | .8 | .40 | 734 | 25 | 0 | -- | -- | 1,210 | 8 |
| 19- 2N-6E | 300-353 | 1d | 10/20/48 | 55 | 13 | 2 | -- | 26 | 4.6 | 284 | -- | .8 | 126 | 6 | 440 | 94 | 1.6 | 1.4 | .22 | 953 | 84 | 0 | -- | 13 | 1,480 | 8.2 |
| 21- 3N-1E | 183-225 | 1d | 10/14/48 | 52 | 13 | .60 | -- | 46 | 2 | 458 | -- | 4.4 | 85 | 0 | 1,000 | 12 | .7 | .3 | .08 | 1,590 | 123 | 53 | -- | 18 | 2,060 | 7.5 |
| 36- 3N-1E | 77 | 1d | 10/14/48 | 50 | 13 | 2.2 | -- | 450 | 167 | 748 | -- | 5.6 | 342 | 0 | 2,760 | 158 | .7 | .3 | .18 | 4,700 | 1,810 | 1,530 | -- | 7.6 | 4,790 | 7.7 |
| 5- 3N-2E | 70-100 | 1d | 8/14/50 | 58 | 10 | -- | -- | 33 | .5 | 459 | -- | 1.3 | 78 | 0 | 990 | 8.5 | .8 | .8 | .10 | 1,550 | 85 | 21 | -- | 22 | 2,180 | 7.5 |
| 26- 3N-2E | 296-321 | 1d | 10/18/48 | 53 | 13 | 2 | -- | 46 | .1 | 445 | -- | 7.6 | 22 | 0 | 988 | 18 | .7 | .2 | .22 | 1,560 | 116 | 98 | -- | 18 | 2,160 | 7.1 |
| 6- 3N-3E | 240-270 | 1d | 10/26/51 | 52 | 21 | -- | -- | .9 | .1 | 97 | -- | .2 | 74 | 33 | 42 | 38 | 1.6 | .4 | .21 | 272 | 3 | 0 | -- | 30 | 446 | 9.7 |
| 26- 3N-3E | 228-244 | 1d | 10/19/48 | 49 | 11 | .28 | -- | 27 | .1 | 332 | -- | 4 | 23 | 0 | 664 | 59 | 1 | .3 | .12 | 1,130 | 68 | 49 | -- | 18 | 1,660 | 7.1 |
| 29- 3N-4E | 76 | 1d | 9/17/49 | 49 | 9.2 | 3 | -- | 74 | 7.9 | 473 | -- | 4.8 | 416 | 0 | 848 | 17 | 1.1 | .7 | .28 | 1,670 | 217 | 0 | -- | 14 | 2,190 | 7.8 |
| 33- 3N-5E | 35 | 1d | 10/16/48 | 47 | 19 | .06 | -- | 206 | 41 | 735 | -- | 3.2 | 330 | 0 | 1,760 | 58 | 1.1 | 44 | .34 | 3,130 | 682 | 411 | -- | -- | 3,830 | 7.6 |
| 15- 3N-6E | 451-495 | 1d | 10/27/60 | -- | 10 | .08 | -- | 4.8 | 1 | 179 | -- | .6 | 168 | 2 | 234 | 12 | 3 | .7 | -- | 565 | 16 | 0 | -- | 19 | 847 | 8.3 |
| 11- 4N-1E | 110-175 | 1c | 11/2/66 | -- | 6.9 | -- | -- | 149 | 15 | 1,500 | -- | 6.3 | 212 | 0 | 3,250 | 77 | 1.2 | .1 | .07 | 5,000 | 435 | 261 | -- | 31 | 6,300 | 7.8 |
| 29- 4N-2E | 248-258 | 1d | 8/14/50 | 50 | 12 | -- | -- | 31 | .1 | 548 | -- | 1.8 | 64 | 0 | 1,090 | 48 | 1.1 | .3 | .10 | 1,810 | 78 | 26 | -- | 32 | 2,560 | 8.2 |
| 13- 4N-3E | 425-436 | 1d | 10/26/51 | 51 | 10 | .25 | -- | 5.5 | .1 | 256 | -- | .6 | 32 | 16 | 435 | 49 | 2 | .4 | .35 | 802 | 14 | 0 | -- | 26 | 1,270 | 9.5 |
| 36- 4N-3E | 120 | 1d | 10/29/60 | -- | 28 | .13 | -- | 320 | 224 | 520 | -- | 8.2 | 254 | 0 | 2,510 | 56 | 1 | 0 | -- | 4,040 | 1,720 | 1,510 | -- | -- | 6,180 | 7.7 |
| 20- 4N-4E | 170-210 | 1d | 10/26/51 | 52 | 8 | 1.6 | -- | 31 | .9 | 556 | -- | .9 | 34 | 0 | 1,020 | 160 | 3.2 | .3 | .22 | 1,820 | 81 | 53 | -- | 27 | 2,740 | 7.2 |
| 21- 5N-4E | 279-295 | 1c | 10/26/66 | -- | 5.7 | -- | -- | 34 | 8 | 819 | -- | 3 | 72 | 0 | 1,370 | 335 | 2.2 | .1 | .19 | 2,580 | 118 | 59 | -- | 33 | 3,810 | 7.5 |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180°C) | Hardness as $CaCO_3$ Calcium, Magnesium | Hardness as $CaCO_3$ Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WIND RIVER FORMATION -- continued | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33-5N-5E | 182-188 | 1c | 10/26/66 | -- | 4.9 | -- | -- | 52 | 7.9 | 1,070 | -- | 3.0 | 76 | 0 | 1,800 | 416 | 3.8 | 0.1 | 0.23 | 3,310 | 162 | 100 | -- | 37 | 4,730 | 7.9 |
| 4-3N-3W | 30-55 | 1b | 11/4/65 | -- | 23 | .05 | -- | 39 | 17 | -- | -- | .8 | 190 | 0 | 23 | 1 | .5 | .7 | .01 | 203 | 168 | 12 | -- | .2 | 340 | 7.8 |
| 25-4N-1W | 487 | 1c | 12/19/66 | -- | 1.8 | -- | -- | 32 | 3.2 | 342 | -- | 1.8 | 50 | 4 | 763 | 15 | .5 | .5 | .03 | 1,190 | 93 | 45 | -- | 15 | 1,770 | 8.5 |
| 33-6N-3W | 90-95 | 1c | 10/31/66 | -- | 6.2 | -- | -- | 11 | .1 | 294 | -- | .4 | 90 | 0 | 438 | 86 | 3.4 | .1 | .17 | 880 | 28 | 0 | -- | 24 | 1,380 | 8 |
| 2-1S-3E | 60 | 1b | 11/4/64 | -- | -- | -- | -- | 27 | 5 | 80 | -- | 1 | 211 | 0 | 58 | 0 | -- | -- | 2 | 336 | -- | -- | -- | 3.5 | 540 | 7.3 |
| 10-1S-3E | 375-390 | 1b | 10/27/64 | -- | -- | -- | -- | 3 | 3 | 155 | -- | 0 | 153 | 24 | 157 | 11 | 1 | 0 | .18 | 466 | -- | -- | -- | 11.4 | 569 | 8.2 |
| 14-1S-3E | 91-108 | 1b | 11/19/64 | -- | -- | -- | -- | 163 | 5 | 580 | -- | 1 | 85 | 0 | 1,640 | 36 | .8 | .7 | .09 | 2,560 | 430 | -- | -- | 12 | 3,380 | 7.8 |
| 24-1S-3E | 220-230 | 1b | 11/19/64 | -- | -- | -- | -- | 5 | 2 | 175 | -- | 1 | 122 | 15 | 239 | 14 | 1.1 | 0 | .09 | 540 | 23 | -- | -- | 12 | 879 | 8.6 |
| 4-1S-4E | 320-450 | 1d | 9/30/64 | -- | 7.0 | .06 | -- | 2 | 1 | 139 | -- | 1 | 223± | -- | 139 | 4 | 1.1 | .04 | -- | 388 | -- | 8 | -- | 20 | 670 | 8.5 |
| 18-1S-4E | 314-325 | 1b | 10/26/64 | -- | -- | -- | -- | 4 | 2 | 150 | -- | 1 | 156 | 18 | 132 | 11 | 1.2 | 0 | 0.14 | 378 | 19 | -- | -- | 10.5 | 697 | 8.8 |
| 11-1S-5E | 118-215 | 1d | 11/5/65 | 55 | 16 | .26 | -- | 150 | 39 | 340 | -- | 7.4 | 469 | 0 | 782 | 77 | 1.2 | .3 | .33 | 1,710 | 534 | 149 | -- | 6.4 | 2,320 | 8 |
| WILLWOOD FORMATION | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 21-50N-99W | 97 | 2g | 8/10/57 | 51 | 15 | .07 | -- | 120 | 139 | 72 | -- | 5.5 | 546 | 0 | 538 | 15 | 0.6 | 5.7 | 0.01 | 1,230 | 870 | 422 | 15 | 1.1 | 1,640 | 7.4 |
| 15-51N-95W | 124 | 2h | 10/9/57 | 56 | 6.8 | .95 | -- | 22 | 4.4 | 610 | -- | 3.3 | 268 | 0 | 974 | 135 | 2.5 | 3.4 | .13 | 1,880 | 73 | 0 | 95 | 31 | 2,790 | 7.8 |
| 13-51N-98W | 100 | 2h | 8/9/57 | -- | 8.9 | .13 | -- | 13 | 6.7 | 532 | -- | 2.7 | 541 | 10 | 740 | 12 | 1.5 | 2.3 | .27 | 1,590 | 60 | 0 | 95 | 30 | 2,360 | 8.4 |
| 8-52N-95W | 147 | 2h | 8/10/57 | 55 | 17 | .13 | -- | 118 | 48 | 400 | -- | 4.3 | 459 | 0 | 950 | 22 | 2.8 | 23 | .44 | 1,830 | 492 | 116 | 64 | 7.9 | 2,440 | 7.8 |
| | | | 4/11/58 | -- | -- | -- | -- | 71 | 29 | 380 | -- | -- | 384 | 0 | 745 | -- | -- | -- | -- | -- | 298 | 0 | 73 | 9.5 | 2,120 | 8 |
| 26-52N-97W | 180 | 2h | 8/9/57 | 55 | 8.9 | .12 | -- | 4 | 0 | 245 | -- | 1.3 | 476 | 16 | 50 | 47 | 4.3 | 1.2 | .18 | 621 | 10 | 0 | 98 | 34 | 1,030 | 8.6 |
| FORT UNION FORMATION | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9-1S-2E | 365-412 | 1b | 11/6/64 | -- | 6.9 | .60 | .09 | 8.3 | 1.8 | 387 | -- | 3.1 | 561 | 16 | 1.5 | 291 | 2.6 | 0 | 0.18 | 1,010 | 28 | 0 | -- | 32 | 1,760 | 8.4 |
| 10-1S-2E | 412-418 | 1b | 11/19/66 | -- | -- | -- | -- | 6 | 3 | 400 | -- | 3 | 522 | 33 | 1 | 270 | 1.8 | 0 | .10 | 992 | 30 | -- | -- | 30 | 1,720 | 8.6 |

TABLE III-3 — continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (°F) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180°C) | Hardness as $CaCO_3$ Calcium, Magnesium | Hardness as $CaCO_3$ Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CODY SHALE** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 36-1N-1E | 300+ | 1b | 5/18/45 | — | — | — | — | 15 | 12 | — | 598 | — | 390 | 23 | 730 | 182 | 1.2 | 4.3 | — | 1,750* | 87 | 0 | — | 36 | 2,660 | — |
| 31-4N-1W | 384 | 1c | 11/14/51 | — | 7.4 | 0.06 | — | 71 | 4.1 | — | 716 | — | 138 | 0 | 1,520 | 37 | 1.2 | 1 | 0.21 | 2,450 | 194 | 81 | — | 16 | 3,380 | 7.5 |
| 12-43N-95W | 53 | 2a | 7/22/46 | — | — | .90 | — | 23 | 10 | — | 674 | — | 403 | — | 1,120 | 46 | .6 | 1.6 | — | 2,120 | 98 | 0 | 94 | — | 2.960 | 7.8 |
| **CODY SHALE AND ALLUVIUM** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20-44N-94W | 400 | 2a | 7/23/46 | — | — | .10 | — | 446 | 335 | — | 868 | — | 448 | — | 3,650 | 87 | .8 | 100 | — | 6,240 | 2,490 | 2,120 | 43 | — | 5,760 | 7.8 |
| **FRONTIER FORMATION** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33-1N-1E | 543-620 | 1b | 10/30/57 | — | — | — | — | 0.4 | 0.3 | 772 | — | 3.5 | 951 | 117 | 500 | 57 | — | — | 3.8 | 1,800 | — | — | — | — | 2,530 | 9.1 |
| 7-8N-2E | 440 | 2f | 7/22/46 | — | — | 0.20 | — | 10 | 8 | — | 1,510 | — | 516 | 33 | 2,700 | 52 | 2.8 | 10 | — | 4,600 | 58 | 0 | 98 | — | 5,660 | 8.4 |
| 14-4N-4W | 329-359 | 1b | 11/4/65 | — | 7.4 | .21 | — | 33 | 11 | 680 | — | 2.4 | 166 | 0 | 1,230 | 116 | 1.6 | 1 | 2 | 2,220 | 126 | 0 | — | 6 | 3,170 | 7.9 |
| 21-43N-92W | 391-397 | 2b | — | — | — | — | — | 0 | 0 | — | 342 | — | 745 | 67 | 16 | 4 | — | — | — | 795** | — | — | — | — | — | — |
| 2-44N-96W | 3,028-3,042 | 2f | — | — | — | — | — | 0 | 0 | — | 863 | — | 1,135 | 456 | 70 | 80 | — | — | — | 2,057* | — | — | — | — | — | — |
| 26-46N-91W | 6,760-6,795 | 2b | — | — | — | — | — | 0 | 0 | — | 2,946 | — | 2,890 | 350 | 66 | 2,400 | — | — | — | 7,183** | — | — | — | — | — | — |
| 29-48N-92W | 7,636-7,724 | 2a | — | — | — | — | — | 40 | 17 | — | 5,095 | — | 780 | 0 | 35 | 7,500 | — | — | — | 13,071* | — | — | — | — | — | — |
| 7-51N-100W | 715-721 | 2h | — | — | — | — | — | 0 | 0 | — | 606 | — | 1,280 | 72 | 0 | 105 | — | — | — | 1,412* | — | — | — | — | — | — |
| 15-55N-97W | 3,223 | — | — | — | — | — | — | 0 | 0 | — | 4,575 | — | 7,800 | 185 | 0 | 2,305 | — | — | — | 10,901** | — | — | — | — | — | — |
| 8-1S-1W | 497-543 | 1b | 5/19/45 | — | — | — | — | 1 | 1.3 | 435 | — | — | 430 | 70 | 430 | 20 | 3.8 | .0 | — | 1,170* | 8 | 0 | — | — | 1,800 | — |
| 7-2S-1E | 350 | 1b | 5/10/63 | — | — | — | — | — | — | 680 | — | — | — | — | — | — | .95 | — | — | 2,350 | 25 | — | — | — | — | 8.6 |
| **FRONTIER FORMATION AND ALLUVIUM** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16-8N-4E | 50 | 2f | 7/23/46 | — | — | 0.05 | — | 114 | 41 | — | 445 | — | 332 | — | 1,060 | 30 | .8 | 1.6 | — | 1,930 | 453 | 181 | 68 | — | 2,440 | 8.0 |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$ Calcium, Magnesium | Hardness as $CaCO_3$ Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **D A K O T A   S A N D S T O N E** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15-44N-98W | 1,744-1,773 | 2f | -- | -- | -- | -- | -- | 11 | 3 | -- | 785 | -- | 1,684 | 63 | 114 | 101 | -- | -- | -- | 1,905* | -- | -- | -- | -- | -- | -- |
| 19-45N-92W | 8,217 | 2b | -- | -- | -- | -- | -- | 466 | 105 | -- | 4,263 | -- | 9,520 | 0 | 1,982 | 708 | -- | -- | -- | 13,213* | -- | -- | -- | -- | -- | -- |
| 29-48N-100W | 4,703-4,723 | 2g | -- | -- | -- | -- | -- | 5 | 1 | -- | 953 | -- | 2,090 | 120 | 0 | 120 | -- | -- | -- | 2,232* | -- | -- | -- | -- | -- | -- |
| 27-52N-94W | 10,358-10,363 | 2h | -- | -- | -- | — | -- | 147 | 21 | -- | 5,678 | -- | 1,290 | 0 | 44 | 8,300 | -- | -- | -- | 14,825** | -- | -- | -- | -- | -- | -- |
| Lot 57-56N-97W | 1,530-1,545 | 2j | -- | -- | -- | -- | -- | 6 | 5 | -- | 991 | -- | 2,280 | 24 | 40 | 170 | -- | -- | -- | 2,358** | -- | -- | -- | -- | -- | -- |
| 4-7S-21E (Montana) | 6,010-6,075 | -- | -- | -- | -- | -- | -- | 7 | 1 | -- | 1,519 | -- | 2,020 | 175 | 3 | 985 | -- | -- | -- | 3,683** | -- | -- | -- | -- | -- | -- |
| **L A K O T A   S A N D S T O N E** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13-46N-99W | 2,155 | 2f | -- | -- | -- | -- | -- | 6 | 0 | -- | 1,082 | -- | 1,330 | 192 | 40 | 650 | -- | -- | -- | 2,624* | -- | -- | -- | -- | -- | -- |
| 3-7S-21E (Montana) | 5,718-5,810 | -- | -- | -- | -- | -- | -- | 10 | 0 | -- | 1,233 | -- | 2,160 | 120 | 112 | 440 | -- | -- | -- | 2,979** | -- | -- | -- | -- | -- | -- |
| **M O R R I S O N   F O R M A T I O N** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16-49N-99W | 9,259-9,318 | 2g | -- | -- | -- | -- | -- | 79 | 25 | -- | 4,950 | -- | 725 | 29 | 192 | 7,250 | -- | -- | -- | 12,881* | -- | -- | -- | -- | -- | -- |
| Lot 46-56N-97W | 3,710-3,820 | 2j | -- | -- | -- | -- | -- | 19 | 11 | -- | 827 | -- | 1,280 | 0 | 700 | 80 | -- | -- | -- | 2,267* | -- | -- | -- | -- | -- | -- |
| **S U N D A N C E   F O R M A T I O N** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32-51N-100W | 1,940-2,040 | 2h | -- | -- | -- | -- | -- | 8 | 0 | -- | 1,260 | -- | 1,255 | 300 | 33 | 850 | -- | -- | -- | 3,069* | -- | -- | -- | -- | -- | -- |
| 21-54N-100W | 13,725 | 2j | -- | -- | -- | -- | -- | 496 | 36 | -- | 3,299 | -- | 2,015 | 0 | 4,053 | 1,910 | -- | -- | -- | 10,786* | -- | -- | -- | -- | -- | -- |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$ Calcium, Magnesium | Hardness as $CaCO_3$ Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C H U G W A T E R   G R O U P** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10-43N-97W | 400 | 2f | 7/22/46 | -- | -- | 0.50 | -- | 38 | 15 | -- | 913 | -- | 232 | -- | 1,830 | 26 | 1.3 | 2.7 | -- | 3,040 | 157 | 0 | 93 | -- | 3,950 | 8.0 |
| 35-44N-91W | 5,434-5,459 | 2b | -- | -- | -- | -- | -- | 144 | 6 | -- | 1,376 | -- | 405 | 0 | 2,860 | 50 | -- | -- | -- | 4,635* | -- | -- | -- | -- | -- | -- |
| 11-44N-98W | 2,328-2,336 | 2f | -- | -- | -- | -- | -- | 528 | 235 | -- | 14,979 | -- | 3,026 | 0 | 10,800 | 15,000 | -- | -- | -- | 43,032** | -- | -- | -- | -- | -- | -- |
| 14-44N-98W | 1,874-1,922 | 2f | -- | -- | -- | -- | -- | 366 | 141 | -- | 7,966 | -- | 1,010 | 0 | 8,893 | 6,200 | -- | -- | -- | 24,054** | -- | -- | -- | -- | -- | -- |
| 20-46N-98W | (from treater) | 2f | -- | -- | -- | -- | -- | 697 | 241 | -- | 12,544 | -- | 152 | 29 | 8,794 | 14,677 | -- | -- | -- | 36,057** | -- | -- | -- | -- | -- | -- |
| 36-51N-101W | 3,840 | 2h | -- | -- | -- | -- | -- | 646 | 187 | -- | 14,280 | -- | 135 | 0 | 10,472 | 15,850 | -- | -- | -- | 41,505* | -- | -- | -- | -- | -- | -- |
| 31-53N-92W | 753 | 2d | -- | -- | -- | -- | -- | 457 | 168 | -- | 5,174 | -- | 170 | 0 | 12,139 | 219 | -- | -- | -- | 18,241* | -- | -- | -- | -- | -- | -- |
| **P E R M I A N   R O C K S   A N D/O R   D I N W O O D Y   F O R M A T I O N** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14- 5N-6W | 980 | 1b | 9/30/64 | 51 | 9.4 | 0.29 | -- | 409 | 68 | 557 | -- | 18 | 734 | 0 | 1,560 | 219 | 2.1 | 0.0 | 0.48 | 3,240 | 1,300 | 698 | -- | 6.7 | 3,920 | -- |
| 35- 5N-6W | 75-200 | 1b | 10/1/65 | 48 | 14 | .44 | 0.59 | 447 | 171 | 469 | -- | 7.6 | 367 | 0 | 2,320 | 76 | 1.1 | .1 | .06 | 4,030 | 1,820 | 1,520 | -- | 4.8 | 4,230 | 8.2 |
| **P H O S P H O R I A   F O R M A T I O N** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 36- 9N-2E | 3,417-3,454 | 2f | -- | -- | -- | -- | -- | 192 | 86 | -- | 38 | -- | 366 | 0 | 558 | 24 | -- | -- | -- | 1,078* | -- | -- | -- | -- | -- | -- |
| 36-44N-91W | 6,005-6,200 | 2b | -- | -- | -- | -- | -- | 389 | 108 | -- | 10,937 | -- | 878 | 0 | 15,000 | 6,300 | -- | -- | -- | 33,166** | -- | -- | -- | -- | -- | -- |
| 21-45N-92W | 10,011-10,043 | 2b | -- | -- | -- | -- | -- | 765 | 539 | -- | 13,783 | -- | 24,300 | 1,920 | 3,778 | 5,000 | -- | -- | -- | 37,753** | -- | -- | -- | -- | -- | -- |
| 9-46N-99W | 6,890-6,943 | 2f | -- | -- | -- | -- | -- | 334 | 91 | -- | 2,865 | -- | 427 | 0 | 6,041 | 570 | -- | -- | -- | 10,111** | -- | -- | -- | -- | -- | -- |
| 19-48N-92W | 10,453-10,484 | 2a | -- | -- | -- | -- | -- | 520 | 118 | -- | 16,631 | -- | 16,000 | 1,205 | 6,901 | 11,100 | -- | -- | -- | 44,355** | -- | -- | -- | -- | -- | -- |
| 32-52N-100W | 3,248-3,290 | 2h | -- | -- | -- | -- | -- | 600 | 193 | -- | 1,497 | -- | 1,290 | 0 | 3,543 | 570 | -- | -- | -- | 7,038** | -- | -- | -- | -- | -- | -- |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$: Calcium, Magnesium | Hardness as $CaCO_3$: Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T E N S L E E P   S A N D S T O N E ***** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13-43N-92W | 3,690-3,700 | 2b | -- | -- | -- | -- | -- | 84 | 31 | -- | 129 | -- | 600 | 0 | 67 | 40 | -- | -- | -- | 646** | -- | -- | -- | -- | -- | -- |
| 18-44N-97W | 3,170-3,237 | 2f | -- | -- | -- | -- | -- | 507 | 96 | -- | 549 | -- | 1,440 | 0 | 1,047 | 414 | -- | -- | -- | 3,321** | -- | -- | -- | -- | -- | -- |
| 19-46N-98W | 4,128-4,164 | 2f | -- | -- | -- | -- | -- | 552 | 227 | -- | 1,109 | -- | 1,560 | 0 | 2,064 | 920 | -- | -- | -- | 5,640** | -- | -- | -- | -- | -- | -- |
| 25-49N-91W | 2,640-2,700 | 2c | -- | -- | -- | -- | -- | 296 | 98 | -- | 3 | -- | 190 | 0 | 932 | 16 | -- | -- | -- | 1,439** | -- | -- | -- | -- | -- | -- |
| 4-50N-100W | 3,865-3,992 | 2h | -- | -- | -- | -- | -- | 489 | 158 | -- | 986 | -- | 1,450 | 0 | 2,296 | 310 | -- | -- | -- | 4,953** | -- | -- | -- | -- | -- | -- |
| 8-54N-93W | 1,012-1,031 | 2e | -- | -- | -- | -- | -- | 624 | 100 | -- | 0 | -- | 161 | 0 | 1,756 | 8 | -- | -- | -- | 2,567* | -- | -- | -- | -- | -- | -- |
| 2-1S-1W | Spring | 1b | 5/18/45 | 116 | -- | -- | -- | 162 | 41 | 49 | -- | -- | 290 | 0 | 362 | 41 | 2.6 | 0.1 | -- | 801* | 573 | 336 | -- | 0.9 | 1,180 | -- |
| 2-1S-1W | Spring | 1b | 8/18/53 | 103 | 34 | -- | -- | -- | -- | 49 | -- | --- | 280 | 0 | 358 | 43 | -- | -- | -- | -- | 556 | 326 | -- | .9 | 1,170 | 7.3 |
| **A M S D E N   F O R M A T I O N** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1-47N-100W | 4,964-5,040 | 2f | -- | -- | -- | -- | -- | 140 | 114 | -- | 747 | -- | 1,769 | 0 | 546 | 300 | -- | -- | -- | 2,718* | -- | -- | -- | -- | -- | -- |
| 10-50N-91W | 3,516-3,567 | 2c | -- | -- | -- | -- | -- | 143 | 53 | -- | 45 | -- | 138 | 24 | 491 | 7 | -- | -- | -- | 831* | -- | -- | -- | -- | -- | -- |
| 23-56N-97W | 5,432-5,456 | 2j | -- | -- | -- | -- | -- | 210 | 59 | -- | 16 | -- | 317 | 0 | 258 | 196 | -- | -- | -- | 895* | -- | -- | -- | -- | -- | -- |
| **D A R W I N   S A N D S T O N E** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19-46N-98W | 4,520-4,550 | 2f | -- | -- | -- | -- | -- | 155 | 41 | -- | 1,403 | -- | 525 | 24 | 2,008 | 743 | -- | -- | -- | 4,633** | -- | -- | -- | -- | -- | -- |
| 32-48N-90W | 4,903-4,950 | 2c | -- | -- | -- | -- | -- | 54 | 22 | -- | 19 | -- | 195 | 0 | 92 | 8 | -- | -- | -- | 291* | -- | -- | -- | -- | -- | -- |
| 29-55N-95W | 5,733-5,783 | 2j | -- | -- | -- | -- | -- | 361 | 102 | -- | 319 | -- | 195 | 0 | 727 | 38 | -- | -- | -- | 1,198* | -- | -- | -- | -- | -- | -- |

TABLE III-3 -- continued

| Well Location Section-Township-Range | Interval or depth (feet) | Study Area | Date of Collection | Temperature (oF) | Silica ($SiO_2$) | Total Iron (Fe) | Manganese (Mn) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | (Na + K) | Potassium (K) | Bicarbonate ($HCO_3$) | Carbonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Boron (B) | Dissolved Solids (residue at 180oC) | Hardness as $CaCO_3$: Calcium, Magnesium | Hardness as $CaCO_3$: Noncarbonate | Percent Sodium | Sodium adsorption ratio | Specific conductance (micromhos at 25oC) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MADISON LIMESTONE*** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 24-44N-98W | 3,431-3,490 | 2f | -- | -- | -- | -- | -- | 361 | 102 | -- | 319 | -- | 878 | 0 | 593 | 480 | -- | -- | -- | 2,287** | -- | -- | -- | -- | -- | -- |
| 19-46N-98W | 4,528-4,558 | 2f | -- | -- | -- | -- | -- | 677 | 140 | -- | 472 | -- | 1,488 | 0 | 1,568 | 312 | -- | -- | -- | 3,902** | -- | -- | -- | -- | -- | -- |
| 29-51N-100W | 4,246-4,276 | 2h | -- | -- | -- | -- | -- | 616 | 195 | -- | 448 | -- | 1,635 | 0 | 1,625 | 200 | -- | -- | -- | 3,889** | -- | -- | -- | -- | -- | -- |
| 29-55N-95W | 6,122-6,170 | 2j | -- | -- | -- | -- | -- | 238 | 51 | -- | 134 | -- | 230 | 0 | 856 | 12 | -- | -- | -- | 1,404* | -- | -- | -- | -- | -- | -- |
| 6-57N-97W | (from tank battery) | 2j | -- | -- | -- | -- | -- | 150 | 26 | -- | 83 | -- | 366 | 0 | 319 | 22 | -- | -- | -- | 780** | -- | -- | -- | -- | -- | -- |
| 25-58N-98W | 3,325-3,371 | 2j | -- | -- | -- | -- | -- | 134 | 38 | -- | 54 | -- | 268 | 0 | 360 | 10 | -- | -- | -- | 728* | -- | -- | -- | -- | -- | -- |
| MADISON LIMESTONE AND BIGHORN DOLOMITE | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18-2N-1W | 4,222 | 1b | 12/13/62 | -- | -- | -- | -- | 178 | 34 | 46 | -- | -- | 293 | 0 | 360 | 50 | -- | -- | -- | 930 | -- | -- | -- | 0.7 | -- | 7.4 |
| DEVONIAN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1-47N-100W | 5,828-5,841 | 2f | -- | -- | -- | -- | -- | 583 | 150 | -- | 304 | -- | 1,049 | 0 | 1,502 | 220 | -- | -- | -- | 3,276* | -- | -- | -- | -- | -- | -- |
| ORDOVICIAN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12-49N-91W | 2,830-2,880 | 2c | -- | -- | -- | -- | -- | 42 | 11 | -- | 98 | -- | 280 | 0 | 95 | 24 | -- | -- | -- | 408* | -- | -- | -- | -- | -- | -- |
| 35-9S-23E (Montana) | 5,940-5,990 | -- | -- | -- | -- | -- | -- | 440 | 97 | -- | 379 | -- | 537 | 0 | 1,450 | 264 | -- | -- | -- | 2,895* | -- | -- | -- | -- | -- | -- |
| CAMBRIAN | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19-47N-98W | 6,035-6,068 | 2f | -- | -- | -- | -- | -- | 222 | 46 | -- | 368 | -- | 670 | 0 | 753 | 150 | -- | -- | -- | 1,869* | -- | -- | -- | -- | -- | -- |
| 12-43N-96W | 2,370-2,520 | 2f | -- | -- | -- | -- | -- | 327 | 43 | -- | 778 | -- | 210 | 0 | 993 | 1,050 | -- | -- | -- | 3,294* | -- | -- | -- | -- | -- | -- |
| 29-51N-100W | 6,341-6,346 | 2h | -- | -- | --- | -- | -- | 450 | 10 | -- | 985 | -- | 44 | 0 | 1,337 | 1,333 | -- | -- | -- | 4,137** | -- | -- | -- | -- | -- | -- |

* TDS calculated.

** Water produced with oil; TDS calculated.

† Includes both bicarbonate and carbonate.

*** See pages 89 & 90 for additional data.

study area this amounts to:

| Study Area | Acre-feet Groundwater Available to Wells |
|---|---|
| 1. Wind River | 330,000 |
| 2. Bighorn River | 570,000 |
| 3. Little Bighorn River | --- |
| 4. Clarks Fork | 28,000 |
| Total | 928,000 |

Natural annual recharge to these aquifers is estimated to be 49,000 acre-feet in the Wind River Study Area, 125,000 acre-feet in the Bighorn River Study area, and 9,500 acre-feet in the Clarks Fork Study Area. Only a very small amount of the groundwater is beneficially consumed annually by man's activities in the report area. Most of the 183,500 acre-feet of annual natural recharge to unconsolidated aquifers discharges as base flows of surface streams, recharges consolidated aquifers, and evaporates. During times of lower than average precipitation, the normal water level declines, with a resultant decrease in the amount of groundwater in transient storage in the alluvium. Local irrigation practices may contribute abnormally large quantities of water as recharge to alluvial aquifers. When this happens, the water table may rise very high during periods of irrigation and decline when irrigation ceases, or the table may rise and not decline and cause water logging.

Stream terraces are gravel-capped remnants of earlier floodplains, now topographically higher than the streams due mainly to past geologic events. Where these remnants are areally extensive, the capping gravels may be potential aquifers. Because the gravels are topographically higher than the floodplain, they commonly discharge groundwater through gravity drainage in the form of springs and seeps. Terrace gravels are recharged by precipitation, and by irrigation in some places. Irrigation contributes a much greater amount of annual recharge than direct precipitation, but the quality of the contributed irrigation water may be poor. Irrigated terrace gravels are not included in the inventory of alluvial aquifers and available groundwater.

An enormous quantity of water is available in shallow underground storage in bedrock (within 1,000 feet of surface) in the report area. The following estimate is made for the Tertiary formations (uppermost 1,000 feet):

| Study Area | Acre-feet Groundwater Available to Wells |
|---|---|
| 1. Wind River | 35,000,000 |
| 2. Bighorn River | 47,000,000 |
| 3. Little Bighorn River | --- |
| 4. Clarks Fork | 3,000,000 |
| Total | 85,000,000 |

TABLE III-4 -- Availability of Groundwater

STUDY AREA 1 -- WIND RIVER DRAINAGE

Quaternary sediments -- Floodplain alluvium probably is capable of yielding 200+ gpm (gallons per minute) at most places. Yields of 60-100 gpm are reported in the upper Wind River drainage area, and to 300 gpm in the drainage area of the east Wind River tributaries. Depth to water generally is less than 20 feet.

Tertiary formations -- Hundreds of water wells tap the Wind River formation, but most have small yields. Well depths commonly are in the range 250-400+ feet, although a maximum depth of about 1,200 feet has been reported. The depth to water is 80-200 feet below the surface.

Small yields (± 25 gpm) are reported from the Fort Union formation. The potential for greater yields exists, if the entire aquifer (formation) thickness is penetrated by the well.

Cretaceous formations -- Sandstones of the Lance, Mesaverde, Cody, and Frontier formations reportedly yield 1-300 gpm. Water from the Mesaverde, Cody, and Frontier may be unfit for domestic uses and in some instances unpalatable to livestock (14).

The Cloverly and pre-Cretaceous formations -- The Cloverly formation is the principal source of domestic water in some parts of the Gas Hills area (Study Area 1e), producing from a depth range of 475-1,750 feet (14). Yields vary from 45 to 350 gpm. Jurassic and Triassic sandstones are known to yield small supplies to wells. The Nugget sandstone probably is capable of moderate yields.

Large yields are reported from Permian, Pennsylvanian, and Mississippian formations. A yield of 1,000 gpm is reported from a well on the flank of the Owl Creek Mountains, flowing from the Phosphoria-Tensleep-Madison interval. The Park City (Phosphoria) formation yields 150 and 700 gpm adjacent to the Beaver Divide (Study Area 1b), from depths of 269 and 408 feet.

Wells in the Tensleep yield variable quantities of water. Two wells on the edge of the Wind River Range reached the Tensleep at depths of 400 and 500 feet and flowed 75 and 100 gpm (14). A well drilled to supplement the Lander municipal supply flowed 500 gpm from a depth of 3,000 feet. The Chief Washakie Hot Springs in Section 2, Township 1 South, Range 1 West (Study Area 1b), which was flowing 1,200 gpm in 1945, is thought to have its source in the Tensleep.

The Madison limestone yields up to 600 gpm and probably is capable of greater yields. Madison wells have been drilled to depths greater than 1,600 feet.

TABLE III-4 -- Availability of Groundwater (Continued)

STUDY AREA 2 -- BIGHORN RIVER DRAINAGE

Quaternary sediments -- Floodplain alluvium and terrace gravels yield large supplies of water to wells. Yields up to 1,000+ gpm are reported in the valleys of the Greybull River and Dry Creek (Study Area 2h). A yield of 2,000 gpm is reported in the valley of Owl Creek (Study Area 2f). Much of the recharge to alluvial aquifers, especially the terrace gravels, is by irrigation. The shallow groundwater may be classified as "doubtful" to "unsuitable" for irrigation due to high salinity or high sodium content.

Tertiary formations -- The Willwood and Polecat Bench (Fort Union) formations yield small to moderate supplies of water (5-120 gpm) to wells. Yields probably could be increased in many cases if the entire saturated formation thicknesses were penetrated by wells.

Cretaceous formations -- Sandstones in the Mesaverde yield 5-200+ gpm.

The Cloverly and pre-Cretaceous formations -- The Tensleep, Amsden, Madison, Bighorn, and Flathead yield water to wells along the front of the Big Horn and Owl Creek Mountains. Numerous large-yield wells have been drilled along the front of the Big Horn Mountains in Study Area 2c. Most of the large yields (500-2,500+ gpm) are from the Madison limestone. The largest reported yield is 3,250 gpm from the Flathead, with contributions from overlying formations. All the large-yield wells were flowing when originally developed. Sandstones in the Dakota (Cloverly) yield small to moderate supplies.

The chemical quality of the water is good. Following are partial water analyses of samples collected by the USGS in 1962-1963 in the Tensleep-Hyattville area (6). Analyses are given in parts per million or as indicated for the Tensleep-Madison aquifer.

Well Location--Township North-Range West
Section Number

| | 50-90<br>14 | 49-89<br>24 | 49-89<br>28 | 48-88<br>9 | 47-87<br>6 | 47-88<br>21 | 47-89<br>12 | 46-87<br>21 | 44-87<br>8 | 43-87<br>11 | 48-89<br>8* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (feet) | 2,000 | 570 | 944 | --- | --- | 758 | 901 | 912 | 1,040 | 443 | 3,850 |
| Silica ($SiO_2$) | 7.9 | 9.9 | 9.4 | 8.9 | 9.9 | 7.3 | 8.3 | 9.6 | 8.0 | 11 | --- |
| Iron (Fe) | 0.05 | 0.03 | 0.00 | 0.25 | 0.01 | 1.0 | 0.71 | 2.3 | 0.07 | 0.00 | --- |
| Calcium (Ca) | 89 | 80 | 41 | 56 | 37 | 50 | 49 | 58 | 43 | 43 | 31 |
| Magnesium (Mg) | 47 | 33 | 21 | 24 | 17 | 21 | 25 | 28 | 16 | 22 | 12 |
| Sodium (Na) | 12 | 7.2 | 1.5 | 2.0 | 1.8 | 12 | 2.4 | 3.0 | 1.3 | 1.4 | 10 |

TABLE III-4 -- Availability of Groundwater (continued)

| | 50-90<br>14 | 49-89<br>24 | 49-89<br>28 | 48-88<br>9 | 47-87<br>6 | 47-88<br>21 | 47-89<br>12 | 46-87<br>21 | 44-87<br>8 | 43-87<br>11 | 48-89<br>8* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Potassium (K) | 3.0 | 2.2 | 1.0 | 1.4 | 0.8 | 3.6 | 2.1 | 1.4 | 1.2 | 1.8 | 6.3 |
| Bicarbonate ($HCO_3$) | 176 | 259 | 225 | 290 | 194 | 217 | 256 | 289 | 166 | 228 | 159 |
| Sulfate ($SO_4$) | 272 | 118 | 2.0 | 2.0 | 1.0 | 56 | 15 | 24 | 34 | 9.0 | 22 |
| Chloride (Cl) | 2.5 | 5.5 | 0.5 | 2.5 | 1.5 | 3.0 | 2.0 | 2.0 | 1.0 | 1.0 | 1.7 |
| Nitrate ($NO_3$) | 4.6 | 8.8 | 2.0 | 5.5 | 2.4 | 0.0 | 0.5 | 0.0 | 0.0 | 1.0 | 0.0 |
| Boron (B) | 0.06 | 0.05 | 0.02 | 0.03 | 0.00 | 0.04 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 |
| Dissolved Solids | 560 | 410 | 202 | 246 | 168 | 266 | 232 | 282 | 188 | 202 | 166 |

(*Analysis of Flathead sandstone water reported by the Wyoming Department of Agriculture)

The Big Horn Hot Springs in the vicinity of Thermopolis (Study Area 2a) flow large quantities of hot water (135° F) from a number of springs which are thought to originate within the Tensleep-Amsden-Madison interval.



## STUDY AREA 3 -- LITTLE BIGHORN RIVER DRAINAGE

This is a small area in Wyoming, surfaced by Cretaceous and pre-Cretaceous formations inclined steeply towards the east and the Powder River geological basin. Water probably is available in numerous formations, including the Lance, Mesaverde, Shannon, Frontier, Cloverly, Tensleep, Amsden, Madison, and perhaps the Big Horn and Flathead. Two of the better potential aquifers are the Tensleep and Madison. Depths to these aquifers increase rapidly east of the Big Horn Mountains.

## STUDY AREA 4 -- CLARKS FORK (OF THE YELLOWSTONE RIVER) DRAINAGE

Information is sparse for this part of the report area. From information available in nearby areas, the following estimate of groundwater availability is made: the alluvium in the valley of the Clarks Fork should provide well yields of several hundred (perhaps 500+) gpm; small to moderate well yields should be possible from Tertiary sandstones at relatively shallow depths; Cretaceous sandstones are known to be water bearing and probably would yield small to moderate supplies of water to wells; large yields most likely could be obtained from the Madison limestone and perhaps other pre-Cretaceous formations, but at depths beyond economic feasibility for most uses.

By estimate, about 85,000,000 acre-feet of groundwater in the uppermost 1,000 feet of Tertiary bedrock in the Basin are available to wells. The large quantity of water is due to the great areal extent of the Tertiary aquifer material and the thick aquifer interval below the water table. Annual recharge to bedrock aquifers is much less than the quantity of water in storage. Recharge effects to Tertiary bedrock aquifers are not always apparent because of the distances water must travel underground from recharge areas to places of withdrawal. Older bedrock aquifers, mostly below 1,000 feet excepting near the mountains or in uplifted areas, have much additional water in storage. The geologically older formations are thousands of feet below the surface in the centers of the geologic basins, and gradually rise to or near the surface along the basin rims. Flanking the mountain cores which rim sections of the basins, some of these older formations are inclined at angles of $45^{0}$ or greater towards the basin centers. Steeply inclined formations provide conduits which transmit recharge to aquifers and, in cases where the formations are impervious, provide confining covers and floors for artesian aquifers. Fractures and faults[3] locally increase aquifer permeability and therefore enhance the availability of groundwater. Intense faulting has also been known to cut off an aquifer from its source of recharge, and create barriers to groundwater movement.

The quality of groundwater affects its availability for a specific use. Generally, water quality is better near the outcrop (recharge) areas and deteriorates towards the centers of the geologic basins. Alluvial groundwater has from 250 ppm (mg/l) TDS (rated good) to 4,600 ppm (mg/l) TDS (rated poor), and commonly has less than 1,000 mg/l (rated good to fair). The quality of groundwater in the floodplain alluvium and terrace deposits is influenced by the quality of applied irrigation water.

In the Riverton area (Study Area 1 d) the concentration of TDS tends to be variable at shallow depths, but uniformly lower at greater depth. Water from most of the wells that are 300 feet or more in depth in the Wind River formation contains less than 1,000 ppm (mg/l) TDS. The sulfate content, however, exceeds the desired limit of 250 mg/l unless TDS concentrations are less than 500 mg/l. Sodium sulfate is a precipitate that sometimes leaves a salt deposit on the ground. Sulfate and iron concentrations are higher than desirable in many water supplies in the study area (9).

Sulfate is a common constituent in groundwater in much of the entire report area. Relatively high TDS concentrations are also common. For example, the TDS range in the Owl Creek area (Study Area 2 f) is 1,830 to 11,600 ppm (1). The highest TDS concentrations reported in the Bighorn River Basin are in the range 33,000-44,000 ppm, from groundwater in the Chugwater group and Phosporia formation, at subsurface depths of 2,300 to 10,000 + feet (refer to Table III-3).

Occurrences of selenium are reported in the Gas Hills Uranium District, at the southeastern boundary of Study Area 1 e (see Figures III-2 and IV-4). The selenium is erratically distributed in small irregular bodies, and is found as interstitial material above, below, and adjacent to lenses of uranium ore (17). Selenium is toxic to humans and may be toxic to livestock. The maximum recommended concentration of selenium for drinking water is 0.01 mg/l (3). Water containing 0.4-0.5 mg/l is believed to be nontoxic to cattle, while water containing more than 0.5 mg/l

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[3] In geology, a fault is a break in the continuity of a body of rock, usually indicated by up or down movement on either side of the break. The amount of movement may be inches or thousands of feet.

should be used with caution.[4] The intake of selenium by animals is mainly from vegetation, especially where some of the local plant species are particularly notable for taking up selenium from the soil. Some plants in the Western U.S. have been found to contain several thousand milligrams of selenium per kilogram of dry plant parts. Drainage water from seleniferous irrigated soil in Colorado has been reported to contain as much as 1 mg/l of dissolved selenium. This type of water, as collected from a drainage ditch in Mesa County, Colorado, is so high in dissolved solids (10,900 mg/l) that it most likely would not be used for domestic or livestock water (3).

Radioactive elements are not commonly reported as mineral constituents in groundwater. The presence of mineable uraniferous ore bodies in the Gas Hills area suggests the possibility of such elements being found in underground waters. Public Health Service standards have been adopted for general use if the presence of radioactive minerals is detected in water supplies (3).

## USE OF GROUNDWATER

Domestic and stock uses require low-yield intermittent water production from wells. Adequate sources of groundwater usually can be found at shallow depths (above a subsurface depth of 100 feet) although some wells have to be drilled much deeper because either the shallow formations contain little available water, or the quality of the shallow groundwater is not satisfactory. It is estimated that about 4,000 to 5,000 acre-feet of groundwater are consumed annually by these uses.

The total municipal population of the report area is about 43,300 persons. Of this number, about 17,100 persons are entirely dependent upon groundwater for water supplies. The depletion attributed to this use is about 1,700 acre-feet per year; the withdrawal is approximately twice this amount.

Industry uses a large quantity of groundwater. The petroleum industry withdraws more than 50,000 acre-feet of groundwater annually, some by oil-producing wells, and some by wells drilled specifically for water. Water that is withdrawn with oil is disposed of as waste, or injected into the oil-bearing formation to produce more oil. Almost all the water produced from water wells is used for waterflooding oil fields through injection wells. The water that is injected for this purpose is considered to be consumed. Approximately 25,000 acre-feet of groundwater was consumed in waterfloods in 1967. It is estimated that 33,000 acre-feet will be consumed in 1972.

The uranium industry consumes about 1,000 acre-feet annually in the milling process. The mining operation does not require water (except perhaps as a means of controlling dust), but does withdraw groundwater to dewater the working area inasmuch as the mineable orebodies usually have been found at or beneath the water table. Recently uranium producers have started filing permits to appropriate large amounts of groundwater produced by dewatering for irrigating reclaimed land.

A relatively small amount of groundwater is presently used as the original water supply for agricultural irrigation. According to information received in the State Engineer's Office, approximately 6,140 acres of irrigated land in the

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[4] Selenium was not detected or showed only a trace in samples of water from the Wind River formation of the Gas Hills area that were analyzed for selenium (14).

report area were using groundwater as the original water supply in 1970 (see Table III-5). Based on field observations elsewhere in Wyoming, it is estimated that only 75 percent of these acres actually were irrigated. Table III-6 shows that an estimated 22,000 acre-feet of groundwater were withdrawn for irrigation; about 9,800 acre-feet were consumed by agricultural crops. An estimated additional 3,000 acre-feet were used as supplemental irrigation supplies.

TABLE III-5 -- An Historical Record of Acres Irrigated with Groundwater as the Original Supply (Based on State Engineer Permit Records)

| County | Pre-1950 | 1950-1955 | 1956-1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Big Horn | 82 | 655 | 144 | 168 | 367 | 573 | -- | -- | 5 | -- | 34 | -- | -- | 1,331 | 3,359 |
| Fremont | 10 | 24 | 177 | -- | 1 | 25 | -- | 107 | 11 | -- | -- | 4 | 1 | 3 | 363 |
| Hot Springs | 288 | 842 | 134 | -- | -- | -- | -- | -- | -- | -- | -- | 3 | -- | 327 | 1,594 |
| Park | -- | -- | -- | 2 | -- | -- | -- | -- | -- | -- | 10 | -- | -- | 160 | 172 |
| Washakie | 22 | -- | -- | -- | 63 | -- | 70 | -- | 391 | -- | -- | -- | -- | 106 | 652 |
| Total | 402 | 1,521 | 455 | 170 | 431 | 598 | 70 | 107 | 407 | -- | 44 | 7 | 1 | 1,927 | 6,140 |

TABLE III-6 -- Summary of Irrigation Using Groundwater as the Original Supply

| Study Area | Acres Irrigated Using Groundwater as Original Supply, by Permits | | Average Consumptive Use [1] (Acre-Feet/Acre) | Estimated Annual Consumptive Use, Based on Permits (Acre-Feet) | | Estimated Annual Withdrawal, Based on Permits [2] (Acre-Feet) | | Estimated Annual Withdrawal, Based on 75% of Permit Acreage [3] (Acre-Feet) | |
|---|---|---|---|---|---|---|---|---|---|
| 1a | ----- | | 1.5 | ------- | | ----- | | ----- | |
| 1b | 120 | | 1.8 | 216 | | 480 | | 360 | |
| 1c | ----- | | 1.7 | ------- | | ----- | | ----- | |
| 1d | 163 | | 2.0 | 326 | | 725 | | 544 | |
| 1e | 81 | | 1.7 | 137.7 | | 306 | | 229 | |
| Total | | 364 | | | 679.7 | | 1,511 | | 1,133 |
| 2a | 383 | | 2.3 | 880.9 | | 1,958 | | 1,469 | |
| 2b | 20 | | 1.8 | 36 | | 80 | | 60 | |
| 2c | 2,270 | | 1.9 | 4,313 | | 9,585 | | 7,189 | |
| 2d | 5 | | 1.9 | 9.5 | | 20 | | 15 | |
| 2e | ----- | | 2.0 | ----- | | ----- | | ----- | |
| 2f | 1,218 | | 2.0 | 2,436 | | 5,413 | | 4,060 | |
| 2g | 10 | | 1.7 | 170 | | 378 | | 283 | |
| 2h | 1,708 | | 2.5 | 4,270 | | 9,489 | | 7,117 | |
| 2i | 2 | | 1.9 | 3.8 | | 8 | | 6 | |
| 2j | ----- | | 2.3 | ----- | | ----- | | ----- | |
| Total | | 5,616 | | | 12,119.2 | | 26,931 | | 20,199 |
| 3 | ----- | ----- | 1.8 | ----- | -------- | ----- | ------ | ----- | ------ |
| 4 | 160 | 160 | 1.9 | 284 | 284 | 631 | 631 | 473 | 473 |
| TOTAL (1970) | | 6,140 | (2.1-Basin average) | | 13,082.9 [4] | | 29,073 | | 21,805 |

[1] In addition to normal effective precipitation.

[2] The amount of water actually applied to the land is greater than the amount consumptively used and depends largely on climatic factors and the method of applying the water.

[3] The number of irrigated acres reported on a permit usually is greater than the number finally irrigated. The estimate of validity used here is based on random sampling.

[4] Based on the estimate of 75 percent validity, the amount consumed by agricultural crops is 9,812.2 acre-feet.

Groundwater issuing from springs near the towns of Cody and Tensleep is used for fish culture. It is estimated that combined flows amounting to 16,800 acre-feet per year support fish hatcheries in the Basin.[5]

The northwestern part of the Basin adjoins Yellowstone National Park, which is a high volcanic plateau of many known high-temperature hot springs and geysers. The park includes within its boundary the potential for geothermal energy production. Thermal areas within the park are, naturally, unavailable for the production of energy. Several localities outside the park boundary, in the report area, may be valuable for geothermal resources (16). The development of geothermal resources could produce large flows of hot, mineralized groundwater that might be desalted and assimilated in the available water supply (see Figure IV-4).

## POTENTIAL GROUNDWATER DEVELOPMENT

Groundwater will continue to be used extensively for rural domestic and livestock supplies. The amounts used for these purposes will increase, as the human and livestock populations increase.

The municipal populations served exclusively by groundwater are projected to increase, and water requirements will increase accordingly.

The industrial use of groundwater is projected to increase considerably in the uranium sector. The annual consumptive use will increase 15-fold (to 15,000 acre-feet) by the year 2000. All of this increase is projected to occur in the Gas Hills Uranium District (Study Area 1 e) in the Wind River Basin. It is assumed that the groundwater will be obtained from consolidated aquifers of Tertiary ( and perhaps earlier) age.

Between now and the year 2000, the annual consumptive use of groundwater for waterflooding oil fields (Figure IV-3) is projected to decrease. A slight increase in the consumptive use by the gypsum industry (in Big Horn County) is projected. The total amount of groundwater consumptively used annually by industry in the year 2000 is projected to be about 25,800 acre-feet (refer to Table IV-10).

At present only a slight annual increase in the number of acres irrigated with groundwater is projected. It is estimated that about 500 acres of new land will be irrigated annually with groundwater. At this rate (500 acres per year) there will be a total of about 21,000 acres of land in the report area irrigated with groundwater by the year 2000. Much of the new development with groundwater most likely will occur near the mountain fronts, in localities where large sustained yields (±1,000 gpm) of suitable water can be obtained economically from wells. One drawback to local development may be the type of soil that would be irrigated. In areas where the soil was formed of ( or on ) dark colored shales, the sodium or salinity hazard may be great. Referring to Figure III-1, the large horseshoe-shaped area outlined by the exposure of Cretaceous formations, open to the northwest, is prospective for the development of large-yield wells from relatively shallow depths in the Bighorn Basin. The area outlined by Cretaceous exposures in the Wind River Basin is discontinuous and much less extensive, but is also prospective for the development of large-yield wells from relatively shallow depths. The bands of Cretaceous outcrops provide a confining cover for the basinward-inclined limestone and sandstone aquifers of earlier geologic ages which are effectively recharged

5 From a report in preparation by the USGS Water Resources Division, Cheyenne.

at higher elevations in the mountainous areas. Wells which are drilled through the Cretaceous formations into underlying aquifers usually tap artesian groundwater supplies. In certain areas, such as in the vicinity of Tensleep and Hyattville (Study Area 2 c), many of the artesian wells flow water to the surface.

Projections have not been made concerning the potential development of geothermal resources. It is conceivable that geothermal steam, or very hot thermal springs, may be discovered near the Yellowstone National Park boundary (or elsewhere in the report area) and may be utilized to produce electricity, with potable water as a byproduct (see Figure IV-4, page 123).

## DATA NEEDS AND ACQUISITION

The report area is not now a region of intense groundwater use. The use of groundwater is projected to increase in the industrial sector, and probably in the agricultural sector as well. Most of the increased withdrawals will be from consolidated aquifers at intermediate depths (1,000-5,000 feet below the surface).

Some groundwater data has been collected in the past by the USGS and others. A hydrologic atlas of the Wind River Basin (14) has been published, and a similar atlas of the Bighorn Basin is being prepared for publication by the USGS. Almost all the observation wells being monitored in the report area are within the boundaries of the Wind River Indian Reservation, and are no deeper than the Wind River formation. It is not too early to be looking for additional candidate wells that will provide data on the water levels and pressure surfaces of deeper aquifers, in areas where future groundwater development might occur.

Additional basic geologic data need to be collected and evaluated. This is a necessity in areas where carbonate and other potential large-yield aquifers are exposed in mountainous (recharge) areas. Data of this type will be useful in evaluating potential dam sites and transportation routes as well as in evaluating the groundwater hydrology.

Very little can be surmised about the potential for development of geothermal resources. The possibility of such development should be considered, and basic geothermal data should continue to be collected and evaluated.

If detailed hydrologic studies of specific areas are contemplated, the active uranium districts should be included for three reasons: (1) Mining uranium does not require the use of industrial water, but the mining areas usually are dewatered of large quantities of groundwater before and during mining operations. (2) Groundwater supplies the water for milling operations. The projected increase in uranium production will require the use of more water, which suggests the possibility that "mining" of groundwater may occur. (3) Land reclamation in strip-mined areas will require irrigation.

# CHAPTER IV

# THE ECONOMY AND RELATED WATER USES

# THE ECONOMY AND RELATED WATER USES

## AGRICULTURE

There are about 13,100,007 acres of land area and 79,038 acres of water area in the Basin. The total area is 13,179,045 acres or 20,592 square miles.

The descriptions of agriculture and statistical data on agricultural activities in the Basin are based on county data except for irrigated acreage data which was obtained by field mapping and is reported by drainage basin. Big Horn, Fremont, Hot Springs, Park, and Washakie Counties are representative of conditions within the Basin. Parts of Fremont, Park, and Washakie Counties are outside the drainage area. Portions of Natrona, Sheridan, Johnson, Teton, and Sublette Counties lie within the drainage boundary (see Figure I-1).

According to the U. S. Census of Agriculture, the total land area of farms and ranches in the representative five-county area increased from 5.4 million acres in 1959 to 5.9 million acres in 1964, then decreased to 5.3 million acres in 1969.

Dry cropland and summer fallow land total about 4,000 acres in the five-county area. There are 538,830 acres of irrigated land within the drainage boundary of the Basin. In terms of acres, the most important land use is for livestock grazing. Many of the livestock operators are dependent upon grazing leases on Federal land to supplement feed grown on ranches. About 60.1 percent of the Basin drainage area is owned or administered by the Federal government. These Federal lands are mainly used for livestock grazing and other multiple uses except badlands and lands where livestock is not permitted due to watershed management or other specific uses.

### Present Economy

Agriculture is an important segment of the economy in the Basin. This has been true historically and can be expected to continue. Despite the decline in farm numbers and farm operators, agriculture is an expanding industry in the Basin. This inverse relationship between expanding production and declining farm population stems from the increase in farm efficiency through the use of conservation programs, improved technology, feed additives, fertilizers, pesticides, and modern farm machinery. Further increases in efficiencies are expected through the year 2020. The total consumption of agricultural products will expand as the population of the area and the Nation increases. Rising personal income leads to additional expenditures for beef and other food products. These trends should provide a growing market for agricultural products. The area has a potential for producing much more than its present production.

The Basin has followed the national trend of larger but fewer farms. The number of farms declined from 3,501 in 1954 to 2,275 in 1969, a reduction of 35 percent over a fifteen year period. There are 1,798 commercial farms and 477 part-time, retirement, and other non-commercial farms in the Basin. During the period 1954 to 1969, sales per farm increased from $8,900 to $27,700. During the same period the average size of farm and ranch unit increased from 1,490 acres to 2,340 acres (see Table IV-1). Average farm size has a limited significance in an area where farm and ranch units vary from those specializing in intensive row crops to those with extensive ranch livestock operations.

TABLE IV-1--Farm Numbers, Average Farm Size and Value of Farm Products Sold, 1954-1969, Five-County Area[1]

| Item | Unit | 1954 | 1959 | 1964 | 1969 |
|---|---|---|---|---|---|
| All Farms and Ranches | Number | 3,501 | 2,953 | 2,650 | 2,275 |
| Average Farm Size | Acres | 1,490 | 1,843 | 2,243 | 2,340 |
| Total Sales All Agricultural Products | Thousand Dollars | 31,255.1 | 42,705.7 | 42,062.9 | 63,083.3 |
| All Crops and Farm Forest Product Sales | Thousand Dollars | 11,720.3 | 12,526.5 | 13,914.3 | 18,350.3 |
| All Livestock Sales | Thousand Dollars | 15,215.8 | 30,179.2 | 28,148.6 | 44,733.0 |
| Average Sales Per Farm | Thousand Dollars | 8.9 | 14.5 | 15.9 | 27.7 |

[1] Bighorn, Fremont, Hot Springs, Park, and Washakie Counties.

Source: U. S. Census of Agriculture.

Many farmers in the area supplement their income with jobs off the farm. In 1969, about 1,081 farm operators worked off their farms. Sixty-six percent of those with off-farm employment worked at these jobs 100 days or more. Employees in agriculture declined from 7,413 in 1940 to 3,521 in 1970.

The agricultural census shows that the value of all farm products sold increased from $31,255,100 in 1964 to $63,083,300 in 1969 for the five-county area. During the same period livestock sales increased from $15,215,800 to $44,733,000.

In 1969 the sale of livestock and livestock products was about 70.9 percent of the sale of all farm products. Crop sales amounted to about 29.1 percent of the total agricultural sales. Average sales per farm in 1969 varied from $20,365 in Fremont County to $51,536 in Washakie County. County-census data for 1969 is summarized in Table IV-2, and includes farm and ranch sales of livestock, crops, production expense, number of farms, farm size, and sales per farm.

The Statistical Reporting Service reports show that in the five-county area, all cattle and calves on hand January 1 increased from 189,000 head to 320,800 head or an increase of 69.7 percent for the period 1950 to 1970. During the same period sheep numbers decreased from 363,000 to 307,800 head or a decline of 15.2 percent.

TABLE IV-2 -- Farm and Ranch Income and Sales, Production Expense, Number of Farms and Farm Size, 1969 Census of Agriculture, County Data

| Item | Unit | County[1] | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Big Horn | Fremont | Hot Springs | Park | Washakie | |
| All Agricultural Products | Dollars | 12,859,478 | 15,681,404 | 4,211,950 | 20,126,278 | 10,204,211 | 63,083,321 |
| All Livestock, Poultry and Product Sales | Dollars | 8,154,933 | 12,503,818 | 3,965,949 | 13,161,310 | 6,947,010 | 44,733,020 |
| All Livestock and Products as a Percent of All Products | Percent | 63.42 | 79.74 | 94.16 | 65.39 | 68.08 | 70.91 |
| All Crop and Hay Sales | Dollars | 4,704,149 | 3,177,486 | 244,801 | 6,964,968 | 3,257,201 | 18,348,605 |
| All Crops Sold as a Percent of All Agricultural Products Sold | Percent | 36.58 | 20.26 | 5.81 | 34.61 | 31.92 | 29.09 |
| Forest Product Sales | Dollars | 396 | 100 | 1,200 | -- | -- | 1,696 |
| Forest Products as a Percent of All Agricultural Products | Percent | -- | -- | .03 | -- | -- | -- |
| Farm Production Expense | Dollars | 10,269,248 | 13,442,436 | 3,584,246 | 18,042,144 | 8,480,692 | 53,818,766 |
| Farms and Ranches | Number | 539 | 770 | 126 | 642 | 198 | 2,275 |
| Average Farm Size | Acres | 975 | 3,249 | 6,385 | 1,817 | 1,648 | 2,341 |
| Average Sales per Farm | Dollars | 23,858 | 20,365 | 33,428 | 31,349 | 51,536 | 27,729 |

[1] Part of Fremont, Park and Washakie Counties are outside the drainage area. A portion of Natrona, Sheridan and Johnson Counties and minor areas of Federal land in Teton and Sublette Counties lie within the drainage boundary.

The Basin has also experienced some shifts in crop production. Barley, corn, hay, and sugar beets have shown moderate to large increases in acres and production for the period 1950 to 1970. Oat acreage and production have shown some decline while wheat and bean acreage and production are down sharply for the period. Total crop production in the Basin has shown a significant increase. Most of the increased production resulted from increased yields as there was only about a 9.4 percent increase in irrigated cropland during the period 1950 to 1970.

## Dry Cropland

There are about 2,600 acres of dry cropland hay and grain and 1,400 acres of summer fallow in the Basin.

## Irrigated Lands

The irrigated lands of the Basin were mapped during the irrigation season of 1969. Irrigated lands conform to the drainage boundary of the Basin and include the Wind, Bighorn, Clarks Fork, and Little Bighorn drainage basins. For the mapping program, irrigated land was defined as "all land that can be identified as receiving water induced by the works of man." Lands irrigated directly by ditches, sprinklers or other means, as well as subirrigated lands and seeped areas under ditches, were identified. This category included lands on small streams with erratic water supplies and lands under ditch systems that apparently are not irrigated every year. The idle lands also include lands on which a crop was planted but not harvested. The idle lands were subtracted from total irrigated lands to determine the average annual irrigated acreage.

There are about 6,140 acres of land irrigated with groundwater as the original supply. The remainder of the irrigated lands are supplied from surface flows and storage. The total water supply is about 84 percent of total needs in an 80-percent-chance year.

There are 538,830 acres of irrigated lands in the drainage basin, of which 29,190 acres are classed as idle. The average area irrigated is about 509,640 acres (see Table IV-3).

TABLE IV-3--Tabulation of Irrigated Land in the Bighorn River Basin

| Study Area[1] | Total Irrigated Acres | Idle Acres | Average Acres Irrigated |
|---|---|---|---|
| Wind River | 195,770 | 10,605 | 185,165 |
| Bighorn River | 329,500 | 17,850 | 311,650 |
| Little Bighorn River | 2,440 | 130 | 2,310 |
| Clarks Fork | 11,120 | 605 | 10,515 |
| Total | 538,830 | 29,190 | 509,640 |

[1] See Figure II-6.

Source: Wyoming Water Planning Program.

## Economic Importance of Agriculture

Irrigated land to provide a winter feed base for the livestock enterprise is a necessary component of the ranch enterprise. The production of cash crops on irrigated land is an important part of agricultural production and many operators depend entirely on crop sales for cash income. However, livestock and livestock products are the principal sources of cash income.

Current normal crop distribution, yields, value of production, and returns to land are summarized in Table IV-4 for the irrigated lands in the Basin. The estimated gross annual value of crop and pasture production on irrigated lands in the Basin is about $32,522,630. The net return to irrigated lands in the Basin is about $7,964,860. The net return to irrigated land in Table IV-4 does not necessarily measure the full value of irrigated lands to the farm and ranch enterprise as essentially all hay and feed grains produced are marketed through livestock. Most of the cash crops produced provide a moderate to high net return to land and management.

TABLE IV-4 -- Bighorn River Basin - Summary of Current Normal Crop Distribution, Yield, Production, Value of Production, Production Costs and Net Return to Irrigated Land

| Crop | Acres | Yield Per Acre [1] | | Production | Price [2] | Value of Production (Dollars) | Production Cost (Dollars) | Net Return [3] to Land (Dollars) |
|---|---|---|---|---|---|---|---|---|
| Alfalfa | 146,000 | 2.8 | ton | 408,800 | 21.88 | 8,944,540 | 8,786,280 | 158,260 |
| Native Hay | 10,400 | 1.2 | ton | 12,480 | 21.88 | 273,060 | 273,210 | -150 |
| Other Hay | 25,000 | 1.3 | ton | 32,500 | 21.88 | 711,100 | 785,750 | -74,650 |
| Barley | 49,400 | 64.0 | Bu. | 3,161,600 | 1.30 | 4,110,080 | 2,446,780 | 1,663,300 |
| Oats | 28,900 | 55.0 | Bu. | 1,589,500 | .67 | 1,064,960 | 1,413,500 | -348,540 |
| Wheat | 2,700 | 38.6 | Bu. | 104,220 | 1.13 | 117,770 | 133,730 | -15,960 |
| Corn (Grain) | 3,400 | 61.4 | Bu. | 208,760 | 1.23 | 256,770 | 220,460 | 36,310 |
| Corn (Silage) | 15,200 | 15.0 | ton | 228,000 | 7.66 | 1,746,480 | 1,102,150 | 644,330 |
| Sugar Beets | 42,000 | 17.2 | ton | 722,400 | 14.73 | 10,640,950 | 6,741,840 | 3,899,110 |
| Beans | 15,000 | 16.47 | cwt. | 247,050 | 7.35 | 1,815,820 | 1,185,750 | 630,070 |
| Pasture | 168,000 | 3.0 | AUM [4] | 504,000 | 4.00 | 2,016,000 | 1,468,320 | 547,680 |
| Other Crops | 3,640 | | | | | | | |
| Aftermath Grazing [5] | | | AUM | 206,275 | 4.00 | 825,100 | | 825,100 |
| Idle | 29,190 | | | | | | | |
| | 538,830 | | | | | 32,522,630 | 24,557,770 | 7,964,860 |

[1] Four year average 1967-1970, all crops except hay which is three year average 1967-1969.

[2] Average prices 1967 to 1970. Silage estimated at 35 percent of hay price. Malting barley was estimated at $3.00 per cwt. and feed barley at $.95 per Bu. for a composite price of $1.30 per Bu.

[3] Gross value of production, less fixed costs of production, operating costs and all other production costs except interest on land investment.

[4] Animal unit month grazing.

[5] Aftermath grazing yields are estimated at 1.0 AUM for native hay and other hay, 0.5 AUM for alfalfa and 1.25 AUM per acre for small grain.

Source: Wyoming Water Planning Program, the University of Wyoming Agricultural Sector Study, and other University of Wyoming data on costs of production.

University of Wyoming production cost data developed for the Agricultural Sector Study were used for estimating production costs. These figures include all costs of production, interest on invested capital, and labor costs, but do not include interest on land investment.

Secondary benefits stemming from or induced by irrigation in the community include increased income to service industries, local business establishments and processors of agricultural products. A significant portion of the net income of the irrigation enterprise is spent for family living and supports local business establishments and service industries. Farm and ranch operators are dependent upon imports for machinery, fuels, tools, and supplies. A major portion of crop-production costs on irrigated land, estimated at $24,557,770, flows through local business channels. In many communities of the Basin irrigation and the associated livestock industry provide the major economic base for supporting local business activity.

The percent of local taxes generated by agriculture varies considerably between counties. The 1971 assessed valuation of selected items used by agriculture is tabulated in Table IV-5. In the five-county area, agriculture provides about 13 percent of the total assessed valuation. The percent of total valuation varies from 9.15 percent in Hot Springs County to 21.67 percent in Washakie County.

TABLE IV-5 -- Assessed Valuation, 1971 Selected Items, Land, Improvements, Livestock and Machinery

| Item | COUNTY [1] Big Horn (dollars) | Fremont (dollars) | Hot Springs (dollars) | Park (dollars) | Washakie (dollars) | Total (dollars) |
|---|---|---|---|---|---|---|
| Land | | | | | | |
| Suburban | 14,198 | 178,782 | 36,917 | 276,661 | 97,157 | 603,715 |
| Irr. Land First Class | 1,074,767 | 758,519 | 255,234 | 1,481,986 | 1,231,859 | 4,802,365 |
| Irr. Land Second Class | 1,430,549 | 1,401,495 | 204,308 | 1,178,387 | 261,501 | 4,476,240 |
| Uncultivated w/ Water Rights | 101,197 | 119,046 | 62,894 | 158,389 | 43,669 | 485,195 |
| Irrigated Pasture | 178,585 | 136,101 | 9,275 | 37,940 | 8,195 | 370,096 |
| Dry Farmlands | -- | 3,611 | 650 | -- | 1,980 | 6,241 |
| Grazing Land | 387,050 | 1,501,051 | 778,900 | 1,294,096 | 611,024 | 4,572,121 |
| Subtotal | 3,186,346 | 4,098,605 | 1,348,178 | 4,427,459 | 2,255,385 | 15,315,973 |
| Total Improvements on Land | 2,195,320 | 6,012,435 | 973,968 | 5,802,154 | 1,653,487 | 16,637,364 |
| Livestock | | | | | | |
| Cattle | 1,225,465 | 2,880,735 | 1,043,185 | 1,768,345 | 861,735 | 7,779,465 |
| Horses and Mules | 41,135 | 164,550 | 31,600 | 179,455 | 24,665 | 441,405 |
| Sheep | 355,439 | 344,608 | 137,012 | 202,635 | 231,085 | 1,270,779 |
| Other Livestock | 12,091 | 27,476 | 1,559 | 17,260 | 5,522 | 63,908 |
| Dogs, Furbearing Animals, Poultry and Bees | 7,885 | 45,416 | 1,187 | 8,119 | 2,600 | 65,207 |
| Subtotal | 1,642,015 | 3,462,785 | 1,214,543 | 2,175,814 | 1,125,607 | 9,620,764 |
| Machinery and Equipment [2] | | | | | | |
| Farm Machinery | 174,445 | 178,255 | 62,860 | 205,180 | 111,920 | 732,660 |
| Threshing Machines and Hay Balers | 115,185 | 291,803 | 40,096 | 323,427 | 153,706 | 924,217 |
| Tractors | 345,552 | 439,983 | 120,397 | 479,137 | 241,315 | 1,626,384 |
| Engines, Gasoline and Steam | 1,100 | 600 | 11,071 | 12,570 | 42,020 | 67,361 |
| Saddles and Harness | 5,670 | 22,189 | 7,569 | 24,132 | 3,355 | 62,915 |
| Subtotal | 641,952 | 932,830 | 241,993 | 1,044,446 | 552,316 | 3,413,537 |
| Total Agriculture | 7,665,633 | 14,506,655 | 3,778,682 | 13,449,873 | 5,586,795 | 44,987,638 |
| Total Assessed Valuation | 39,508,305 | 114,480,505 | 41,284,892 | 124,333,288 | 25,775,575 | 345,382,565 |
| Agriculture - Percent of Total Assessed Valuation | 19.40 | 12.67 | 9.15 | 10.82 | 21.67 | 13.02 |

[1] Part of Fremont, Park, and Washakie Counties are outside the drainage area. A portion of Natrona, Sheridan and Johnson Counties and minor areas of Federal land in Teton and Sublette Counties lie within the drainage boundary.
[2] Does not include motor vehicles or miscellaneous tools and equipment.
Source: State Board of Equalization, 1971 Annual Report.

Agriculture, when measured by employment, is the third largest industry in the Basin.

## Projections of Future Conditions

The agricultural enterprises with the greatest potential for future expansion are livestock production, mainly beef, and the feed grains and forage crops needed to support the livestock industry. Sugar beets and malting barley also have potential for future expansion for both acres and total production. The acreage of beans and oats is expected to decline in the future.

The past national trend shows a sharp increase in per capita beef consumption and a decrease in lamb and mutton consumption. This trend is expected to continue. Projected national needs for lamb and mutton indicate no additional lamb and mutton production will be needed by 1980. A national increase in lamb and mutton production by the year 2020 is projected. It is estimated that the Wyoming share of lamb and mutton production will be slightly higher than the current Wyoming share. National beef and veal production is projected to increase by about 142 percent by 2020.

It is estimated that the projected increase in yields and a modest increase in irrigated lands will provide the feed grains and forage necessary for livestock producers in the Basin to maintain their projected share of national beef, veal, lamb, and mutton production. The present and future status of irrigated lands and new lands projected for development are tabulated in Table IV-6. The acreage of irrigated land is projected to increase by 25 percent in the next 50 years, from 538,830 to 675,500 acres.

TABLE IV-6--Projected Acreage of Irrigated Land in the Bighorn River Basin

| Present Use | Current Acres | 1980 Acres | 2000 Acres | 2020 Acres |
|---|---|---|---|---|
| Presently Irrigated | 509,640 | 512,430 | 516,330 | 520,430 |
| Idle | 29,190 | 26,400 | 22,500 | 18,400 |
| Projected New Land Development | | 46,670 | 102,670 | 136,670 |
| Total | 538,830 | 585,500 | 641,500 | 675,500 |

Historical trends and Wyoming's share of national production are the basis for projecting changes in land use and crop distribution. Projections also considered the availability of land and water resources. Yield projections are based on data provided by the University of Wyoming Agricultural Sector Study, the Great Plains Agricultural Council and Economic Research Service. Current normal and projected yields, crop distribution and production are summarized in Table IV-7.

Projected yield increases assume improved water management, additional land leveling, drainage, improved water supply resulting from improved efficiency, development of small storage facilities, and improved cultural and management practices.

## Availability of Land for Potential Development

Estimates of the availability of potentially irrigable land were made by the Soil Conservation Service during the Wind-Bighorn-Clarks Fork River Basin Survey. These estimates, given in Table IV-8, were based on soil surveys and reconnaissance studies of the Basin, and indicate that large tracts of land with soil suited for irrigation are available. Figure IV-1 shows the location of the 875,674 irrigable acres that have been identified. The major portion of these lands have soils of sufficient depth, on level to gentle slopes with little or minor soil limitations, so that their use for irrigated agriculture is feasible. A large portion of these lands is owned by the Federal Government. Other areas are owned by the State and by private interests.

TABLE IV-7 -- Irrigated Lands, Yields, Distribution and Production-
Bighorn River Basin

Projected Yields

| Crop | Unit | Current Normal | 1980 | 2000 | 2020 |
|---|---|---|---|---|---|
| Alfalfa | Tons/acre | 2.8 | 3.2 | 3.7 | 4.3 |
| Native Hay | Tons/acre | 1.2 | 1.3 | 1.4 | 1.5 |
| Other Hay | Tons/acre | 1.3 | 1.8 | 2.3 | 2.8 |
| Barley | Bu/acre | 64.0 | 80.0 | 96.0 | 113.0 |
| Oats | Bu/acre | 55.0 | 69.0 | 85.0 | 101.0 |
| Wheat | Bu/acre | 38.6 | 42.0 | 54.0 | 66.0 |
| Corn (grain) | Bu/acre | 61.4 | 85.0 | 96.0 | 108.0 |
| Corn (silage) | Tons/acre | 15.0 | 18.0 | 23.2 | 27.1 |
| Sugar Beets | Tons/acre | 17.2 | 19.9 | 24.5 | 29.4 |
| Beans | Cwt/acre | 16.47 | 20.1 | 25.2 | 30.0 |
| Pasture | AUM/acre | 3.0 | 3.3 | 4.0 | 4.5 |
| Aftermath Grazing | | | | | |
| Alfalfa | AUM/acre | .5 | .5 | .5 | .5 |
| Native Hay | AUM/acre | 1.0 | 1.0 | 1.0 | 1.0 |
| Other Hay | AUM/acre | 1.0 | 1.0 | 1.0 | 1.0 |
| Small Grain | AUM/acre | 1.25 | 1.25 | 1.25 | 1.25 |

Crop Distribution

| | Unit | Current Normal | 1980 | 2000 | 2020 |
|---|---|---|---|---|---|
| Alfalfa | Acre | 146,000 | 185,000 | 223,000 | 244,100 |
| Native Hay | Acre | 10,400 | 10,000 | 10,000 | 10,000 |
| Other Hay | Acre | 25,000 | 22,000 | 20,000 | 20,000 |
| Barley | Acre | 49,400 | 60,000 | 67,000 | 71,000 |
| Oats | Acre | 28,900 | 25,000 | 23,000 | 20,000 |
| Wheat | Acre | 2,700 | 2,500 | 2,400 | 2,300 |
| Corn (grain) | Acre | 3,400 | 5,000 | 6,000 | 7,000 |
| Corn (silage) | Acre | 15,200 | 19,000 | 25,000 | 31,000 |
| Sugar Beets | Acre | 42,000 | 42,000 | 49,900 | 60,000 |
| Beans | Acre | 15,000 | 13,000 | 12,000 | 11,000 |
| Pasture | Acre | 168,000 | 174,900 | 177,000 | 177,000 |
| Other Crops | Acre | 3,640 | 3,700 | 3,700 | 3,700 |
| Idle | Acre | 29,190 | 26,400 | 22,500 | 18,400 |
| Total | | 538,830 | 588,500 | 641,500 | 675,500 |

Crop Production

| | Unit | Current Normal | 1980 | 2000 | 2020 |
|---|---|---|---|---|---|
| Alfalfa | Tons | 408,800 | 592,000 | 825,100 | 1,049,630 |
| Native Hay | Tons | 12,480 | 13,000 | 14,000 | 15,000 |
| Other Hay | Tons | 32,500 | 39,600 | 46,000 | 56,000 |
| Barley | Bu | 3,161,600 | 4,800,000 | 6,432,000 | 8,023,000 |
| Oats | Bu | 1,589,500 | 1,725,000 | 1,955,000 | 2,020,000 |
| Wheat | Bu | 104,220 | 105,000 | 129,600 | 151,800 |
| Corn (grain) | Bu | 208,760 | 425,000 | 576,000 | 756,000 |
| Corn (silage) | Tons | 228,000 | 342,000 | 580,000 | 804,100 |
| Sugar Beets | Tons | 722,400 | 835,800 | 1,222,550 | 1,764,000 |
| Beans | Cwt | 247,050 | 261,300 | 302,400 | 330,000 |
| Pasture | AUM | 504,000 | 577,170 | 708,000 | 796,500 |
| Aftermath Grazing | AUM | 206,275 | 230,750 | 254,000 | 265,800 |

Source: Wyoming Water Planning Program, Economic Research Service, and Great Plains Agricultural Council.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE 10 0 10 20 30 40 Miles

## FIGURE IV-I
## IRRIGATED AND POTENTIALLY IRRIGABLE LANDS

LEGEND

IRRIGATED LANDS

IRRIGABLE LANDS

NUMBERS REFER TO STUDY AREAS

1 Wind River

2 Bighorn River

3 Little Bighorn River

4 Clarks Fork

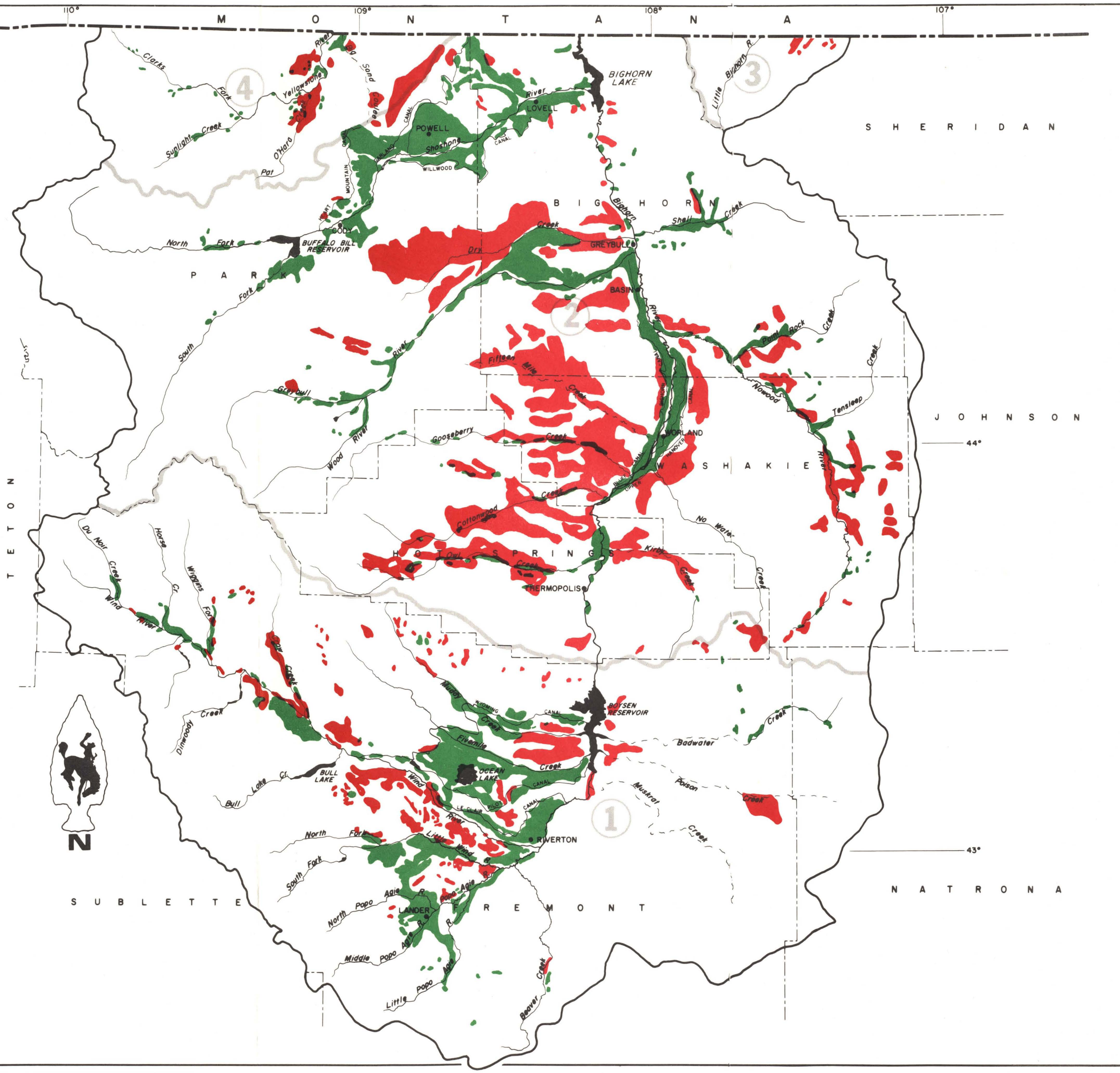


FIGURE IV-I

TABLE IV-8--Irrigable Lands by Subbasin

| Study Area | Acres |
|---|---|
| 1. Wind River | 181,621 |
| 2. Bighorn River | 642,811 |
| 3. Little Bighorn River | 9,651 |
| 4. Clarks Fork | 41,591 |
| Total | 875,674 |

Potential irrigation project units have been identified in various Federal, State, and private investigations. The acreages of land that might be irrigated in the 60 units is given in Table IV-9, along with the agency who investigated or identified the units. Future new land developments of the listed units would provide the irrigated crops to meet the projected production requirements.

TABLE IV-9 -- Identified Potential Irrigation Projects

Study Area 1 - Wind River

| Project | Agency | Acreage | Project | Agency | Acreage |
|---|---|---|---|---|---|
| Upper Wind | BIA[1] | 2,215 | Tipperary [2] | BIA | 3,630 |
| Johnstown | BIA | 83 | Stagner Ridge | BIA | 1,450 |
| Left Hand | BIA | 1,145 | Hudson Bench | BIA | 1,498 |
| Little Wind | BIA | 6,406 | Kirby Draw | BIA | 5,490 |
| Dinwoody Extension | BIA | 1,469 | Big Horn Draw | BIA | 3,328 |
| Willow Creek Extension | BIA | 1,259 | Badwater Unit | USBR | 1,100 |
| Coolidge Extension | BIA[3] | 5,180 | Riverton Project | USBR | |
| Popo Agie Pump | BIA | 265 | Muddy Ridge [4] | | 8,710 |
| Ray Extension | BIA | 1,868 | Cottonwood Bench | | 9,820 |
| North Fork Popo Agie | BIA | 1,300 | Midvale | SCS | |
| North Crowheart | BIA | 11,600 | Airport Bench[5] | | 4,880 |
| Winchester (Big Horn Flat) | BIA | 9,680 | Big Ridge | | 1,950 |
| South Crowheart | BIA[6] | 11,329 | Muddy Ridge | | 8,750 |
| Shoshoni | BIA | 3,010 | Upper Beaver Creek | SCS | 1,587 |
| | | | Total | | 100,292 |

Study Area 2 - Bighorn River

| Project | Agency | Acreage | Project | Agency | Acreage |
|---|---|---|---|---|---|
| Polecat Bench | USBR | 19,200 | Whistle Creek | USBR | 2,230 |
| Shoshone Extension South | USBR | 17,300 | Greybull Bench | USBR | 3,350 |
| Greybull Flat Unit | USBR | 980 | Table Mountain | USBR | 2,100 |
| Bighorn Unit | USBR | 1,730 | Kirby Unit | USBR | 320 |
| South additions | USBR | | Hanover Units [7] | USBR | 970 |
| McCollough Section | | 1,100 | Bighorn Unit No. 1 | USBR | 390 |
| Sage Section | | 2,140 | Pease Units | USBR | 2,200 |
| North Fan Section | | 1,620 | Red Flat Unit [7] | USBR | 590 |
| Dry Creek Valley | USBR | 9,080 | Beaver Flat Unit | USBR | 990 |
| Little Dry Creek Basin | USBR | 8,970 | Kane Unit | USBR | 120 |
| Nowood River [8] | SCS | 3,000 | Wagonhound Bench | USBR | 8,880 |
| Gooseberry Creek Valley | USBR | 1,540 | Putney Flat | USBR | 2,080 |
| Buffalo Basin | USBR | 4,430 | Pryor Slope | USBR | 3,500 |
| Schuster Flats | USBR | 6,260 | Meeteetse Rim | USBR | 10,000 |
| Sheet Flats | USBR | 1,330 | Cody and Ralston Pumplifts | USBR | 2,000 |
| Grass Creek Basin | USBR | 1,200 | Banjo Flats | Private | 4,000 |
| | | | Total | | 123,600 |

Table IV-9 continued on next page of text (Study Area 3 has no identified irrigation projects).

Table IV-9 continued

Study Area 4 - Clarks Fork

| Project | Agency | Acreage | Project | Agency | Acreage |
|---|---|---|---|---|---|
| Badger Basin Unit | USBR | 1,600 | Kimball Bench and Cyclone Bar Areas | WWPP | 12,550 |
| Chapman Bench | USBR | 7,350 | | | |
| | | | Total | | 21,500 |

[1] From Reference (24); the 1971 BIA Land and Water Inventory (26) identified 198,542 acres as irrigable (see Table V-3).

[2] The SCS Watershed Investigation Report for Crow Creek proposes to develop 2,600 acres.

[3] The USBR has identified 2,030 acres as irrigable.

[4] Included in the Midvale Project.

[5] The BIA has identified 4,310 acres on Airport and Burma Benches.

[6] The USBR has identified 4,260 acres as irrigable.

[7] Has partially been developed by private interests.

[8] The USBR has identified 1,630 acres in the Paint Rock Unit.

## Water Resource Requirements

### Present Water Uses and Needs

Most of the water presently used in the Basin is for irrigation. Because of the limited precipitation in the Basin, irrigation is required for dependable crop production. About 90 percent of man's present streamflow depletions in the Basin is irrigation consumptive use, and about 9 percent is evaporation from reservoirs which are presently used primarily for irrigation, recreation, and hydropower production.

The consumptive use of irrigation water is variable depending upon crop types and climatic factors such as temperature, humidity, and radiation. Climatic factors are related to the area's physiographic features such as latitude and elevation. The consumptive use of irrigation water was estimated for the Basin by watershed areas, taking into account the variable consumptive use rates and water supplies of the areas. The data were summarized by study areas as shown in Figure II-6.

The estimated consumptive irrigation requirement for alfalfa varies from 1.45 acre-feet per acre at Dubois in Study Area 1a to 2.03 acre-feet per acre at Riverton in Study Area 1d, and from 1.08 acre-feet per acre at Sunshine in Study Area 2i to 2.48 acre-feet per acre at Basin in Study Area 2a (37).

The present average consumptive use of irrigation water is about 1,028,500 acre-feet per year. The evaporation from man-made impoundments in the Basin is 105,300 acre-feet per year. Of that amount, 47,900 acre-feet per year evaporates from Boysen Reservoir, and the remainder is from other reservoirs in the Basin.

Diversion requirements depend upon the crop consumptive water requirements and the losses incurred in getting the water from the source (point of diversion) into the root zone for crop consumption. Irrigation water losses include canal and lateral losses and farm losses incurred in irrigating the fields. Most diversion losses accrue to groundwater and eventually flow back into the stream as return flow. The Soil Conservation Service made an analysis of irrigation efficiencies in the Wind-Bighorn-Clarks Fork River Basin Survey which is in progress. Measured canal diversions and estimated consumptive irrigation requirements of water were used for the determination. Overall water use efficiencies (consumptive irrigation requirement divided by diversions) were estimated to be 35 percent for large irrigation projects that have storage available, 35 percent for ditch companies or irrigation districts with early priority water rights and/or storage, 30 percent for irrigation ditches with a water supply or management deficiency, and 25 percent for irrigation of meadow lands.

In many cases, the lower irrigation efficiencies result from diversions at maximum ditch capacities during the spring runoff when crop consumption is relatively low, and minimal diversions later in the year when streamflow has diminished but crop consumptive use is high. If reservoir storage were available to save early runoff for use later in the summer, irrigation efficiencies and crop production could be improved. Construction of reservoirs to regulate water supplies is an obvious means of improving water supplies and water use efficiencies.

Reservoirs provide storage water for many areas in the Basin. Table IV-10 lists the principal reservoirs of the area, and Figure IV-2 shows the reservoir locations.

TABLE IV-10 -- Principal Reservoirs in the Bighorn River Basin
(Reservoirs of over 1,000 acre-foot Capacity)

| Reservoir | Capacity (Acre-Feet) | Use [1] | Water Source |
|---|---|---|---|
| Adelaide | 3,147 | I | Shell Creek |
| Anchor | 17,412 | I,D,S | South Fork Owl Creek |
| Bighorn Lake | 1,375,000 | I,M&I,P,FC Rec,FW,EC | Bighorn River |
| Boysen | 922,560 | I,P,D,S, M&I,Mining | Bighorn-Wind River |
| Brooks Lake | 9,719 | M&I | Wind River |
| Buffalo Bill (Shoshone) | 456,600 | I,P,D,M&I | Shoshone River |
| Bull Lake | 151,951 | I,Ind | Bull Lake Creek |
| Christina Lake | 3,860 | I,S,D | Little Popo Agie River |
| Cody | 4,508 | P,Mun | Shoshone River |
| Enterprise | 1,494 | I,S,D, | Roaring Fork |
| Fairview | 1,411 | I,D,S | Greybull River, Wardell Draw |
| Lake Creek | 1,373 | I | Lake Creek |
| Louis Lake | 8,014 | P | Little Popo Agie River |
| Lower Sunshine (under construction) | 56,850 | I,D,S,P,Ind | Greybull River |
| Luce | 2,129 | I | Paint Creek |
| Newton | 4,525 | I | Trail Creek |
| Paint Creek | 1,217 | I | Paint Creek |
| Perkins and Kinney | 1,259 | I | South Sage Creek |
| Pilot Butte | 36,960 | I,P,M&I | Off stream filled from Wind River |
| Sage Creek | 2,058 | I | Sage Creek, Meeteetse Creek |
| Shell | 1,949 | I | Shell Creek |
| Shoshone | 9,740 | I,S | Shoshone Creek |
| Teapot | 1,578 | I | Dry Creek |
| Tensleep | 3,509 | I,S,D,P,FC | Tensleep Creek |
| Upper Sunshine | 52,988 | I,S,D,Ind | Greybull River |
| Worthen Meadows | 1,504 | I,M&I | Roaring Fork |

[1] Includes uses listed on water right records: I-Irrigation; M&I-Municipal and Industrial; P-Power; FC-Flood Control; S - Stock water; Re-Reg-Reregulation; Mun-Municipal; Ind-Industrial; D-Domestic; Rec-Recreation; EC-Erosion Control; FW-Fish and Wildlife.

Table IV-11 shows the average annual consumptive use of the present and projected irrigation in the Basin. It is expected that virtually all of the increased use will occur within the Wind-Bighorn River and Clarks Fork Study Area. Irrigation project potentials and the ramifications of the Yellowstone River Compact are discussed in Chapter V.

TABLE IV-11--Present and Projected Irrigated Acreage and Consumptive Uses of Water in the Bighorn River Basin, Wyoming
(Consumptive Uses in Acre-feet per Year)

| | Irrigated Acres | Consumptive Use (c.u.) | Supplemental Supplies (c.u.) | Totals Acres | Totals C. U. |
|---|---|---|---|---|---|
| Present | 538,830 | 1,028,500 | - - - | 538,830 | 1,028,500 |
| 1980 | 538,830 | 1,028,500 | 30,000 | | |
| New Lands | 46,670 | 93,300 | | 585,500 | 1,151,800 |
| 2000 | 538,830 | 1,028,500 | 67,700 | | |
| New Lands | 102,670 | 205,300 | | 641,500 | 1,301,500 |
| 2020 | 538,830 | 1,028,500 | 98,800 | | |
| New Lands | 136,670 | 270,300 | | 675,500 | 1,397,600 |

Hydrology studies by the Soil Conservation Service and the Wyoming Water Planning Program were directed toward determining the supplemental water supply and storage requirements for providing a full-season water supply for all existing irrigation in the Basin. Water supplies were determined with the aid of a hydrologic simulation model developed by the SCS. Diversion requirements were estimated from crop consumptive irrigation requirements and irrigation efficiencies. Where reuse of irrigation return flows appears to be minimal, an irrigation efficiency of 35 percent was used. Where return flows from upstream irrigation are available for diversion by downstream ditches, an overall irrigation efficiency of 50 percent was assumed. Besides determining the storage capacities required, the depletions that would result from the supplemental supplies were determined. Some streams do not produce enough water to provide a full water supply to all lands presently irrigated from them. In these instances, the amount of storage that would develop all the divertable supply and the amount of "import" water required for a full supply were determined. "Import" water might be diverted from an adjacent stream, from groundwater, or from other sources such as weather modification. The results of the studies are tabulated by study area in Table IV-12. The hydrology studies did not include reservoir site or feasibility analyses.

The increase in average annual depletion resulting from supplying supplemental water to existing irrigation by reservoirs would be 67,700 acre-feet per year. If water were transferred from streams with surpluses to streams with shortages, another 31,800 acre-feet per year of streamflow depletion would occur. The total storage required in an average year to provide a full water supply from locally available water supplies is 168,800 acre-feet. Total storage required to provide a full water supply from locally available water supplies 8 years out of every 10 (80-percent-chance supply) is 230,000 acre-feet. Controlling "import" water supplies would require additional storage capacity.

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WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE 10 0 10 20 30 40 Miles

## FIGURE IV-2
## EXISTING PRINCIPAL RESERVOIRS
### (Over 1000 Acre-Feet Capacity)

### Legend

1 Adelaide
2 Anchor
3 Bighorn Lake
4 Boysen
5 Brooks Lake
6 Buffalo Bill (Shoshone)
7 Bull Lake
8 Christina Lake
9 Cody
10 Enterprise
11 Fairview
12 Lake Creek
13 Louis Lake
14 Lower Sunshine (Under Constr.)
15 Luce
16 Newton
17 Paint Creek
18 Perkins and Kinney
19 Pilot Butte
20 Sage Creek
21 Shell
22 Shoshone
23 Teapot
24 Tensleep
25 Upper Sunshine
26 Worthen Meadows

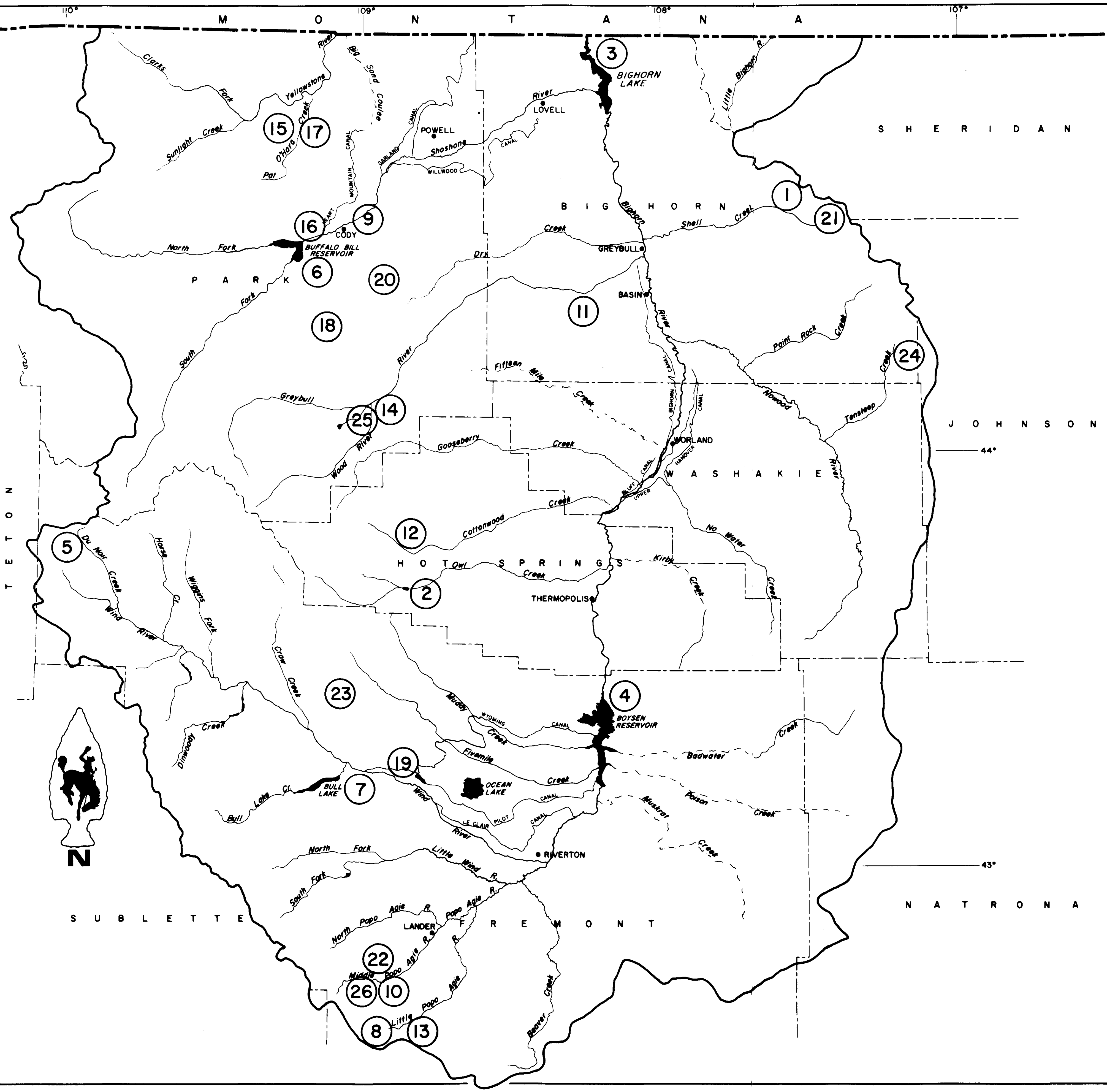


FIGURE IV-2

TABLE IV-12 -- Summary of Supplemental Water Supply Studies

| Study Area | Present Irrigated Acreage (Acres) | Consumptive Irrigation Requirement (Acre-Feet per Year) | Present Average Consumptive Use of Irrigation Water (Acre-Feet per Year) | Storage Required [1] for full Water Supply: Average Year (Acre-Feet) | Storage Required [1] for full Water Supply: For 80% Chance Supply (Acre-Feet) | Average Depletion With Storage (Acre-Feet per Year) | "Import" Supply Needed [2]: Average Year (Acre-Feet) | "Import" Supply Needed [2]: 80% Chance Year (Acre-Feet) |
|---|---|---|---|---|---|---|---|---|
| 1a. Upper Wind River | 7,605 | 11,000 | 11,000 | 0 | 0 | 11,000 | 0 | 0 |
| 1b. South Wind River Tributaries | 75,228 | 133,100 | 103,600 | 84,200 | 90,000 [3] | 133,100 | 0 | 23,400 |
| 1c. North Wind River Tributaries | 4,483 | 7,800 | 4,400 | 6,600 [3] | 7,200 [3] | 7,100 | 2,800 | 5,300 |
| 1d. Main Stem Wind River | 105,314 | 212,900 | 212,900 | 0 | 12,700 | 212,900 | 0 | 0 |
| 1e. East Wind River Tributaries | 3,139 | 5,400 | 2,500 | 7,200 [3] | 2,700 [3] | 5,000 | 1,200 | 8,700 |
| Wind River Subtotal | 195,769 | 370,200 | 334,400 | 98,000 | 112,600 | 369,100 | 4,000 | 37,400 |
| 2a. Main Stem Bighorn River | 61,579 | 140,000 | 140,000 | 0 | 0 | 140,000 | 0 | 0 |
| 2b. East Bighorn River Tributaries | 384 | 700 | 300 | 800 [3] | 300 [3] | 600 | 100 | 900 |
| 2c. Nowood River | 19,167 | 37,000 | 33,100 | 11,000 | 14,400 | 37,000 | 0 | 0 |
| 2d. Shell Creek | 10,493 | 20,300 | 17,700 | 5,400 [3] | 7,500 [3] | 19,600 | 2,000 | 3,400 |
| 2e. Bighorn Lake Tributaries | 1,486 | 3,300 | 2,500 | 2,200 | 2,800 | 3,300 | 0 | 0 |
| 2f. West Bighorn River Tributaries | 22,414 | 46,900 | 17,700 | 7,900 [3] | 4,400 [3] | 20,500 | 75,200 | 94,600 |
| 2g&h. Greybull River | 65,256 | 148,500 | 128,600 | 32,700 [3,4] | 30,500 [3,4] | 145,000 | 5,200 | 55,700 |
| 2i. Upper Shoshone River | 26,026 | 50,200 | 49,900 | 800 | 1,300 | 50,200 | 0 | 0 |
| 2j. Lower Shoshone River | 122,698 | 285,100 | 280,300 | 4,700 [5] | 49,800 [5] | 285,100 | 0 | 0 |
| Bighorn River Subtotal | 329,503 | 732,000 | 670,100 | 65,500 | 111,000 | 701,300 | 82,500 | 154,600 |
| 3. Little Bighorn River | 2,441 | 4,300 | 2,900 | 4,300 | 5,100 | 4,300 | 0 | 0 |
| 4. Clarks Fork | 11,119 | 21,500 | 21,100 | 1,000 | 1,300 | 21,500 | 0 | 0 |
| Total | 538,832 | 1,128,000 | 1,028,500 | 168,800 | 230,000 | 1,096,200 | 86,500 | 192,000 |

[1] Storage capacity required in addition to capacities of existing reservoirs.

[2] See report narrative for definition of "Import".

[3] Storage capacity to totally regulate the water available at points of diversion.

[4] Lower Sunshine Reservoir, under construction, will help alleviate Lower Greybull River water shortages.

[5] Water shortages are to lands not irrigated from the Shoshone Project.

# MINERAL RESOURCES AND INDUSTRIES

In 1970 Wyoming ranked 11th among the states in the value of mineral production as reported by the U. S. Bureau of Mines. Wyoming's mineral production and rank in national mineral production are increasing, and the present economy of the State is greatly dependent upon the mineral industries.

Wyoming has very little manufacturing to serve as a market for mineral products; therefore, the mineral industry relies on the production of raw materials that can be shipped to distant market centers and yet be competitive.

In September of 1968 Cameron Engineers of Denver, Colorado, was commissioned by the Wyoming Natural Resource Board (now Department of Economic Planning and Development) and the State Engineer to study the existing mineral resources and industries of Wyoming and project to the year 2020 mineral development, water and utility requirements, employment, and the probable economic benefits to the State. The Cameron Report (4) is the basis for the following discussion on the mineral industries in the Bighorn River Basin.

Mineral resources in the Bighorn River Basin include petroleum, uranium, coal, bentonite, gypsum, and phosphate. The following discussion also includes a brief section on the timber industry in the Basin.

## Oil and Gas

Early oil production began in the Basin at Dallas Dome, eight miles southeast of Lander. Here, in 1883, a 300-foot well produced crude oil from the Chugwater formation. Subsequent deeper drilling at the Dallas Oil Field disclosed the presence of oil in the Embar formation at 750 feet and in the Tensleep formation at 1,200 feet. The Dallas Field, which is still in production, has grown to 73 wells covering 430 acres. By the end of 1967, the Dallas Field had produced 7,000,000 barrels of oil, and more than 2,000,000 barrels apparently remained to be produced. Oil and gas fields are shown in Figure IV-3.

Although the rate of early growth varied, there was a period of sustained exploration and increasing oil and gas production from 1933 to the early 1960's. Present Wyoming production is about 140 million barrels of oil and 270 billion cubic feet of gas annually.

### Reserves and Present Development

Table IV-13 shows the 1967 estimated gross production and gross field value of crude oil, natural gas, and natural gas liquids by county in the Bighorn River Basin. The area totals are compared with Wyoming totals, which in turn are compared with U. S. totals.

### Economic Importance

The oil and gas industry provides a significant payroll in Wyoming. In terms of taxes paid, the industry is the State's most important. In 1968 it paid slightly more than 30 percent of all property taxes collected in Wyoming.

Benefits to the State accrue in the form of a production tax, a conservation tax, a severance tax, ad valorem property taxes, sales and use taxes, State royalties, the State's share of Federal royalties, private interest royalties, and

WYOMING STATE ENGINEERS OFFICE
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# WYOMING'S BIGHORN RIVER BASIN

SCALE 10 0 10 20 30 40 Miles

## FIGURE IV-3
## OIL & GAS FIELDS

(From USGS Oil & Gas Fields and Pipelines of Wyo. Northeastern Region Map Number 800 Revised 1-1-70)

LEGEND

Gas

Oil

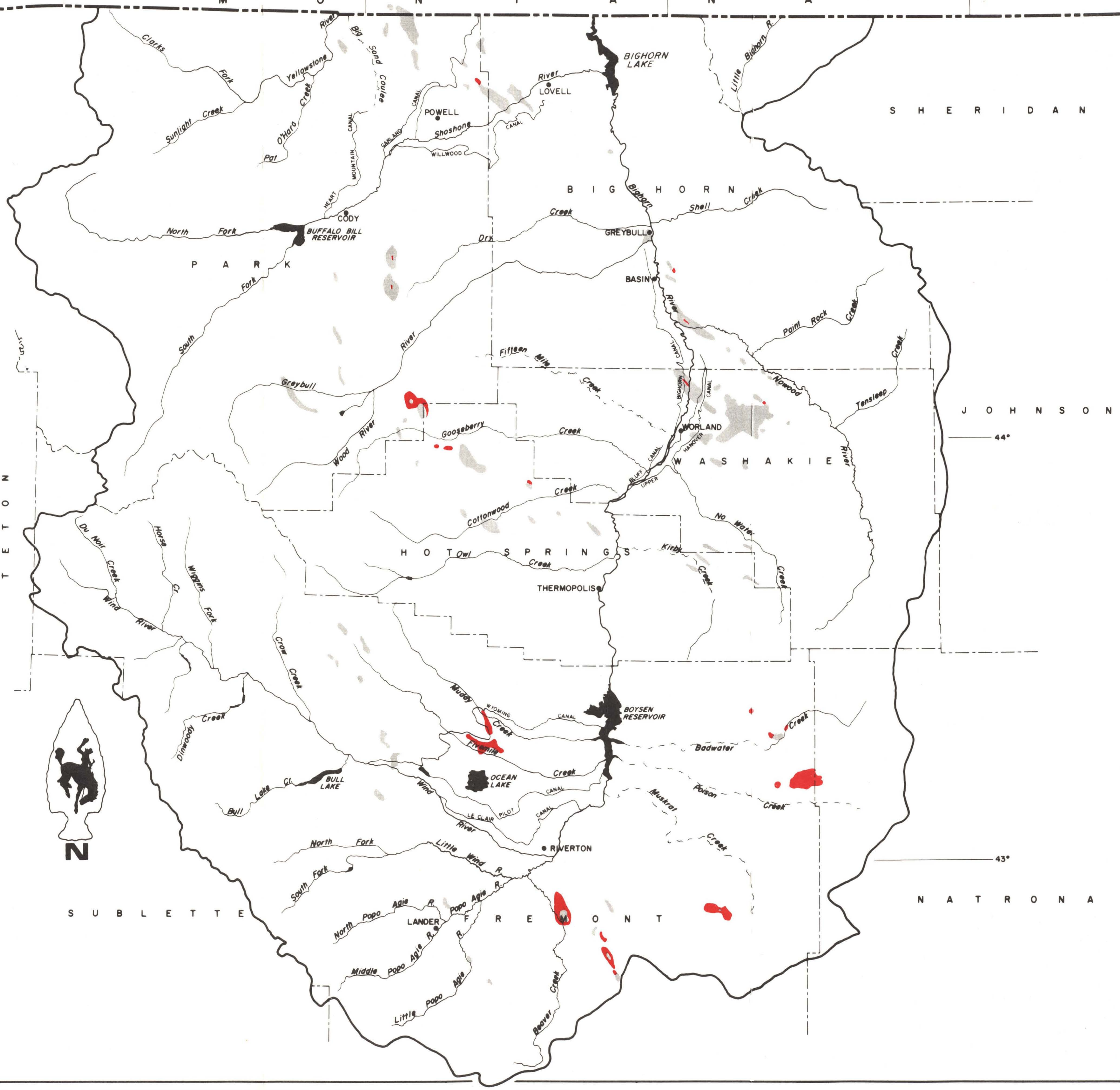


TABLE IV-13 -- Total 1967 Oil, Natural Gas, and Natural Gas Liquids Production and Gross Value for Counties with Major Production Occuring in the Bighorn River Basin, and Comparison with State and National Figures

| | Crude Oil | | Natural Gas | | Natural Gas Liquids | | |
|---|---|---|---|---|---|---|---|
| | Gross Production 1,000 barrels | Gross Value $ million | Gross Production million cubic feet | Gross Value $ million | Gross Production 1,000 barrels | Gross Value $ million | Total Value $ million |
| Big Horn County | 6,315 | 16.3 | 2,364 | 0.35 | 85 | 0.19 | 16.84 |
| Fremont County | 11,805 | 30.5 | 47,091 | 6.88 | 1,132 | 2.47 | 39.85 |
| Hot Springs County | 13,354 | 34.5 | 207 | .03 | 15 | .03 | 34.56 |
| Park County | 33,984 | 87.7 | 12,200 | 1.78 | 1,907 | 4.16 | 93.64 |
| Washakie County | 2,112 | 5.4 | 14,680 | 2.14 | 911 | 1.99 | 9.53 |
| Bighorn River Basin | 67,570 | 174.4 | 76,542 | 11.18 | 4,050 | 8.84 | 194.42 |
| Wyoming | 135,810 | 350.4 | 253,095 | 36.95 | 7,798 | 17.03 | 404.38 |
| U. S. A. | 3,037,579 | 9,375.7 | 18,380,838 | 2,899.00 | 644,493 | 1,180.00 | 13,454.70 |
| Basin Share of Wyoming Total | 49.8% | 49.8% | 30.2% | 30.2% | 51.9% | 51.9% | 48.1% |
| Wyoming's Share of U. S. Total | 4.5% | 3.7% | 1.4% | 1.3% | 1.2% | 1.4% | 3% |

lease bonuses and filing fees. Gross production and ad valorem property taxes paid by the oil and gas industry in the Basin in 1968 (based on 1967 production) amounted to about $9.7 million. The 1970 severance tax (based on 1969 production) on oil and gas production in the Basin was about $1.8 million. Figures on other taxes paid by the oil and gas industry are not readily available on a county basis. Other benefits to the State include payroll unemployment taxes and vehicle registration and license fees.

## Growth Factors

The oil and gas industry is extractive, with an apparently finite limit of the resources. It must be recognized that the industry will decline and may in time pass out of existence (see Table IV-14).

Several factors may have an effect on the future of the industry. Some of these are:

1. Because of the petroleum deficiency in the United States, it is assumed that no market constraint on production will be enacted. It appears that the domestic deficit will become more severe in the future.

2. Any significant change in economic parameters such as changes in prices, taxes or import policies will affect the rates of discovery and production.

3. Any increase in the price of crude oil that encourages discovery and production will also hasten the development of alternative sources of liquid fuel such as coal and oil shale.

4. A decrease in the cost of exploration, or the development of new exploratory techniques, would result in an increased rate of discovery.

In the Cameron Report, the following generalizations are made regarding the anticipated exploration potential in the Bighorn and Wind River Basins. High drilling costs and little encouragement for the discovery of large accumulations

TABLE IV-14 -- Projected Trends of the Petroleum Industry in Wyoming's Bighorn River Basin

| | 1967 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Crude Oil | | | | |
| Production, million barrels | 67.6 | 37.2 | 14.9 | 14.9 |
| Value, million dollars | 174.4 | 96 | 38.4 | 38.4 |
| Employment | 560 | 340 | 130 | 130 |
| Annual Payroll, million dollars | 5 | 3.1 | 1.2 | 1.2 |
| Water Consumed, thousand acre-feet/year | 24.8 | 20.5 | 9.7 | 9.7 |
| Power Required, million kwh/year | 193 | 149.3 | 99.5 | 99.5 |
| Natural Gas | | | | |
| Production, billion cubic feet | 76.5 | 75.6 | 30.2 | 30.2 |
| Value, million dollars | 11.2 | 11 | 4.4 | 4.4 |
| Employment [1] | 550 | 520 | 370 | 270 |
| Annual Payroll, million dollars | 5 | 4.7 | 3.3 | 2.4 |
| Water Consumed, acre-feet/year | - - - -N E G L I G I B L E - - - - | | | |
| Power Required, million kwh/year | .6 | .6 | .3 | .3 |
| Natural Gas Liquids | | | | |
| Production, million barrels | 4.1 | 3.3 | 1.3 | 1.3 |
| Value, million dollars | 9 | 7.2 | 2.8 | 2.8 |
| Water Consumed, acre-feet/year | 1,020 | 950 | 380 | 380 |
| Power Required, million kwh/year | 1 | 1 | .5 | .5 |
| Other (Including Service Supply, Refineries, Pipelines and By-Products) | | | | |
| Employment | 1,820 | 810 | 200 | 200 |
| Annual Payroll, million dollars | 16.4 | 7.3 | 1.8 | 1.8 |
| Water Consumed, acre-feet/year | 1,080 | 850 | 620 | 420 |
| Power Required, million kwh/year | 14.3 | 8.5 | .2 | .2 |
| Total Petroleum Industry in Wyoming's Bighorn River Basin | | | | |
| Employment | 2,930 | 1,670 | 700 | 600 |
| Annual Payroll, million dollars | 26.4 | 15.1 | 6.3 | 5.4 |
| Water Consumed, thousand acre-feet/year | 26.9 | 22.3 | 10.7 | 10.5 |
| Power Required, million kwh/year | 208.9 | 159.4 | 100.5 | 100.5 |
| Capital Investment, million dollars [2] | 68.6 | 65 | 60 | 50 |

[1] Includes natural gas liquids.

[2] Estimated replacement cost of facilities in operation in 1967, 1980, 2000, 2020.

should limit deep drilling in the central portion of the Bighorn Basin. Continued shallow exploration drilling should occur along the west flank at only a moderate level unless an encouraging discovery is made. In the Wind River Basin, a good level of activity should continue in exploring Cretaceous and Pennsylvanian sediments. There are good prospects for additional gas discoveries in Tertiary rocks.

The average annual crude oil production rate in the Basin was projected by Cameron to remain at about the 1967 level through 1972, and then decline through 1990 to a level which will remain constant throughout the remainder of the forecast period. This and other aspects of the petroleum industry are portrayed numerically in Table IV-14.

## Water Resource Requirements

Table IV-14 shows the 1967 and estimated future water requirements of the petroleum industry as determined by Cameron Engineers. Total water consumed in 1967 was 26,900 acre-feet. The largest demand was for 24,800 acre-feet of water injected into the petroleum reservoirs to displace oil into producing oil wells (secondary recovery).

# Uranium

## Existing Conditions

Interest in Wyoming uranium remains high because much of the ore is at a depth that permits open-pit mining. In Wyoming approximately 77 percent of the uranium ore mined comes from open-pit mines, compared with only 30 percent for the entire United States. Figure IV-4 shows the location of the active major uranium district in the Basin.

## Reserves and Present Development

Wyoming presently ranks first in the United States in tons of ore reserves and second only to New Mexico in tons mined per year.

As of January 1, 1968, the Atomic Energy Commission (AEC) reserve figure for Wyoming was 52,931 tons of contained $U_3O_8$, or 35.8 percent of the national total of 148,000 tons of $U_3O_8$. These figures are for uranium mineable at $8 per pound price. With the uranium industry in the midst of a transition from a government market to a competitive private market, most individual companies are reluctant to provide information pertaining to ore reserves. For this reason the AEC will not subdivide the total reserve figure for the State into districts.

In 1967 the Gas Hills and Crooks Gap districts accounted for 80 percent of Wyoming's total uranium production, ranking this the number one area in the State. It is assumed that about one-half of this production is in the Bighorn River Basin and the other half in the Platte River Basin.

## Economic Importance

The gross value of Wyoming concentrates sold to the AEC and to private and foreign interests since the inception of the industry in the early 1950's was $372,000,000 through 1968. Of this total, only $13,000,000 worth of concentrates was sold to private and foreign interests. The 1968 production value of $46,274,000 ranks uranium second in the Wyoming mineral sector, being exceeded only by the value of oil and gas.

A larger part of the State's gross production value since 1953 has been a direct benefit to Wyoming in the form of payrolls, consumption of locally produced fuels and sulfuric acid, utilities, and an appreciable part of royalty and profit revenues. The industry also pays property, severance, production, sales, and use taxes.

Growth Factors

The mining of uranium for use as a generator source, a use which presently is an inefficient one, will continue to increase until the advent of the breeder reactor. With the efficiency which will then be possible, most of the market for newly mined uranium will be eliminated.

Although uranium from the Basin will be in demand as a powerplant fuel, the market will be largely out-of-State. This is due to the abundance of low-cost coal in Wyoming, which indicates that the Basin and State may be among the last regions of the country to utilize nuclear-generated electricity.

The projected trends of the uranium industry in the Bighorn River Basin of Wyoming are shown in Table IV-15.

TABLE IV-15--Projected Trends of the Uranium Industry in the Bighorn River Basin of Wyoming

| | 1967 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Uranium Ore Mined, million tons/year | .5 | 2.1 | 3 | 1 |
| $U_3O_8$ Produced, thousand tons/year | .7 | 2 | 3 | .15 |
| Employment | 420 | 1,600 | 1,950 | 250 |
| Annual Payroll, million dollars | 3.8 | 14.4 | 17.6 | 2.3 |
| Capital Investment, million dollars[1] | 23.4 | 92 | 119 | 14.5 |
| Water Consumed, acre-feet/year | 975 | 7,758 | 15,000 | 6,000 |
| Power Required, million kwh/year | 7.1 | 38.3 | 72.5 | 24 |

[1] Figures show approximate value of facilities in operation in 1967, 1980, 2000, 2020.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE 10 0 10 20 30 40 Miles

## FIGURE IV-4
## URANIUM, GEOTHERMAL AND OTHER RESOURCES
(as shown on the Energy Resources Map of Wyoming, 1972, by the Geological Survey of Wyoming)

Legend

*URANIUM DISTRICT*

URANIUM MILL

AREA POTENTIALLY VALUABLE FOR GEOTHERMAL RESOURCES

Nonfuel Minerals Operations

*(Locations Approximate)*

1. Bentonite Processing Plant
2. Gypsum Processing Plant
3. Phosphorus Plant projected to be in operation by the year 2020
4. Copper deposit being investigated
5. Feldspar production

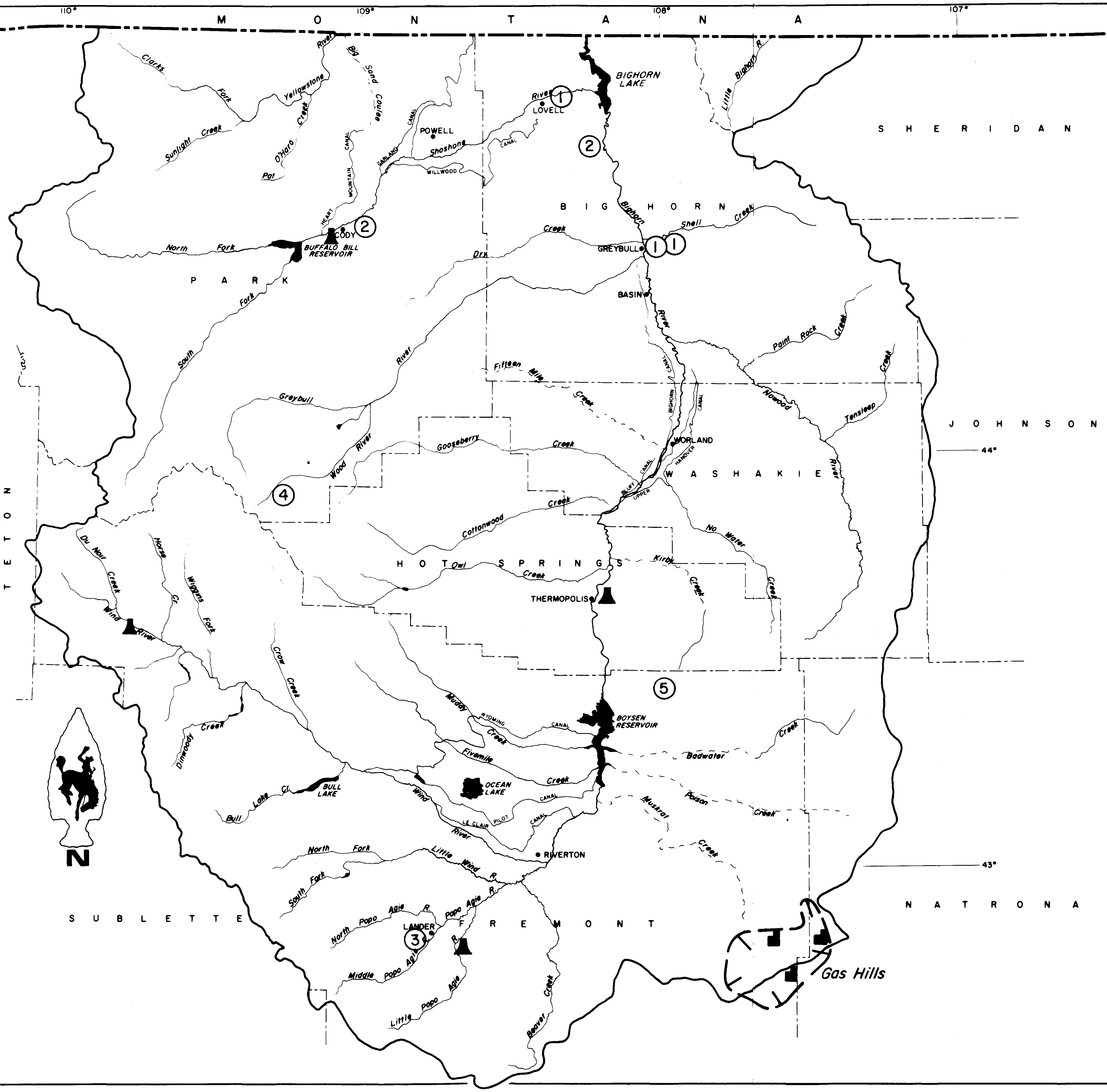



FIGURE IV-4

## Water Resource Requirements

The present and projected future water requirements of the uranium industry in Wyoming's Bighorn River Basin are shown in Table IV-15. Most of the water requirements are in milling operations, since little water is used in the mining of uranium. Groundwater sources will probably supply all the water needed.

# Coal

## Existing Conditions

Coal was first mined in Wyoming in 1868 by the Union Pacific Railroad at Carbon, Wyoming. Forty years later coal mining was Wyoming's leading industry, producing over 6 million tons in 1908. Most of the coal was used by railroads.

With the demands of World War II, Wyoming coal production soared to an all-time peak of 9,836,793 tons in 1945. The railroads were the largest consumers of coal in Wyoming until the conversion to diesel locomotives beginning in 1953.

Though coal is now practically unused by railroads, coal production in Wyoming has increased since its low in 1958 because of the demand for powerplant fuel. Today over 79 percent of all coal mined in Wyoming is used in electric power generation.

## Reserves and Present Development

A map of the coal resources in Wyoming's Bighorn River Basin is shown in Figure IV-5. Table IV-16 shows the coal reserves of counties wholly or mostly within the Basin.

TABLE IV-16 -- Bighorn River Basin Coal Reserves by County
(Millions of Tons)

| County | Estimated Original Reserves | Estimated Production Prior to 1950 | Production 1950 to 1968 | Estimated Unrecoverable | Remaining Reserves 1968 |
|---|---|---|---|---|---|
| Big Horn | 18 | 1 | 0 | 0 | 17 |
| Fremont | 734 | 1 | 0 | 1 | 732 |
| Hot Springs | 261 | 3 | 0 | 4 | 254 |
| Park | 215 | 0 | 0 | 0 | 215 |
| Washakie | 88 | 0 | 0 | 0 | 88 |
| Total | 1,316 | 5 | 0 | 5 | 1,306 |
| State Total | 121,556 | 362 | 65 | 419 | 120,710 |
| Bighorn River Basin as Percent of State | 1.1 | 1.4 | 0 | 1.2 | 1.1 |

In the Basin, the Grass Creek mine near Thermopolis recovered 3,555 tons in 1968, the Roncco mine near Thermopolis recovered 4,470 tons in 1968, and the Coleman mine near Kirby produced 2,080 tons in 1968. Due to the greater efficiencies possible in larger operations, operators of small mines are having difficulty remaining in business. In 1966 more than half the national coal production came from only 4 percent of the mines.

## Economic Importance

The coal industry pays property taxes, gross production taxes, a severance tax, and sales, service, and use taxes. Income also accrues to the State from royalties and rentals of coal lands. At the present time the coal industry is a minor part of the Bighorn River Basin's mineral industrial sector.

## Growth Factors

The use of Wyoming coal as a powerplant fuel is expected to expand greatly in the future. Another use of Wyoming coal projected for the future is the conversion of coal to synthetic fuels.

Though most of the growth in Wyoming's coal industry will occur in other areas of the State due to larger and more readily available reserves, some growth will occur in the Basin. This projected growth is shown in Table IV-17. The impact on the Basin is presented in terms of production, employment, payroll, capital investment, consumptive water requirements and electric power requirements.

TABLE IV-17-- Projected Growth of the Coal Industry in Wyoming's Bighorn River Basin

| | 1967 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Steam Electric Plants | | | | |
| Number of Plants | | | 2 | 2 |
| Capacity, megawatts | | | 2,000 | 2,000 |
| Average Output, billion kwh | | | 17.52 | 17.52 |
| Value of Power, million dollars | | | 52.56 | 52.56 |
| Number of Employees | | | 120 | 120 |
| Annual Payroll, million dollars | | | .96 | .96 |
| Capital Investment, million dollars[1] | | | 260 | 260 |
| Water Required, thousand acre-feet/year | | | 30 | 30 |
| Coal Mining Industry (for all purposes) | | | | |
| Number of Mines | | | 2 | 2 |
| Production, million tons/year | | | 10.66 | 10.66 |
| Number of Employees | | | 244 | 215 |
| Annual Payroll, million dollars | | | 2.19 | 1.93 |
| Capital Investment, million dollars | | | 30 | 30 |
| Water Required, acre-feet/year | - - N E G L I G I B L E - - - | | | |
| Power Required, million kwh/year | | | 48 | 48 |

Table IV-17 continued on page 129.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE
10 0 10 20 30 40 Miles

## FIGURE IV-5
## COAL RESERVES

(From USGS Coal Investigations Map C6 Coal Resources Map of Wyoming, 1951)

### Legend - AREAS UNDERLAIN BY....

- BITUMINOUS COAL BEDS MORE THAN 14" THICK
- BITUMINOUS COAL BEDS LESS THAN 14" THICK OR OF UNKNOWN THICKNESS
- SUB-BITUMINOUS COAL BEDS MORE THAN 30" THICK
- SUB-BITUMINOUS COAL BEDS LESS THAN 30" THICK; OR OF UNKNOWN THICKNESS, OR CONCEALED OR DEEPLY BURIED
- APPROXIMATE AREA OF PROJECTED DEVELOPMENTS (FROM THE CAMERON REPORT)

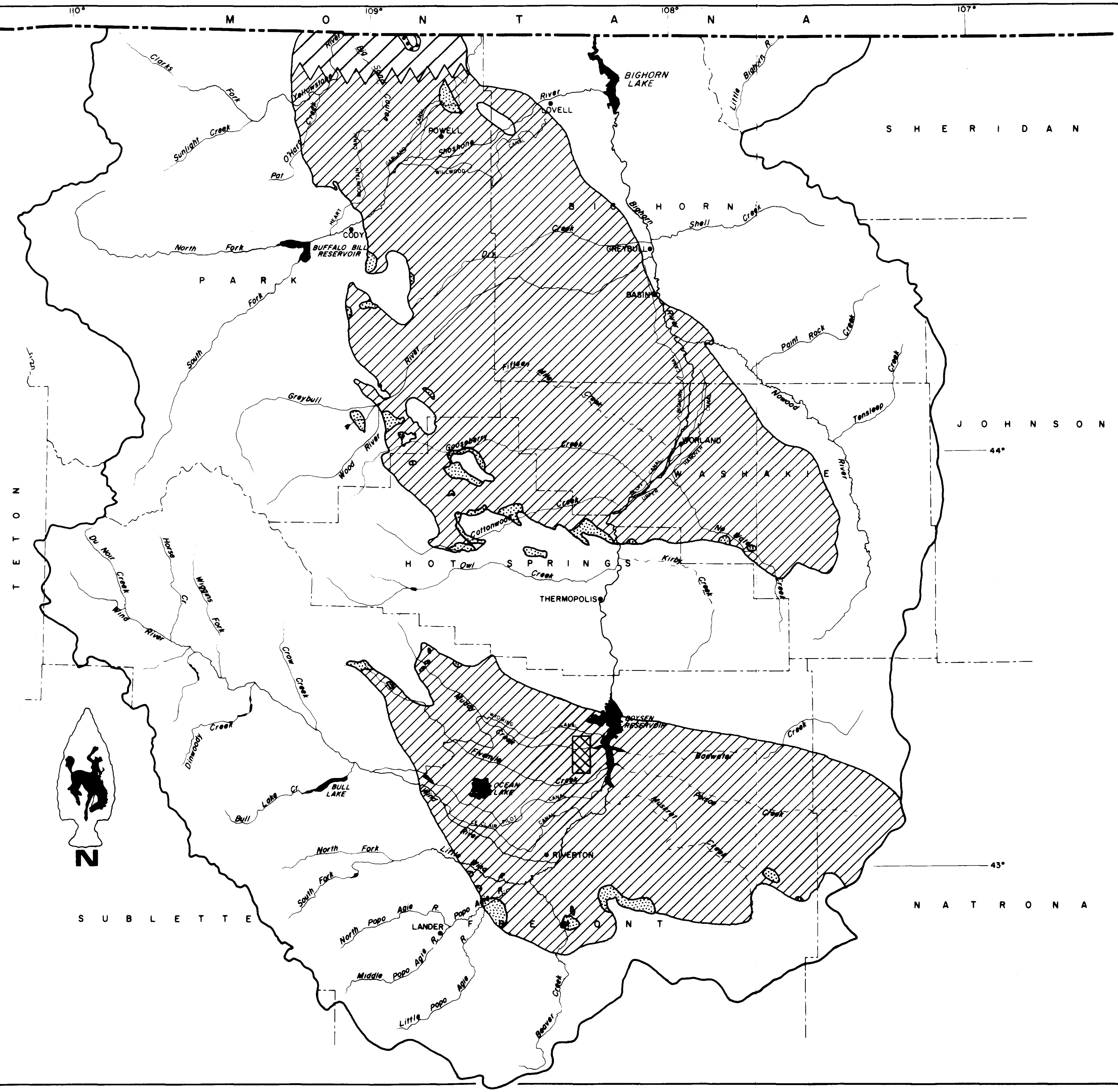


Table IV-17 Continued -

| Summary of the Coal Industry | | |
|---|---|---|
| Number of Employees | 364 | 335 |
| Annual Payroll, million dollars | 3.15 | 2.89 |
| Capital Investment, million dollars | 290 | 290 |
| Amount of Coal Mined, million tons/year | 10.66 | 10.66 |
| Water Required, thousand acre-feet/year | 30 | 30 |
| Power Required, million kwh/year | 48 | 48 |

[1] Figures show approximate value of facilities in operation in 2000 and 2020.

The location of developments by the coal industry in the Basin as projected in the Cameron Report through the year 2020 are shown in Figure IV-5. It may be seen that all the development is projected for Fremont County near Boysen Reservoir. This area, according to the Cameron Report, will have two coal mines and two steam electric plants by the year 2000. It is recognized that unique conditions could make coal development attractive elsewhere in the Basin.

## Water Resource Requirements

Table IV-17 shows the projected future water requirements of the Basin's coal industry. The total water use is projected to increase from a negligible amount at present to 30,000 acre-feet per year by the year 2000, and will continue at that rate through the year 2020. The projections in the Cameron Report were based on the assumption that water would be available in sufficient quantities so as not to limit development. The projected water requirements are 15,000 acre-feet per year for each 1,000 megawatt powerplant. New technological developments, such as the use of air condensers, the magnetohydrodynamics (MHD) process to produce electricity, and others may reduce future water needs below those shown in Table IV-17.

## Nonfuel Minerals and Timber

A number of nonfuel minerals are now, or are projected to become, economically important in the Bighorn River Basin. These include gypsum, bentonite, phosphate, and copper (see Figure IV-4). These industries, and the timber industry, require minor amounts of water but are included in this discussion because of their effects on employment and other economic considerations and the subsequent effect on municipal water projections.

Two companies, Big Horn Gypsum at Cody and Georgia-Pacific at Lovell, produce gypsum wallboard primarily for markets located in the Northwest. The manufacture of wallboard has become one of the State's major industries. About 120 gallons of water are consumed in the manufacture of one ton of gypsum wallboard. If any of the methods for removing elemental sulfur become commercially successful, a large new market for gypsum would be created. Similarly, a new method for producing ammonium sulfate fertilizer from gypsum could create a new demand for gypsum.

Wyoming bentonite is a unique swelling clay found in commercial deposits throughout the State. About 60 percent of the quality reserves are on the western flank of the Big Horn Mountains. Thus the towns of Lovell, Greybull, Basin, and Worland should feel most of the impact resulting from the Wyoming bentonite industry's growth. Consumptive use of water is not required for mining or processing bentonite.

One phosphate mine and one elemental phosphorus plant were forecast to be in operation by year 2020 in the Lander area by Cameron Engineers. Consumptive water use will only be about 132 acre-feet per year for this industry.

A copper deposit of possible commercial interest in Park County is being investigated by American Metals Climax. This company has purchased a portion of the storage rights in the Lower Sunshine Reservoir now under construction. Actual water depletion rates are unknown but will probably be small.

The production of small quantities of feldspar in Fremont County is expected to continue. Water consumption for this purpose is small.

Timber production in Wyoming amounts to about 0.2 percent of the Nation's output of forest products. The timber resources of the Basin are largely within the Shoshone and Bighorn National Forests. The timber industry itself is not a heavy user of water; at present, total water consumption by all firms in the State's timber industry is less than 200 acre-feet annually.

The projected water requirements of the Basin's gypsum, bentonite, phosphate, copper, feldspar and timber industries are shown in Table IV-18.

TABLE IV-18 -- Bighorn River Basin Industrial Water Projections

| | 1967 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| | (Acre-Feet Per Year) | | | |
| Petroleum Industry [1] | 26,900 | 27,300 | 10,700 | 10,500 |
| Uranium Industry [2] | 975 | 7,758 | 15,000 | 6,000 |
| Coal Industry | 0 | 0 | 30,000 | 30,000 |
| Gypsum Industry | | | | |
| Big Horn County [2] | 0 | 74 | 111 | 141 |
| Park County | 38 | 138 | 207 | 265 |
| Bentonite Industry | NO | WATER | REQUIRED | |
| Phosphate Industry | 0 | 0 | 0 | 132 |
| Timber Industry | 50 | 50 | 100 | 100 |
| Total Surface Water Consumed | 2,188 | 1,988 | 31,307 | 31,297 |
| Total Groundwater Consumed | 25,775 | 28,332 | 24,811 | 15,841 |
| Total Water Consumed | 27,963 | 30,320 | 56,118 | 47,138 |

[1] Most water for the petroleum industry is supplied from groundwater. The actual amounts supplied by groundwater are as follows: 1967 - 24,800; 1980 - 20,500; 2000 - 9,700; 2020 - 9,700.

[2] Supplied from groundwater.

## Summary of Water Requirements for Industrial Purpose

Table IV-18 shows a summary of the projected industrial consumptive water requirements in the Basin. The projections show that surface water will reach a level of about 31,300 acre-feet per year after which it will remain nearly constant. Groundwater use is projected to peak at about 28,330 acre-feet per year sometime around the year 1980, after which it will decline.

## Summary of Industrial Economic Factors

Table IV-19 is a summary of projected economic factors in the Bighorn River Basin of Wyoming.

TABLE IV-19--Summary of Industrial Economic Factors

| | 1967 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Total Number of Industrial Employees | 3,870 | 4,520 | 4,520 | 2,535 |
| Annual Payroll, million dollars | 31 | 36 | 36 | 20 |
| Capital Investment, million dollars[1] | 99.2 | 194 | 551 | 467 |
| Electric Power Required, million kwh/year | 222.4 | 242.8 | 262.3 | 1,301.9 |

[1] Figures show approximate value of facilities in operation in 1967, 1980, 2000, and 2020.

## MUNICIPAL, DOMESTIC, AND STOCK WATER USE

Municipal water is provided largely by municipally operated water systems, although water in some smaller communities is supplied from small, privately owned systems. Table IV-20 gives the sources of municipal water supply and the 1970 population of towns in the Basin. It may be seen from the table that nearly 98 percent of the people residing in towns in the Basin have as their sources of supply municipal water systems. About 61 percent of the people in towns use surface water as a source of supply, while the remaining 39 percent use groundwater.

The term "water consumption" is often used in connection with municipal water usage to mean treated water delivered into the municipal distribution system. In this report the terms "diversions" from a water source, "returns" to a water source, and "consumptive uses," which are the diversions less the returns, are used.

A diversion of approximately one acre-foot per year normally is required to serve five people. This is equivalent to an average diversion of 180 gallons per day per person, commonly abbreviated as 180 gpcd (gallons per capita per day). About one-half the municipal water diverted is consumptively used, and the balance may be considered a return. These figures are used later in this section to estimate future water needs.

Domestic water and stock water are supplied from lakes, streams, ponds, ditches, water wells, and reservoirs. Since these are private supplies, little factual data exist concerning domestic and stock water uses in the Basin. The quantity of domestic water consumed in the Basin is small compared with other water uses.

TABLE IV-20 -- Municipal Water Supplies in the Basin

| Town | Study Area [1] | 1970 Population | Type of Water Supply System(s): Municipal | Type of Water Supply System(s): Private | Source of Supply: Surface Water | Source of Supply: Groundwater | Remarks |
|---|---|---|---|---|---|---|---|
| Arminto | 1e | 10 | | X | | X | |
| Basin | 2a | 1,145 | X | | X | | |
| Burlington | 2h | 100 | | X | | X | |
| Burris | 1d | 10 | | X | | X | |
| Byron | 2j | 397 | X | | | X | |
| Cody | 2i | 5,161 | X | | X | | |
| Cowley | 2j | 366 | X | | | X | |
| Crowheart | 1d | 10 | | X | | X | |
| Deaver | 2j | 112 | X | | X | | |
| Dubois | 1a | 898 | X | | | X | |
| E. Thermopolis | 2a | 316 | X | | X | | |
| Emblem | 2h | 10 | | X | | X | |
| Ethete | 1b | 50 | X | | X | | (Federal) Small public water supply system |
| Fort Washakie | 1b | 300 | X | | X | | (Federal) Small public water supply system |
| Frannie | 2j | 139 | X | | | X | |
| Garland | 2j | 50 | | X | | X | |
| Gebo | 2a | 25 | | X | | X | |
| Grass Creek | 2f | 115 | | X | | X | |
| Greybull | 2a | 1,953 | X | | X | | |
| Hamilton Dome | 2f | 100 | | X | | X | |
| Hiland | 1e | 10 | | X | | X | |
| Hudson | 1b | 381 | X | | | X | |
| Hyattville | 2c | 100 | | X | | X | |
| Kinnear | 1d | 50 | | X | | X | |
| Kirby | 2a | 75 | | X | | X | |
| Lander | 1b | 7,125 | X | | X | | |
| Lost Cabin | 1e | 25 | | X | | X | |
| Lovell | 2j | 2,371 | X | | X | | |
| Lysite | 1e | 50 | | X | | X | |
| Manderson | 2a | 117 | X | | | X | |
| Meeteetse | 2g | 459 | X | | X | | |
| Moneta | 1e | 10 | | X | | X | |
| Morton | 1d | 5 | | X | | X | |
| Otto | 2h | 50 | | X | | X | |
| Pavillion | 1d | 181 | X | | | X | |
| Powell | 2j | 4,807 | X | | | X | |
| Ralston | 2j | 100 | | X | | X | |
| Riverton | 1d | 7,995 | X | | | X | |
| Shell | 2d | 50 | | X | | X | |
| Shoshoni | 1e | 562 | X | | | X | |
| Ten Sleep | 2c | 320 | X | | | X | |
| Thermopolis | 2a | 3,063 | X | | X | | |
| Valley | 2i | 25 | | X | | X | |
| Worland | 2a | 5,055 | X | | X | | |
| Total | | 44,253 | | | | | |
| Population[2] Served by: | | | | | | | |
| a. Municipal systems | | | 43,273 | | | | |
| b. Private systems | | | | 980 | | | |
| Population[2] Served by: | | | | | | | |
| a. Surface Water | | | | | 27,110 | | |
| b. Groundwater | | | | | | 17,143 | |

[1] The numbers in this column refer to study areas as shown on Figure II-6.

[2] Population figures do not include rural population.

It is estimated that there are about 321,000 head of cattle and 308,000 head of sheep in the Basin. Assuming consumptive water use rates of 15 gallons per day each for cattle and 3 gallons per day each for sheep, the present water consumption by both in the Basin is about 6,400 acre-feet per year.

Comprehensive plans for water and sewerage for each county in the State have been prepared by various consulting firms for the Planning Division of the Department of Economic Planning and Development through a Farmers Home Administration grant. The function of this planning effort is to provide a basic plan for municipalities with populations of less than 5,500 persons to insure adequate water supplies and waste disposal facilities to meet future demands.

Table IV-21 shows the projected population of the Basin, and the projected municipal, domestic, and stock water requirements in the Basin through the year 2020.

TABLE IV-21--Projected Population and Municipal, Domestic, and Stock Water Requirements in the Bighorn River Basin, Wyoming

| | 1970 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Basin Population | 68,427 | 84,100 | 127,300 | 175,300 |
| Municipal and Domestic | | | | |
| Diversion, Acre-Feet/Year | 13,700 | 16,800 | 25,500 | 35,100 |
| Consumption, Acre-Feet/Year | 6,900 | 8,400 | 12,700 | 17,500 |
| Stock Water Depletion, Acre-Feet/Year | 6,400 | 6,900 | 8,400 | 9,900 |
| Total Depletion, Acre-Feet | 13,300 | 15,300 | 21,100 | 27,400 |

## RECREATION AND FISH AND WILDLIFE

Outdoor recreation, including fishing and hunting, is of increasing economic importance in the Basin. Fishing, hunting, boating and other water sports, and many other recreational activities have potential for growth in Wyoming's Bighorn River Basin.

The following discussion on fish and wildlife is based upon information extracted from the "Wyoming Fish and Wildlife Plan," Wyoming Game and Fish Commission Planning Report Numbers 2F, 2G, 2AF, 6G, and 8G. (Note: Waters within Wind River Indian Reservation boundary are not included in Game and Fish Commission data).

### Fish

The area covered in this discussion of the Basin fisheries is comprised of Management Areas 2 and 2A of the Fish Division of the Wyoming Game and Fish Commission. These areas approximately coincide with this report's Study Area as shown in Figure I-1, with the primary exceptions being that Management Area 2 includes a large portion of the drainage area of the Sweetwater River, a tributary to the North Platte River, and the drainage area of the Little Bighorn River is excluded in this discussion. Data for these areas is included in other Wyoming Water Planning Program river basin reports.

There are over 4,335 miles of streams in the Basin which have been classified on the basis of present conditions of esthetics, availability, and productivity, according to the following categories:

Class 1 -- Waters of nationwide importance.

Class 2 -- Waters of statewide importance.

Class 3 -- Waters of importance to large areas less than statewide.

Class 4 -- Waters of importance to small areas such as counties.

Class 5 -- Waters of potential importance as fisheries, now polluted or otherwise seriously limited or degraded.

As of July 8, 1971, in this area there were 3 miles of Class 1 streams, 448.6 miles of Class 2 streams, 2,472.6 miles of streams in Class 3, 1,321 miles in Class 4, and 89.9 miles in Class 5.

The Basin also contains over 61,341 surface acres of natural lakes, reservoirs, and farm ponds which produce fisheries. The natural lakes are composed of alpine lakes (elevation over 7,500 feet) and lowland lakes (elevation below 7,500 feet). A similar method of classification separates alpine and lowland reservoirs. Farm ponds are waters which are 5 acres or less in surface area and are categorized as trout, mixed, or non-trout ponds.

Tables IV-22 and IV-23 summarize the classified streams and bodies of water in Fish Management Areas 2 and 2A according to fishing pressure and capacity.

TABLE IV-22 -- Estimated Fishing Pressure and Capacity of Streams for Sport Fishing in the Basin as of July 8, 1971

| Stream Class | Length (Miles) | Annual Fisherman-Days | |
|---|---|---|---|
| | | Use | Capacity |
| Class 1 | 3.0 | 1,404.0 | 2,808.0 |
| Class 2 | 448.6 | 8,292.8 | 28,804.9 |
| Class 3 | 2,472.6 | 14,479.7 | 42,174.6 |
| Class 4 | 1,321.0 | 2,468.5 | 6,946.6 |
| Class 5 | 89.9 | 9.9 | 22.7 |
| Total | 4,335.1 | 26,654.9 | 80,756.8 |

Trout populations are present in all stream classes. The 3 miles of Class 1 stream (Wind River below Boysen Reservoir) contain rainbow and brown trout populations which are supplemented with plants of catchable rainbow trout. This reach also contains walleye, sauger, perch, and crappie which come from Boysen Reservoir. Depending on the stream or stretch of stream, Class 2, 3, and 4 waters in the Basin may contain one or more of the following species: rainbow, brown, brook, golden, cutthroat, and mackinaw trout; whitefish, crappie, walleye, yellow perch, sauger,

TABLE IV-23 -- Estimated Fishing Pressure and Capacity of Lakes, Reservoirs, and Ponds for Sport Fishing in the Basin as of July 8, 1971

| Type | Surface Area (Acres) | Annual Fisherman-Days | |
|---|---|---|---|
| | | Use | Capacity |
| Alpine Lakes | 9,142.3 | 16,827.0 | 72,688.1 |
| Alpine Reservoirs | 540.7 | 3,557.0 | 16,915.8 |
| Lowland Lakes | 555.5 | 371.1 | 1,847.2 |
| Lowland Reservoirs | 50,970.4 | 79,917.8 | 311,700.8 |
| Trout Farm Ponds | 102.3 | 2,672.5 | 2,672.5 |
| Mixed Farm Ponds | 11.4 | 85.6 | 85.6 |
| Non-Trout Farm Ponds | 18.5 | 112.3 | 112.3 |
| Total | 61,341.1 | 103,543.3 | 406,022.3 |

catfish, bullhead, sucker, carp, and chub. In addition, hybrids of the trout species listed may be found in localized areas due to crosses of trout species which spawn at the same time.

Alpine lakes and reservoirs contain rainbow, brown, brook, cutthroat, mackinaw, and golden trout, and the following hybrids: rainbow/cutthroat, rainbow/golden, cutthroat/golden, and mackinaw/brook. Some alpine lakes also contain silver salmon, grayling, whitefish, and ling. Nongame species are present in some of the alpine lakes and reservoirs.

Natural lowland lakes contain brook, cutthroat and rainbow trout, and yellow perch. Lowland reservoirs contain as many as 29 species of fish, including game and nongame species. These include all species previously listed plus largemouth bass and bluegill.

Trout farm ponds contain mostly rainbow and brook trout. Nontrout farm ponds contain primarily largemouth bass.

## Current Fisherman Use and Harvest

From Tables IV-22 and IV-23 it may be seen that lowland reservoirs receive the greatest fishing pressure in terms of fisherman-days. Most of this use is on the larger reservoirs including Boysen Reservoir, Bighorn Lake (Yellowtail Reservoir), Buffalo Bill Reservoir, and Ocean Lake.

The second most popular type of fishing in terms of fisherman-days is stream fishing, followed in order by alpine lakes, alpine reservoirs, trout farm ponds, lowland lakes, nontrout farm ponds, and mixed farm ponds.

The predominant trout species in the catch are rainbow, brook, cutthroat, and brown trout. Walleye and sauger are the most sought after warm-water game fish; while largemouth bass, crappie, perch, bluegill, and bullhead contribute significantly to the fishermen's creels. Many fish of these latter species are caught incidentally while the fisherman is in pursuit of trout or walleye.

The nonresident and tourist anglers (5-day license holders) tend to fish in streams more than lakes and reservoirs, while the opposite is true with resident fishermen. While year-round fishing is permitted in the Study Area, most of the angling takes place during May through September. Twenty-one percent of the ice fishing in the State takes place in the Wind River drainage.

Economic Importance of Fishing

An economic study was completed by the Statistics Department of the University of Wyoming in 1966, based upon a random sample of the 1965 license holders. This survey indicated that fishing generated a total income of $3,835,455 to the five counties within the River Basin. The survey further indicated that the resident fisherman spends an average of $220 per year and the nonresident fisherman spends $142 during his stay in Wyoming. An updated study will be completed in 1972 by the University.

## Wildlife

Wildlife is dependent upon water as a factor in its habitat. For this reason, wildlife must be considered along with fish in the economics of water resources development.

Big game habitat in the Basin consists of alpine peaks, forested mountains, sagebrush-grassland plains, badlands and desert basins, and dryland and irrigated farmland. Mule deer inhabit nearly all of the Basin. Summer range for deer is adequate, but winter range is limited in some areas. The Game and Fish Commission has acquired one deer winter range area in Washakie County. Whitetail deer are few due to limited habitat. Elk have ample summer range in the Basin, even though most of this is shared with domestic livestock. Winter range is the factor which limits the herds to their present sizes. In addition to the deer winter range area mentioned above, the Game and Fish Commission owns and manages five big game winter areas (Red Canyon, East Fork, Whiskey Basin, Sunlight Basin, and Medicine Lodge Units). Other important winter pastures are on lands of the National Forests and Bureau of Land Management and State and private holdings. Moose habitat, consisting of stream bottoms and marsh and lakes areas, exists in the Upper Wind and Popo Agie River drainages and in the western mountains from the Greybull River to the Montana line. Some very marginal moose habitat exists in the Big Horn Mountains. Black bear habitat is located throughout the mountainous and foothill areas, and there is some grizzly bear habitat in the upper reaches of the Wiggins Fork drainage and in the mountainous area adjacent to Yellowstone National Park. Antelope habitat is located throughout the Basin except for the mountain areas and the irrigated lands. The range is limited by activities such as sagebrush eradication, fencing and other developments. Bighorn sheep habitat in this Basin is some of the best and most extensive in the State. The habitat is composed of alpine and subalpine meadows and ridges in the Wind River, Absaroka, and Big Horn Mountain ranges. Winter habitat and competition for forage from other big game species and domestic livestock are the factors limiting the bighorn sheep herds to their present population. Although a large amount of potential mountain goat habitat exists in the alpine areas of the Basin, the present range is limited to the area north of the Clarks Fork River.

Habitat for small game and upland game birds is very diversified. Areas which are covered with sagebrush provide fair to excellent sage grouse habitat, depending on the extent of man's activities such as sagebrush eradication, construction, etc. Chukar partridge habitat, consisting of semiarid grazing lands and adjacent farmlands below 7,500 feet elevation, varies from poor to excellent. Pheasant habitat is confined to the irrigated croplands along creek and river bottoms and in the Riverton Project area. Hungarian partridge habitat is found below 7,000 feet elevation throughout much of the Basin, particularly along creek and river bottoms in farming areas. Blue and ruffed grouse habitat is limited to mountainous areas. The blue grouse is generally found in the higher mountains, while the ruffed grouse range along the foothills and in the drainage bottoms. The Yellowtail Wildlife Management Unit in Big Horn County supports the only huntable bobwhite quail population in the State. The entire Basin below 7,500 feet elevation offers fair to excellent cottontail rabbit habitat. The better areas are the creek bottoms and brushy hillsides as well as irrigated croplands and dryland farms. Migratory waterfowl utilize open water and impoundments for temporary habitat. The Ocean Lake and Yellowtail Units provide excellent waterfowl habitat.

## Current Hunter Use and Harvest

The figures in Table IV-24 show the number of hunters, hunter-days including successful and unsuccessful hunters, and estimated harvest for the Basin in 1969.

TABLE IV-24 -- Estimated Number of Hunters, Hunter-Days, and Harvest in the Basin - 1969

| Category | Hunters | Hunter-Days | Harvest |
|---|---|---|---|
| Deer | 23,210 | 72,898 | 15,991 |
| Elk | 12,969 | 50,347 | 4,623 |
| Moose | 81 | 261 | 70 |
| Black bear | 860 | 4,804 | 103 |
| Antelope | 3,146 | 6,288 | 3,094 |
| Bighorn sheep | 161 | 1,107 | 47 |
| Total Big Game | 40,427 | 135,705 | 23,928 |
| Pheasant | 7,480 | 25,519 | 25,767 |
| Chukar partridge | 4,071 | 14,376 | 14,052 |
| Hungarian partridge | 1,677 | 6,378 | 3,762 |
| Sage grouse | 2,976 | 8,170 | 13,095 |
| Blue and ruffed grouse | 209 | 523 | 410 |
| Bobwhite quail | - - - NO INFORMATION AVAILABLE - - - | | |
| Cottontail rabbit | 4,356 | 22,745 | 41,147 |
| Total Upland and Small Game | 20,769 | 77,711 | 98,233 |

Economic Importance of Hunting

An economic study was completed by the Statistics Department of the University of Wyoming in 1966, based upon a random sample of the 1965 lincese holders. This survey indicated that hunting generated a total income of $7,786,341 to the five counties within the River Basin. Average expenditures by hunters are shown in Table IV-25 and include such items as transportation, food, lodging, arms and ammunition, camping equipment and trailers, guides and other miscellaneous items.

TABLE IV-25--Average Dollars Spent by Hunters, 1965

| Game | Resident | Nonresident |
|---|---|---|
| Deer | $119.65 | $156.45 |
| Elk | 251.09 | 517.31 |
| Antelope | 101.67 | 172.05 |
| Moose | 518.23 | 736.73 |
| Bighorn Sheep | 545.82 | 371.93 |
| Birds | 42.09 | 8.56 |

## Water Sports and Boating

The following discussion is based on "Outdoor Recreation in Wyoming, Volume III" (3).

Boysen Reservoir and State Park, Bighorn Lake and National Recreation Area, Ocean Lake, Louis Lake, Buffalo Bill Reservoir and State Park, and Meadowlark Lake are the most popular boating areas in the Basin. Fishing is the overwhelming activity choice of boaters in Wyoming, followed by pleasure cruising and water skiing.

## Future Demands and Desires

### Sport Fisheries

Increasing population in and adjacent to the Basin will influence the utilization of the area by fishermen.

The principal factors affecting future capacity of the fishery are a projected large increase in outdoor recreational pursuits, a potential reduction in quantity and quality of habitat, a steady reduction in free public access, and an ever-increasing competition for land and water from other resource development programs. All these point to the need for increasing multi-purpose land and water resource management to insure that soil erosion, stream siltation, stream pollution, and reduced volume flows below water developments will not adversely affect the fishery habitat of this region.

Projections obtained from the Wyoming Recreation Plan indicate an estimated increase in the level of angler use in Wyoming from 1967 to 1985 of 28 percent. Tables IV-21 and IV-22 give an indication of the capacity of present Basin fisheries. Stream fisheries could support three times the fishing pressure they presently receive without necessitating large management changes. The lowland reservoirs could support nearly four times the present pressure without changing the existing management policies. Changes in operating criteria would be the greatest influence that could be excercised on lowland reservoirs to raise their fisheries' potential. Alpine lakes and reservoirs could support 4.3 and 4.8 times the present pressure respectively before management changes would be necessary. The use of alpine lakes and streams in the primitive areas of the Basin has increased greatly over the years and this trend is expected to continue. Accessible farm ponds are generally utilized to their practical maximum at present. Ice fishing is becoming more popular and should continue to increase in popularity.

Big Game

The demand for hunting opportunities within the Basin is expected to increase substantially during the next 30 years. Resident demand should parallel an increase in statewide population growth. Nonresident demand will continue to show percentage increases exceeding national population growth figures. Hunting license limitations will continue to be the means to provide proper game management.

The capacity to increase big game species is dependent upon the quality and quantity of habitat available. The acquisition of additional key big game winter ranges and better protection of existing habitat will assist in the preservation of present populations and provide for additional means of expanding the future carrying capacity. Some water development programs have proven beneficial to the sage grouse and antelope, such as stock pond construction or guzzlers which have allowed them to utilize more range.

Small Game and Upland Game

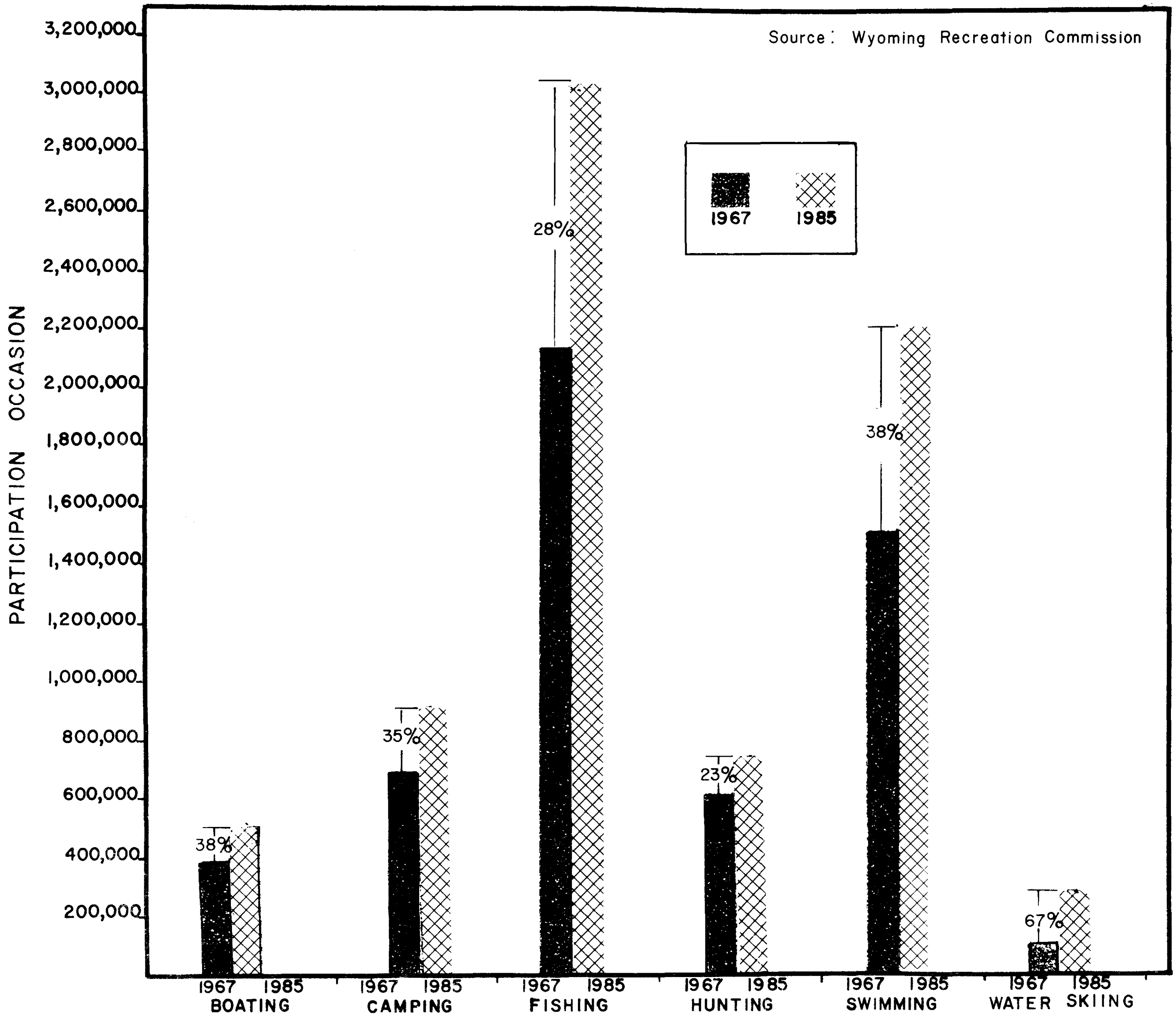
Harvest of fur animals is very light, but the potential demand for outdoor recreation may bring about an increased use of this resource.

The recreational potential of upland game birds could expand since the resource is not at present being fully utilized. Exceptions to this are the Hungarian partridge and bobwhite quail, where the potential harvest has probably been reached. The number of pheasants increases or decreases according to farming practices. Under-harvested populations suffer substantial winter loss. Greater use of the upland game resource may result from publicizing the need and opportunity for sportsmen to hunt in the Basin.

The capacity to provide additional hunting of waterfowl is based upon the size of the population during any one season and the length of time that substantial numbers may stay in the Basin during the fall migration. The prospects for increased numbers of ducks appear to be good, and there is a prospect of increasing the number of water fowl wintering in the Basin. Any liberalization of seasons and bag limits will entice participation in waterfowl hunting.

Water Sports and Boating

The future increases in participation in water-oriented recreation are shown in Figure IV-6. Projected 1985 increases over 1967 participation include




PARTICIPATION ESTIMATES FOR SELECTED RECREATION ACTIVITIES
WYOMING FOR 1967 and 1985
Figure IV-6

boating-38 percent, swimming-38 percent, and water skiing-67 percent. The largest increases in uses will occur on water bodies near population centers or centers of tourist attraction, such as Yellowstone National Park and Bighorn National Recreation area. Wyoming boaters indicate that boating improvements most needed are more and better launching facilities, better picnic and camping facilities, controlled water levels at reservoirs, and increased enforcement of boating regulations and safety rules.

A system of wild and scenic rivers has been established by the Federal Government to preserve sections of the rivers of the Nation in their free-flowing states. The Wyoming position regarding scenic rivers is given in An Outdoor Recreation Plan for Wyoming, October, 1970:

"The State of Wyoming has taken the position that it is the State's responsibility to administer the rivers within its boundaries, and that development of scenic rivers programs and other similar programs affecting the waters of Wyoming should be under the jurisdiction of the State. Portions of the following rivers are under consideration for designation as scenic rivers: The Upper Green, Snake, Platte, Clarks Fork, Shoshone, Wind, and Tongue, (Upper Sweetwater[1], and Upper Popo Agie[1])."

A scenic river designation for a reach of a given stream in Wyoming would have to be made by the Wyoming Legislature. There currently is a proposal for the Legislature to authorize a study of streams in the State that might lead to a stream classification system. In considering a scenic river designation, conflicts with potential economic developments should be evaluated. A scenic designation may insure maintenance of environmental quality, continued public access, and proper management of the recreation values of a desired section of a stream.

## Water Resource Requirements

The present consumptive uses assigned directly to recreation and fish and wildlife activities are small. Other present uses for recreation are largely nonconsumptive, although some stock pond evaporation could probably be assigned to wildlife use. A very large number of existing reservoirs are used for recreation, even though this use is not listed on the permit. The reason recreation use is not listed is usually that recreation was not the primary intended use when the permit application was submitted. In most cases the applicant was unaware of the recreation potential that his reservoir would have. Campgrounds and mountain cabin water uses have been and will continue to be small in comparison with total water uses, although supplying such uses can be of significance locally. Campground and cabin site water supply and sewage disposal will become an increasing problem as these activities increase.

The Wyoming Game and Fish Commission has suggested several provisions and considerations for inclusion in water development projects regarding recreation and fish and wildlife, including the following:

1. All reservoirs should have minimum pools of sufficient depth and size to maintain a permanent fishery. Conditions requiring a minimum of stocking effort to produce a quality fishery should be maintained.

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[1] Added by Wyoming Recreation Commission since October 1970.

2. Storage capacity should be adequate for continuous downstream releases in sufficient quantity to sustain the stream trout fishery.

3. If there are alternate sites available for reservoir construction, consideration should be given to selecting the site which is least detrimental to the stream fishery and game habitat.

4. Funds for fisheries management purposes such as fish screens, rough fish control, or silt settling basins for water quality control should be included as part of the project costs.

5. Reservoir functions and operations, including downstream water releases, should be planned on a cooperative basis with appropriate State and Federal agencies.

6. Water conservation practices such as lining ditches, using overhead sprinklers, and the efficient application of water should be a consideration in any project planning to reduce water quality deterioration.

7. Cost of land necessary for public access to streams and lakes to replace present public use areas should be included in project funding.

8. Cost of land to replace big game wintering areas should be included in project funding.

9. Big game migration routes should be protected by providing bridges across canals.

## FLOOD CONTROL

As mentioned in Chapter II, flood damages frequently occur along streams in the Bighorn River Basin as a result of high spring runoff, summer rainstorms, or ice jams. Although several large reservoirs are located in the Basin, the water right records of only two reservoirs, Bighorn Lake and Tensleep Reservoir, list flood control as a use (see Table IV-9). Bighorn Lake has 250,000 acre-feet of storage allocated to joint use which includes flood control. Boysen Reservoir is operated to use 150,000 acre-feet of storage as a joint use including flood control, even though flood control is not listed as a use.

The town of Thermopolis has experienced serious flooding in the past (1960, 1962, 1963, and 1967) from Candy Jack Creek. Recently, the Soil Conservation Service completed a project to route the floodwater in a pipeline through the town. This project is expected to alleviate the $38,740 of annual flood damages experienced before the project was constructed.

Portions of the business and residental sections of the town of Greybull are located on the floodplain of the Bighorn River. Spring snowmelt, summer rainstorms, ice jams, or a combination of these have caused flood damages to Greybull in the past. The U. S. Army Corps of Engineers in 1958 initiated construction of approximately 13,675 feet of levee along the left bank of the Bighorn River. Rock riprap was placed along three sections of the river bank and levee system to protect them from erosion. Whenever possible, the Corps of Engineers incorporated the existing levees built by the City of Greybull into the project. In addition to the levee system, a number of jetties were built to help prevent ice jams. The Corps flood control project was completed in 1959.

The U. S. Department of Agriculture was requested by the Wyoming State Engineer to survey the Basin for potential water resources programs, including flood, sediment, and erosion control. Information about frequency and type of flood damages is in Chapter II of this report. Summaries of the flood control and related features of potential watershed projects identified in the survey, conducted primarily by the Soil Conservation Service (SCS) and reported in Watershed Investigation Reports, are as follows:

1. Crow Creek - A proposed reservoir at the Tipperary site in T. 7 N., R. 4 W. would provide 100 acre-feet of sediment storage, 5,900 acre-feet of irrigation storage, and 4,000 acre-feet of flood control storage. This reservoir would reduce the average annual flood damages to cropland diversion structures, canals, fences, roads, and farmsteads by 75 percent, from $9,750 to $2,440.

2. Upper Beaver Creek - A potential 14,500-acre-foot reservoir on the stream would provide 1,600 acre-feet of sediment control storage space, 3,500 acre-feet for flood control, and 9,400 acre-feet for irrigation. The project would completely eliminate the average annual flood damage to crops, canals, fences, and irrigation structures of $1,600.

3. Upper Badwater Creek - Even though the major problem in this drainage basin is shortage of irrigation water, flooding and sedimentation can cause serious problems in the form of damages to agricultural property along Badwater Creek below Sioux Creek. A proposed reservoir above the confluence of Dry Badwater Creek with Badwater Creek would provide 850 acre-feet of irrigation storage, 150 acre-feet of sediment storage, and 770 acre-feet of floodwater storage. The sediment and flood storage provided by the reservoir would reduce damages from $7,680 to $3,595 annually.

4. Nowood River - Spring snowmelt runoff, summer rainstorms, or ice jams cause some flood damage nearly every year in the Nowood River basin, damaging crops, irrigation structures, roads, bridges, fences, and urban property in the town of Manderson. Some flood damage has occurred on the Nowood River tributaries of Canyon, Tensleep, and Paint Rock Creeks.

A proposed plan would include a multipurpose reservoir at Big Trails, a streambank stabilization program along the floodplain of the Nowood River and some of its tributaries, and a dike and levee system to protect the town of Manderson.

The multipurpose reservoir would provide 7,000 acre-feet of sediment storage. The 6,000 acre-feet of irrigation storage would provide a full-season water supply to 3,000 acres of new land.

An estimated 7 miles of streambank stabilization below the proposed reservoir would be provided by bank sloping and riprapping and/or installing jetties in the stream channel in a manner similar to the work completed in 1970 under the Emergency Conservation Measures Program. The areas to be controlled would be places where streambank erosion is causing a loss of valuable cropland or where developments such as irrigation structures, farmsteads, or roads are endangered.

A dike and levee system is proposed to completely encircle the town of Manderson to protect it from floodwaters of the Nowood and Bighorn Rivers. About 60 percent of the flood damage to Manderson is caused by flooding of the Nowood River; the remaining 40 percent is caused by the Bighorn River. This levee system is similar to a project proposed by the Corps of Engineers in May of 1969, in an unpublished reconnaissance study, "Bighorn River and Nowood River at Manderson, Wyoming."

The proposed plan would reduce flood damages by 73 percent, from $173,170 to $46,200 per year.

5. Middle Popo Agie River - In September of 1969 the SCS made a General Status Report on the Middle Popo Agie River. This was done in response to an application to the State Conservation Commission sponsored by the City of Lander, the Nicol-Table Mountain Ditch Company, the Enterprise Irrigation and Power Company, and the Popo Agie Conservation District. The watershed problems included flood control, improving Lander's water supply, and irrigation. A multipurpose reservoir above Lander was investigated but did not appear to be economically feasible or physically justified. As an alternative, the report considered a debris basin and an improved channel constructed through Lander. A concrete-lined channel, with a life expectancy of 60 years, could be constructed at a local annual cost of about $6,000. If the streambed were improved by using drop structures and in-place gabions as riprap, the life expectancy would be 25 years, and local annual cost would be $8,250.

The City of Lander has reduced the flood damages by paving the streets and constructing curbs and gutters to route the flow around homes and businesses, and by constructing dikes along the west side of the river. As an annual project, the city has been dredging, cleaning, and shaping the river bed through Lander. The City of Lander's present program, which includes spending about $3,500 a year maintaining and upgrading the river channel and constructing and improving dikes, may be the best alternative.

Several other potentials for reducing flood, sediment, and erosion problems have been investigated in the Basin but have not proven feasible from either a physical or economical standpoint. In many cases the potential projects include other watershed management functions that would incidentally improve flood, sediment, and erosion conditions.

## HYDROELECTRIC POWER

The electrical energy requirements of the Bighorn River Basin are supplied by interconnected power systems with the power being supplied by five Federally operated hydroelectric powerplants. The combined generating capacity of the five Bureau of Reclamation hydroelectric powerplants is 277,200 kilowatts, as shown in Table IV-26.

If the large increase projected in coal-fired thermal powerplants is actually realized in Northeastern Wyoming, hydropower developments may be desired for peaking power. The North Central Power Study lists a 1,240-mw pump-storage project at the Sheep Mountain site. This project will include the existing Buffalo Bill Reservoir near Cody and the proposed 355-foot Sheep Mountain Dam above Buffalo Bill Reservoir. Sheep Mountain Dam will have an active capacity of 6,900 acre-feet. The estimated cost of the proposed pump-storage project was based on the following data (6):

Pumping Generating Plant - 14,240 mw
  Number of units - 3
  Size of units - 413 mw
  Head (Maximum Static Head on Unit) - 1,510 feet (Continued on next page)

Continued from previous page:

Plant Operation

Pumping Period - 14 hours

Peaking Period - 8 hours

Estimated 1970 cost - $175/kw

Estimated 1970 annual O & M cost - $1.50/kw (excluding cost of pumping energy)

TABLE IV-26--Powerplant Data for Bureau of Reclamation Hydroplants in the Bighorn River Basin

| Plant | Source of Supply | Regulation Facility | Installed Capacity (Kilowatts) | Generating Units |
|---|---|---|---|---|
| Pilot Butte | Wind River | Pilot Butte Reservoir | 1,600 | 2-800 kw |
| Boysen | Wind River | Boysen Reservoir | 15,000 | 2-7,500 kw |
| Shoshone | Shoshone River | Buffalo Bill Reservoir | 5,600 | 1-4,000 kw<br>2-800 kw |
| Heart Mountain | Shoshone River | Buffalo Bill Reservoir | 5,000 | 1-5,000 kw |
| Yellowtail | Bighorn River | Bighorn Lake | 250,000 | 4-62,500 kw |
| Total | | | 277,200 | 12-277,200 kw |

In 1956 the Bureau of Reclamation proposed a hydroelectric unit in the upper reaches of the Clarks Fork Study Area. The Beartooth Unit would include three reservoirs on the main stem of the Clarks Fork, one reservoir on Sunlight Creek, and three powerplants and related facilities. A firm energy supply of 778 million kilowatt-hours could be supplied by the unit. The project costs were estimated in 1956 to be $131,000,000, and the annual benefits were estimated to exceed costs by 1.09 to 1.

Hunter Mountain Dam on Clarks Fork would be located the farthest upstream and have a 34,800-foot conduit to Hunter Mountain Powerplant. The Thief Creek Dam, about 12 miles downstream from Hunter Mountain, and the Sunlight Dam, approximately 6 1/2 miles upstream from the mouth of Sunlight Creek would use the facilities of the Sunlight Powerplant, directly below the mouth of Sunlight Creek. A 3,900-foot conduit from Thief Creek Dam and a 34,900-foot conduit from Sunlight Dam would lead to the Sunlight Powerplant. The Bald Ridge Dam would be located approximately 7 miles downstream of Thief Creek Dam and have a 25,600-foot conduit to Bald Ridge Powerplant.

Table IV-27 lists some of the design properties of the Beartooth Unit.

TABLE IV-27 -- Design Properties of the Beartooth Unit

| Facility Name | Reservoir Data | | | Powerplant Data | | |
|---|---|---|---|---|---|---|
| | Dam Height (feet) | Crest Length (feet) | Total Capacity (acre-feet) | Maximum Head (feet) | Number of Generating Units | Installed Capacity (kilowatts) |
| Hunter Mountain | 215 | 1,430 | 130,000 | 649 | 1 | 14,400 |
| Thief Creek | 343 | 750 | 200,000 | 1,470 | 2 [1] | 125,200 [1] |
| Sunlight | 146 | 850 | 50,000 | 2,020 | 1 | 14,900 |
| Bald Ridge | 140 | 1,000 | 14,600 | 390 | 1 | 23,000 |
| Total | | | 394,600 | | | 177,500 |

[1] Located at the Sunlight Powerplant.

Another hydropower project proposed by the Bureau of Reclamation is to enlarge Buffalo Bill Reservoir and replace the existing Shoshone Powerplant. The present powerplant has been operated since 1922 and is now inefficient and costly to operate. Under the proposed project, Buffalo Bill Dam would be raised 25 feet, and the capacity of the Reservoir would be increased 215,500 acre-feet from 494,700 to 710,200 acre-feet.

Because the generating capacity of the existing Shoshone Powerplant would be limited to 10,000 kilowatts, a new powerplant would have to be constructed. Comparative studies were conducted for a one-unit generator with installed capacities of 5,000, 10,000, 15,000, and 20,000 kilowatts to determine the most economical size. These studies revealed that a 15,000-kilowatt unit would be the most feasible. A generator of this size would increase the installed capacity of the Shoshone Powerplant from 5,600 kw to 15,000 kw.

## SUMMARY OF WATER RESOURCE REQUIREMENTS

The previously discussed present and projected water demands in the Bighorn River Basin are summarized in Table IV-28.

TABLE IV-28--Summary of Present and Projected Consumptive Water Uses in the Bighorn River Basin, Wyoming

| | (1,000 Acre-Feet per Year) | | | |
|---|---|---|---|---|
| Water Uses | Present | 1980 | 2000 | 2020 |
| Irrigation | 1,029 | 1,160 | 1,302 | 1,398 |
| Industrial | 28 | 30 | 56 | 47 |
| Municipal, Domestic, and Stock | 13 | 15 | 21 | 27 |
| Total | 1,070 | 1,205 | 1,379 | 1,472 |

In addition to man's present irrigation, industrial, municipal, domestic, and stock water uses, reservoir and stock pond evaporation consume about 105,300 acre-feet per year. Evaporation from Bighorn Lake (Yellowtail Reservoir) on the Wyoming-Montana State line is not included in the present evaporation figures. If Wyoming makes use of water from the reservoir, a portion of its evaporation might be accounted for as a Wyoming use of water under the terms of the Yellowstone River Compact. Construction of additional reservoirs would also increase the amount of water consumed in evaporation.

Water is available in the Bighorn River Basin to meet the future water needs. There are, however, places in the Basin, especially on tributaries, where locally available water supplies are insufficient to meet even the present needs. This is especially true for the North and East Wind River tributaries, Shell Creek, West Bighorn River tributaries, and the Greybull River Basin (see Table IV-11). If a full water supply is to be provided to all present uses, water will have to be conveyed from places of surplus in the Basin to places of need. Construction of additional reservoirs can regulate water supplies both for local uses and for adjacent areas with shortages. Boysen Reservoir, Bighorn Lake, and other reservoirs constructed in the Basin could provide dependable water supplies from water surplus to the needs in the Basin for use in areas of the State where needs exceed the available water supplies.

Chapter V discusses potential projects and alternatives of water resources development.

# CHAPTER V

# POTENTIAL SOURCES OF WATER TO MEET REQUIREMENTS AND ALTERNATIVES OF DEVELOPMENT

# POTENTIAL SOURCES OF WATER TO MEET REQUIREMENTS AND ALTERNATIVES OF DEVELOPMENT

## SUMMARY OF WATER REQUIREMENTS

Projections of future water needs in the Basin were presented in Chapter IV and summarized in Table IV-28. The total present consumptive uses of 1,070,000 acre-feet per year are projected to increase by 38 percent to 1,472,000 acre-feet per year by the year 2020.

Irrigation is currently the largest use of water, consuming 1,029,000 acre-feet annually. Irrigation consumptive water uses are projected to increase to 1,398,000 acre-feet annually by the year 2020. Of the total increase, about 27 percent or 99,000 acre-feet would be for supplemental water supplies for currently irrigated lands. The other 270,000 acre-feet of annual increased use would be consumed in the irrigation of 137,000 acres of land projected to be brought under irrigation. The irrigation water uses would support the agricultural industry in maintaining Wyoming's share of national production.

Industrial consumptive water uses, currently 28,000 acre-feet per year, are projected to reach 56,000 acre-feet annually by the year 2000, and decline somewhat to 47,000 acre-feet by 2020. The petroleum industry currently consumes 96 percent of the industrial water, and groundwater is the source for about 92 percent of the industrial water used. In the year 2020, the coal industry is projected to be using about 63 percent of the industrial water, and groundwater is expected to be supplying only about one-third of the industrial water supply.

Municipal, domestic, and stock water consumptive uses are projected to rise from 13,000 acre-feet annually at present to about 27,000 acre-feet per year by 2020.

The increased water consumption would substantially increase production in the Basin, enhance economic stability, and increase income.

## POTENTIAL SOURCES OF WATER

### Surface Water

The availability of surface water supplies in the Basin is dependent on the locally available streamflow, its variability and dependability, and legal factors of water rights and interstate compacts. These factors are described in Chapter II and in the agriculture section of Chapter IV.

Most of the Basin's streams are characterized by a majority of the runoff occurring in the spring as a result of snowmelt, followed by low flows during the summer, fall, and winter. Streamflows also vary from year to year, depending upon the amount of precipitation received. Because of the annual and seasonal variation in water supplies, dependable streamflows were rapidly put to use during early settlement of the Basin. Later settlers found it necessary to construct reservoirs to store the spring runoff for release in the summer to irrigate crops.

Carry-over storage to provide dependable water supplies during drought periods has also been constructed in Boysen Reservoir, Bull Lake, Buffalo Bill Reservoir, and Upper and Lower Sunshine Reservoirs.

The Yellowstone River Compact allocates the waters of the Clarks Fork of the Yellowstone River, Bighorn River, Tongue River, and the Powder River between the states of Wyoming and Montana. There is no interstate agreement regarding the uses of the Little Bighorn River. Article V of the Yellowstone River Compact provides that all water rights existing as of January 1, 1950 shall remain unimpaired by the terms of the compact. Of the unused and unappropriated water of the interstate streams of the Yellowstone River, each state is allocated sufficient water to provide supplemental water supplies to all water rights existing as of January 1, 1950. The remaining unused and unappropriated water is allocated to Wyoming and Montana as follows:

| | |
|---|---|
| Clarks Fork of the Yellowstone River: | |
| Wyoming | 60 percent |
| Montana | 40 percent |
| Bighorn River (exclusive of the Little Bighorn River): | |
| Wyoming | 80 percent |
| Montana | 20 percent |
| Tongue River: | |
| Wyoming | 40 percent |
| Montana | 60 percent |
| Powder River (including the Little Powder River): | |
| Wyoming | 42 percent |
| Montana | 58 percent |

The Tongue River and Powder River are outside the area covered by this report. However, because of the shortage of water in Northeastern Wyoming, including the Tongue and Powder Rivers, the Bighorn and Clarks Fork Rivers are important as potential sources of water for Northeastern Wyoming through transbasin diversions. A factor in such transfers is the language of the compact which states, "No water shall be diverted from the Yellowstone River Basin without the unanimous consent of all the signatory states" (Wyoming, Montana, and North Dakota). The Clarks Fork, Bighorn, Tongue, and Powder Rivers are tributaries of the Yellowstone River, and under the terms of the compact water can be transferred from any one of the drainages to any other. However, consent of the signatory states would be required before compact water could be taken to the other streams of Northeastern Wyoming outside of the Yellowstone River Basin. The compact also recognizes the rights of the Indians to develop and use the water for purposes for which the Wind River and Crow Indian Reservations were established.

Water available to Wyoming under the Yellowstone River Compact was estimated from records at the compact stream gages (see Figure II-8) corrected for upstream developments affecting a part of the record and adjusted to reflect uses and supplemental supplies for pre-1950 water rights. The unused and unappropriated water in the Bighorn River at Bighorn, Montana subject to percentage allocation was estimated to be around 2.3 million acre-feet per year. Wyoming's 80 percent allocation would be about 1.8 million acre-feet per year. The average annual depletable unused and unappropriated flow of the Clarks Fork at Edgar, Montana is about 714,000 acre-feet. Of this, Wyoming's 60-percent share is 429,000 acre-feet annually.

The Bighorn River flows about 2.4 million acre-feet annually at the Montana-Wyoming State line under present conditions (see Table II-1 and Figure II-5). Of the total water flowing in the Bighorn River, about 35 percent enters from the Shoshone River, 4 percent from Shell Creek, 5 percent from the Greybull River, 5 percent from the Nowood River, 42 percent from the Wind River, and minor amounts are produced from other tributaries.

Although there is an apparent abundance of water available in the Bighorn River system, developing a usable, firm supply is dependent upon the availability of storage water and storage sites. On the Shoshone River, Buffalo Bill Dam can be raised to develop additional water supplies. The Greybull River is nearly fully appropriated in its upper reaches for irrigation and associated storage. Shell Creek flows off the steep western flank of the Big Horn Mountains, and only small storage sites exist. If a dam and reservoir site could be found near the mouth of either Greybull River or Shell Creek, a sizable water supply could be developed. The Nowood River has a good potential for the development of water supplies for supplemental and new uses. A large quantity of Wyoming's Bighorn River compact water can be provided from Boysen Reservoir, near the Wedding of the Waters where the Wind River becomes the Bighorn River and from Bighorn Lake, formed by Yellowtail Dam in Montana. Wyoming could use water from Bighorn Lake by either diverting from the lake near the Wyoming-Montana State line or by diverting back into Wyoming from below the dam. Boysen Reservoir is strategically located for providing water supplies downstream on the Bighorn River or from the reservoir itself, and a considerable water supply is developed by the reservoir. Use of all of Wyoming's compact allocation would require the construction of additional storage and at least a portion of the water supply would have to be diverted from Bighorn Lake or from the river system below Yellowtail Dam.

Boysen Reservoir, with a current inflow of approximately 1.0 million acre-feet per year, presents an opportunity to provide water supplies for new uses. However, more than 40 percent of this water is committed for irrigation of land adjacent to the Bighorn River below the Wind River Canyon. A major portion of the streamflow, including the irrigation water supply, is regulated by the reservoir. Water supplies for new uses can be provided from Boysen Reservoir, but the amount of the supply depends upon the amount of water development above the reservoir in the Wind River Basin, the place of use of the water regulated by Boysen Reservoir, and the amount of sustained streamflow to be provided in the Wind River below Boysen Dam.

## Improved Water Uses

In parts of the Basin overirrigation has resulted in leaching the plant nutrients and has caused drainage problems. By improving irrigation efficiency, crop yields could be improved while requiring less water, thus, making more water available for other uses. Irrigation efficiencies can be increased through the use of ditch lining, pipelines, sprinkler systems, reorganization of irrigation systems, irrigation water control structures, and improved field irrigation methods.

In places where ditches and laterals closely parallel each other, the water losses and operation and maintenance costs could be reduced by consolidating the ditches into one system. In many cases this would mean the merging of canal companies. Supplying irrigation water to the lands proportionally to the consumptive use rate of the crops would also improve irrigation efficiency. On most of the streams in the Basin this requires reservoirs to store spring runoff for release during the peak consumptive use period (July and August) when the flow in the stream is normally low. Reuse of return flows by pump-back systems would also aid in making more efficient use of the available water supplies. Return flow reuse may also be accomplished by connecting drainage systems directly to downstream canals.

In some areas of the Basin, irrigation companies and individuals have undertaken policies of improving their efficiencies. In most cases these policies have arisen from limited water supplies and the economic justification for improving irrigation efficiencies.

The present industrial water use in the Basin is primarily for secondary recovery of oil. Groundwater is the source of most of the water used for secondary recovery and for uranium mining and milling. Small amounts of surface water are currently used in the gypsum and timber industries. Practically all process water diverted by industry is consumed. New industries contemplated in the Basin will likely consume all diverted water to avoid stream pollution, to comply with interstate water quality standards, and to minimize water supply costs.

## Change of Use of Irrigation Water Rights

At this writing, a proposed recodification of Wyoming's water laws is under consideration by the Legislative Joint Agriculture, Public Lands, and Water Resources Interim Committee. The proposals for recodifying Wyoming's water laws will include changes in the statutes regarding changes of use of water rights. Although it is anticipated that the 1973 Legislature will recodify the water laws, the exact language cannot be accurately predicted. The following paragraphs describe the current requirements for change of use of water rights, and although "preference" water rights may be differently defined or eliminated, procedures for change of use of water rights will consider factors stated below.

Current Wyoming statutes provide for a change of use of water rights to higher, preferred uses. The preference order is (1) drinking (domestic and stock) water; (2) water for municipal purposes; (3) "Water for the use of steam engines and for general railway use, water for culinary, laundry, bathing, refrigerating (including the manufacture of ice), for steam and hot water heating plants, and steam powerplants;" (4) industrial purposes. Also implied are preferences: (5) irrigation and (6) hydropower. The statute (Section 41-3, Wyoming Statutes, 1957) provides for the condemnation of irrigation rights for the first three preferred uses (except steam powerplant use). Irrigation water rights may be purchased by industry and the use changed.

Changes of use of adjudicated water rights to new uses must be approved by the Board of Control. The underlying principle used by the Board of Control and the State Engineer in considering changes is that other appropriators must not be adversely affected by the proposed change. Protection of other water rights usually necessitates restrictions by the Board of Control upon the amount of the water right transferred and upon the season of use. For example, the historic use of a direct flow irrigation water right located above a reservoir on a stream system is seasonal. Conversion of the water right to a year-round use could impose a burden on the water resources that was not historically imposed. The winter use could deplete the water supply that would normally be stored in the reservoir during the nonirrigation season. Under this condition the winter use would not be allowed.

Industrial water supplies developed from change of use of irrigation water will likely require at least a part-year supply from storage, groundwater, unappropriated winter streamflows (if available), or transbasin diversion. The Board of Control would have to examine each transfer of use separately to determine the conditions of the change of use.

The cost of a water supply obtained from change of use of a water right is difficult to estimate without analyzing a specific instance. Irrigation water rights are property rights which attach to the land. A water-right purchase would be between the M & I interest and the property owner, and price would be based upon negotiations. A cost of a water right transfer (perhaps a secondary cost) is the loss of the economy associated with the farm and agricultural use in terms of expenditures in the community by the irrigators and the decrease in taxes from the land. If the new industry or water use is in the same locality as the irrigation, then the secondary cost may be offset by secondary benefits of the new industry or use. If, however, the new industry is far removed from the community near the irrigation water use, there may not be an accompanying economic offset to these secondary losses. If new water supplies are provided for M & I purposes, the result is an increase in the total economy.

## Weather Modification

As mentioned in Chapter II, streamflows may be artificially augmented in the future. It has been found that snowfall which would not ordinarily occur can be induced from clouds over mountains by "cloud seeding." An increase in precipitation of 10 percent has been estimated for areas affected by precipitation management operations. Such operations are in the research and development stages, and the areas where precipitation management operations might be performed are presently unknown. Wyoming is participating in research being conducted by the University of Wyoming Department of Atmospheric Research. Snowpack might be increased on the Big Horn Mountains, and that area is included in the State investigations. Runoff from snowpack augmentation will occur during the normal spring snowmelt period. Storage will be required to regulate the water supplies. At this time it appears that benefits of precipitation management would accrue as supplemental water in an area or stream system in general for existing water rights and users within the area. Weather modification may provide for new development if the new water can be accounted for. Since no definite areas are projected for the modification operations, water supply projections do not include water from this source.

## Groundwater

Groundwater is an important source of domestic and stock water. Groundwater satisfies some of the municipal water needs, and is used in the secondary recovery of oil and other industrial applications. A small amount of groundwater is used for irrigation.

Groundwater resources at shallow depths (to 700 feet below the surface) are of such magnitude that supplies should be more than adequate for the future domestic, stock, and municipal uses.

The number of acres irrigated with groundwater as the original supply is small but is expected to increase. The aquifer interval from the Tensleep formation downward through the Flathead sandstone is prospective for large yield wells. Between the towns of Tensleep and Hyattville in the Nowood River drainage is an area of relatively large scale irrigation development using groundwater. Other areas, such as near the Wind River Mountains, the Owl Creek Mountains, the Bridger Mountains, and other uplifts may be prospective for large yield wells. If conditions such as soil type and water quality are favorable, irrigation utilizing groundwater may expand more rapidly than is anticipated. If rapid expansion does occur, certain localities may experience seasonal water level or pressure variations.

Industries withdraw large quantities of groundwater and will continue to do so for some time. The petroleum industry is the largest user at present. The use by the uranium industry will increase about 15-fold over present use by the year 2000 (see Table IV-18). Groundwater may become a logical water supply for other industries because of its availability. This is especially true for industries whose water needs are not great.

The quality of groundwater will affect its availability for a specific use. Groundwater in the report area generally is of fair to poor quality. Even though the resource is in more than adequate supply, desalting techniques may be applicable in the future to provide local water supplies to satisfy specific quality needs.

## POTENTIAL SURFACE WATER PROJECTS

The abundance of natural resources in the Bighorn River Basin has been the basis for the settlement and growth of the area. The prospects for utilization of these resources have prompted several governmental and private investigations concerned with the Basin's water and related land resources. There are several U. S. Bureau of Reclamation (USBR) projects in the Basin. The USBR analyzed irrigation project potentials and summarized the findings in several river basin reports. The Soil Conservation Service (SCS) and other agencies of the U. S. Department of Agriculture are surveying the Basin at the request of the State of Wyoming for applications of USDA and other programs for economic and environmental conservation. The Bighorn Basin Resource Conservation and Development Project covering Big Horn, Fremont, Hot Springs, Park, and Washakie Counties was recently established to enhance conservation and the economy of the area. The Bureau of Indian Affairs (BIA) prepared a resources inventory for the tribes on the Wind River Reservation and has constructed irrigation projects. The Bureau of Land Management (BLM) has classified the lands under its jurisdiction and has undertaken several programs of range improvement and water development.

Data from these previous studies were utilized in preparing this report. In addition, water supply studies from the USBR, SCS, private studies, and the Wyoming Water Planning Program were used to identify potentials for providing supplemental water supplies and for formulating alternatives for meeting future water needs.

Many reservoir sites have been identified in the investigations and by individuals. Existing major reservoirs are listed in Table IV-10. Potential reservoir sites for projects described in this report are listed in Table V-1. Other potential reservoirs that have been identified by investigations or by applications to the State Engineer for water right permits are listed in Table V-2. Figure V-1 shows the locations of the potential dam and reservoir sites.

In the planning studies, reported below by study area, consideration was given to: (1) existing water rights and uses; (2) supplemental water supplies; (3) compact allocations and available supplies; (4) fish, wildlife, and recreation; (5) municipal and industrial water supply; (6) flood, sediment, and erosion control; and (7) watershed management.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE
10 0 10 20 30 40 Miles

## FIGURE V-I
## POTENTIAL RESERVOIR SITES

### Identified Possible Reservoir Sites Not Described In This Report

Note: Reservoir data given in Table V-2

1. Badwater
2. Beck Lake
3. Bethwren
4. Black Mountain
5. Bliss Creek Meadows
6. Blue Draw
7. Blue Holes
8. Brooks Lake
9. Buffalo
10. Buffalo Creek
11. Bull Lake Creek No. 2
12. Cody Canal
13. Cottonwood No. 2
14. Crowheart
15. Dempsey
16. Dry Creek
17. Dry Creek
18. DuNoir (Stoney Point)
19. Elk Creek Valley
20. Farmers
21. Fifteen Mile Creek
22. Fivemile Creek No. 1
23. Fruitland No. 1
24. Fruitland No. 2
25. Fruitland No. 4
26. Gooseberry Creek
27. Gooseberry No. 1
28. Gooseberry No. 2
29. Grave Lake
30. Grey Bull River
31. Hough
32. Jessamine
33. Junietta
34. King Gorm
35. Kirby
36. Lagoon Lake
37. LeClair Warm Springs
38. Lithomsen
39. Little Buffalo Basin
40. Little River SF No. 2
41. Little Wind River
42. Long Bench
43. Lost Wells Butte No. 2
44. Louis Lake
45. Medicine Lodge
46. Moraine Creek No. 1
47. Mountain View
48. Mud Lake No. 1
49. Muddy Creek No. 1
50. Muskrat No. 2
51. Muskrat Conant
52. Needle Mountain
53. (Not Named)
54. Onion Flat
55. Owl Creek Basin
56. Owl Creek SF No. 1
57. Owl Creek SF No. 2
58. Owl Creek SF Trib.
59. Owl Creek Irrigation
60. Paintrock
61. Popo Agie River No. 1
62. Popo Agie River No. 2
63. Porcupine Creek
64. Queen Thyra
65. Rawhide Creek
66. Sage Creek
67. Sage Creek
68. Sage Creek No. 1
69. Sage Creek Coulderwiley
70. Sage SF Creek No. 1
71. Sagwup Draw No. 1
72. Sharp Nose Draw No. 1
73. Sharp Nose Draw No. 2
74. Sheep Creek WF No. 1
75. Shell Creek Lake
76. Shotgun Creek No. 1
77. Solitude
78. Soral Creek
79. Snyder Draw
80. Spring Creek
81. Sulfur Creek
82. Summit
83. Surrell Creek No. 1
84. Teapot Gulch No. 1
85. Tensleep Meadows
86. Tensleep Meadows
87. Thomsen
88. Torrey Lake
89. Wall Mountain
90. Warm Springs Creek
91. West Tensleep Lake
92. Willis
93. Willow Creek
94. Wind River No. 1
95. Wind River No. 4
96. Wind River No. 5
97. Wind River No. 6

### Potential Reservoir Sites For Projects Described In This Report

Note: Reservoir data given in Table V-1

1. Badwater Cr. (Site 4)
2. Bald Ridge
3. Beaver Creek
4. Beaver Cr. (Coyote Basin)
5. Beaver Cr. (Site 1)
6. Big Trails
7. Buffalo Bill Res. Enl.
8. Bull Lake Creek
9. Bull Lake Enl.
10. Clarks Fork
11. Dinwoody Lake
12. East Fork No. 1
13. Fivemile Creek
14. Gooseberry Creek
15. Holden
16. Hunter Mountain
17. Lake Creek
18. Little Wind River SF No. 1
19. Nowood River
20. Oregon Basin
21. Raft Lake
22. Sage Creek (SCS Site 1)
23. Shell Canal
24. Steamboat
25. Sunlight
26. Thief Creek
27. Tipperary
28. Wiggins
29. Wind River
30. Wind River EF No. 2

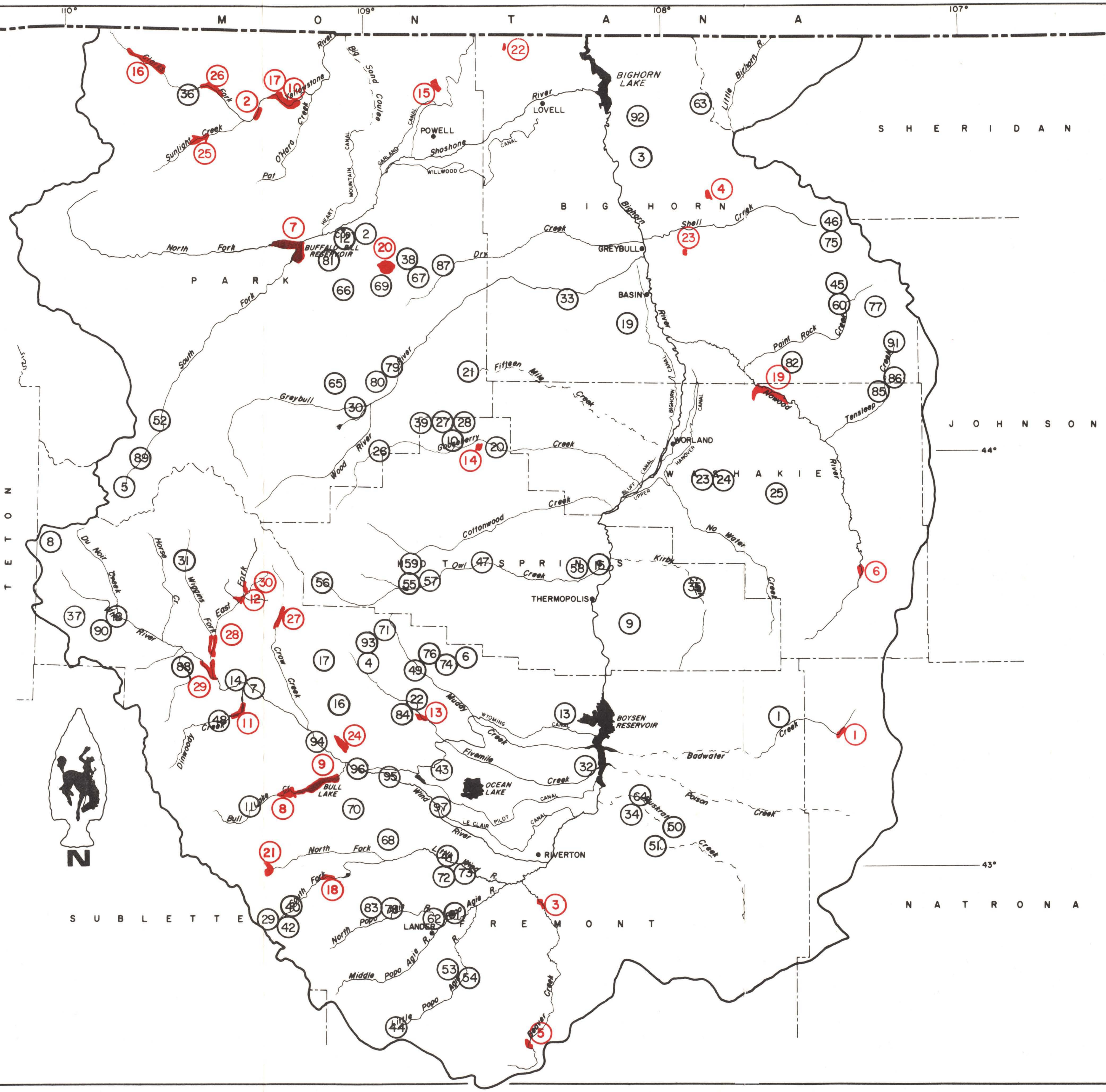



FIGURE V-I

TABLE V-1--Potential Reservoir Sites for Projects Described in this Report and Source of Information

| | Reservoir | Source of Water Supply | Capacity[1] | Source of Information[2] |
|---|---|---|---|---|
| 1. | Badwater Creek (site 4) | Badwater Creek | 1,770 | SCS |
| 2. | Bald Ridge | Clarks Fork | 14,600 | USBR |
| 3. | Beaver Creek | Beaver Creek | 27,320 | BIA |
| 4. | Beaver Creek (Coyote Basin) | Beaver Creek | 1,385 | SCS |
| 5. | Beaver Creek (site 1) | Beaver Creek | 14,500 | SCS |
| 6. | Big Trails | Nowood River | 18,500 | SCS |
| 7. | Buffalo Bill Reservoir Enlargement | Shoshone River | 215,500 Enlg.<br>710,200 Total | USBR |
| 8. | Bull Lake Creek | Bull Lake Creek | 75,740 | BIA |
| 9. | Bull Lake Enlargement | Bull Lake Creek | 50,000 Enlg.<br>202,000 Total | USBR |
| 10. | Clarks Fork | Clarks Fork | 750,000 | WWPP |
| 11. | Dinwoody Lake | Dinwoody Creek | 130,600 | BIA |
| 12. | East Fork No. 1 | East Fork | N.D.[3] | BIA |
| 13. | Fivemile Creek | Crow Creek, Fivemile Creek | 7,780 | BIA |
| 14. | Gooseberry Creek | Gooseberry Creek | 3,690 | SCS |
| 15. | Holden | Shoshone River | 9,900 | USBR |
| 16. | Hunter Mountain | Clarks Fork | 130,000 | USBR |
| 17. | Lake Creek | Clarks Fork | 5,100 | SCS |
| 18. | Little Wind River South Fork (SF) No. 1 | South Fork Little Wind River | 17,100 | BIA |
| 19. | Nowood River | Nowood River | 175,000 | WWPP |
| 20. | Oregon Basin | Shoshone River | 167,000 | USBR |
| 21. | Raft Lake | North Fork Little Wind River | 50,000 | USBR, BIA |
| 22. | Sage Creek (SCS site 1) | Shoshone River | 1,580 | SCS |
| 23. | Shell Canal | Shell Creek | 2,100 | SCS |
| 24. | Steamboat | Wind River | 60,000 | Shoshone and Arapahoe Tribes |
| 25. | Sunlight | Clarks Fork | 50,000 | USBR |
| 26. | Thief Creek | Clarks Fork | 200,000 | USBR |
| 27. | Tipperary (Crow Creek No. 1) | Crow Creek | 10,000<br>36,310 | SCS<br>BIA |
| 28. | Wiggins | East Fork | 80,000 | USBR |
| 29. | Wind River | Wind River | 122,560 | BIA |
| 30. | Wind River East Fork (EF) No. 2 | East Fork | 41,040 | BIA |

[1] The capacity in many instances could be larger than the size indicated.

[2] SCS - Soil Conservation Service; USBR - United States Bureau of Reclamation; WWPP - Wyoming Water Planning Program; BIA - Bureau of Indian Affairs. The original sources of data used for the Wind-Bighorn-Clarks Fork River Basin Summary, as reported by the SCS, are referred to in this Table.

[3] Data not available.

TABLE V-2--Identified Possible Reservoir Sites Not Described in this Report and Source of Information

| Reservoir | Capacity[1] | Source of Information[2] |
|---|---|---|
| 1. Badwater | 6,600 | USBR |
| 2. Beck Lake | 1,000 | WSEO |
| 3. Bethwren | 1,310 | WSEO |
| 4. Black Mountain | 1,710 | WSEO |
| 5. Bliss Creek Meadows | [3] | USBR |
| 6. Blue Draw | 19,970 | BIA |
| 7. Blue Holes | 75,000 | USBR |
| 8. Brooks Lake | 9,720 | WSEO |
| 9. Buffalo | 2,700 | WSEO |
| 10. Buffalo Creek | 145,000 | WSEO |
| 11. Bull Lake Creek No. 2 | 20,350 | BIA |
| 12. Cody Canal | 1,210 | WSEO |
| 13. Cottonwood No. 2 | 21,180 | BIA |
| 14. Crowheart (Red Bluff Dam) | [4] | USBR |
| 15. Dempsey | 1,070 | WSEO |
| 16. Dry Creek | 22,510 | BIA |
| 17. Dry Creek | 74,000 | WSEO |
| 18. DuNoir (Stoney Point) | 220,000 | USBR |
| 19. Elk Creek Valley | 1,140 | WSEO |
| 20. Farmers | 14,510 | WSEO |
| 21. Fifteen Mile Creek | 46,080 | WSEO |
| 22. Fivemile Creek No. 1 | 2,100 | BIA |
| 23. Fruitland No. 1 | 7,250 | WSEO |
| 24. Fruitland No. 2 | 5,320 | WSEO |
| 25. Fruitland No. 4 | 1,050 | WSEO |
| 26. Gooseberry Creek | 42,510 | WSEO |
| 27. Gooseberry No. 1 | 1,770 | WSEO |
| 28. Gooseberry No. 2 | 8,500 | WSEO |
| 29. Grave Lake | 4,500 | USBR |
| 30. Grey Bull River | 84,200 | WSEO |
| 31. Hough | 30,000 | USBR |
| 32. Jessamine | 1,330 | WSEO |
| 33. Junietta | 1,280 | WSEO |
| 34. King Gorm | 5,390 | WSEO |
| 35. Kirby | 3,090 | WSEO |
| 36. Lagoon Lake | 1,320 | WSEO |
| 37. LeClair Warm Springs | 3,000 | WSEO |
| 38. Lithomsen | 1,960 | WSEO |
| 39. Little Buffalo Basin | 75,810 | WSEO |
| 40. Little River South Fork (SF) No. 2 | 56,430 | BIA |
| 41. Little Wind River | 55,080 | BIA |
| 42. Long Beach | 16,080 | WSEO |
| 43. Lost Wells Butte No. 2 | 9,000 | WSEO |
| 44. Louis Lake | 8,010 | USBR |
| 45. Medicine Lodge | 2,250 | WSEO |
| 46. Moraine Creek No. 1 | 1,150 | WSEO |
| 47. Mountain View | 5,830 | WSEO |
| 48. Mud Lake No. 1 | 26,210 | BIA |
| 49. Muddy Creek No. 1 | 57,340 | BIA |
| 50. Muskrat No. 2 | 1,660 | WSEO |
| 51. Muskrat Conant | 2,040 | WSEO |
| 52. Needle Mountain | 100,000 | USBR |
| 53. (Not Named) | 9,000 | USBR |
| 54. Onion Flat | 9,000 | USBR |
| 55. Owl Creek Basin | 5,230 | WSEO |
| 56. Owl Creek South Fork (SF) No. 1 | 22,680 | BIA |
| 57. Owl Creek South Fork (SF) No. 2 | 20,090 | BIA |
| 58. Owl Creek South Fork (SF) Trib. | 3,200 | WSEO |

Table V-2 Continued

| Reservoir | Capacity[1] | Source of Information[2] |
|---|---|---|
| 59. Owl Creek Irrigation | 23,270 | WSEO |
| 60. Paintrock | 1,300 | WSEO |
| 61. Popo Agie River No. 1 | 102,340 | BIA |
| 62. Popo Agie River No. 2 | 38,780 | BIA |
| 63. Porcupine Creek | 14,660 | WSEO |
| 64. Queen Thyra | 1,240 | WSEO |
| 65. Rawhide Creek | 34,740 | WSEO |
| 66. Sage Creek | 1,080 | [5] |
| 67. Sage Creek | 1,470 | WSEO |
| 68. Sage Creek No. 1 | 14,460 | BIA |
| 69. Sage Creek Coulderwiley | 2,060 | WSEO |
| 70. Sage South Fork (SF) Creek No. 1 | 35,630 | BIA |
| 71. Sagwup Draw No. 1 | 17,160 | BIA |
| 72. Sharp Nose Draw No. 1 | 2,380 | BIA |
| 73. Sharp Nose Draw No. 2 | 15,340 | BIA |
| 74. Sheep Creek West Fork (WF) No. 1 | 29,130 | BIA |
| 75. Shell Creek Lake | 2,010 | WSEO |
| 76. Shotgun Creek No. 1 | 7,600 | BIA |
| 77. Solitude | 8,570 | WSEO |
| 78. Soral Creek | 25,000 | USBR |
| 79. Snyder Draw | 2,240 | WSEO |
| 80. Spring Creek | 64,700 | WSEO |
| 81. Sulfur Creek | 18,480 | WSEO |
| 82. Summit | 5,820 | WSEO |
| 83. Surrell Creek No. 1 | 16,690 | BIA |
| 84. Teapot Gulch No. 1 | 5,020 | BIA |
| 85. Tensleep Meadows | 13,490 | WSEO |
| 86. Tensleep Meadows | 12,350 | WSEO |
| 87. Thomsen | 1,010 | WSEO |
| 88. Torrey Lake | 33,000 | [6] |
| 89. Wall Mountain | 50,000 | USBR |
| 90. Warm Springs Creek | 21,000 | |
| 91. West Tensleep Lake | 1,180 | WSEO |
| 92. Willis | 2,130 | WSEO |
| 93. Willow Creek | 1,250 | WSEO |
| 94. Wind River No. 1 | 195,780 | BIA |
| 95. Wind River No. 4 | 62,650 | BIA |
| 96. Wind River No. 5 | 40,630 | BIA |
| 97. Wind River No. 6 | 70,490 | BIA |

[1] The capacity in many instances could be larger than the size indicated.

[2] WSEO - Wyoming State Engineer's Office Records; USBR - United States Bureau of Reclamation; BIA - Bureau of Indian Affairs. The original sources of data used for the Wind-Bighorn-Clarks Fork River Basin summary, as reported by the SCS, are referred to in this table.

[3] Relatively large amounts of storage could be provided with a small dam.

[4] Bishop and Spurlock, in "Report on Water Resources in the Wind River Basin," estimated that 150,000 acre-feet of water could be stored at elevation 6,380 feet.

[5] Soil Conservation Service's "Wind-Bighorn-Clarks Fork River Basin Summary."

[6] "Report on Water Resources in the Wind River Basin," summer of 1962 by Bishop and Spurlock.

## Study Area 1 -- Wind River

As previously stated, the Wind River and tributaries currently flow about 1.0 million acre-feet per year into the Boysen Reservoir. About 66 percent of the total water supply is produced above the Riverton Project diversion dam on the Wind River, and about one-third of the water supply is produced in the Little Wind River. The Little Wind River water originates from a series of parallel streams which provide somewhat limited water supplies until they join together. Many of the existing water users divert where these tributaries emerge from the mountains and have limited water supplies; however, considerable water is availabl in the lower reaches of the Little Wind and Popo Agie Rivers downstream from the diversions.

Over the years, the USBR conducted land classification and irrigation project investigations in the Wind River Basin. The Riverton Project extension would irrigate an additional 18,500 acres. A plan was formulated in 1966 for five units that would bring 30,580 acres of Indian land under irrigation.

As part of the river basin survey, the SCS investigated several potential watershed projects in the Wind River Study Area. A brief watershed investigation report was prepared on each project as a summary report. These reports have not yet been released.

At the request of the tribes the BIA conducted soil surveys and a resources inventory in 1971. This inventory showed a potential for irrigating more than 198,000 acres of new land utilizing regulated water supplies from ten potential reservoirs. Many of the irrigation units identified by BIA include lands within projects identified in other investigations. The new land units are given in Table V-3.

TABLE V-3--Potential Irrigation Units on the Wind River Indian Reservation

| Unit | Acreage |
|---|---|
| East Fork | 37,385 |
| Crowheart Butte | 51,080 |
| North Fork | 14,700 |
| Upper Wind Unit Extension | 5,407 |
| Fivemile | 35,350 |
| Bighorn | 31,760 |
| Coolidge Extension | 9,520 |
| Beaver Creek | 13,340 |
| Total | 198,542 |

Source: Land-Water Inventory, Natural Resources, Wind River Indian Agency, Wyoming.

The Wyoming Water Planning Program conducted studies to analyze a USBR study of Bighorn River Basin water supplies and to help identify water resource potentials. The USBR study was originally made in 1968 and was revised in 1971. The State studies assumed that new irrigation in the Wind River Basin would include 50,000 acres of Indian land and the 18,500-acre Riverton Project extension. The State's study showed that the 68,500-acre development or existing irrigation would have extreme water shortages unless additional upstream storage is provided. An estimated 303,000 acre-feet of storage is required to provide an 80-percent-chance water supply for the 68,500 acres. On the basis of these studies it is concluded that the existing irrigation and the entire 198,000-acre potential for irrigation identified by BIA cannot be provided an adequate water supply, but a certain amount of new land can be irrigated and supplemental water can be provided in many areas where needed. It is assumed that 68,500 acres of land could be considered for irrigation in the foreseeable future. This development might occur on the units described in the following paragraphs.

## Crow Creek

The Crow Creek watershed is entirely within the Wind River Indian Reservation. Crow Creek drains 185 square miles and enters the Wind River west of Crowheart Butte.

Besides having summer irrigation shortages, the lower reaches of Crow Creek are frequently flooded in the spring (see Chapter II). The SCS watershed investigation identified a potential project to supply supplemental water to presently irrigated lands and water for new irrigation. A total of 2,606 acres are presently irrigated in the watershed, with 1,200 acres irrigated from Crow Creek and 1,406 acres irrigated from the Wind River. The 1,200 acres irrigated from Crow Creek experience late-season irrigation shortages estimated to start about July 15.

A potential multipurpose reservoir location was chosen about 1 mile north of Tipperary. A 125-foot dam located at the Tipperary site in Sec. 20, T. 7 N., R. 4 W. would have 10,000 acre-feet of storage: 5,900 acre-feet for irrigation water and 4,100 acre-feet for flood and sediment control. The irrigation storage would provide an 80-percent-chance full supplemental water supply to the 1,200 acres presently receiving a short supply from Crow Creek and 2,600 acres of new land.

The estimated installed cost of this project is $854,000 with an estimated annual cost including operation and maintenance of $48,040. The annual benefits from the project are estimated to be $118,200 consisting of $8,000 for flood control, $94,000 for agriculture, and $16,200 for secondary benefits, with a benefit-cost ratio of 2.5 to 1.0.

The Crow Creek Watershed Project is within one of the units identified in the Wind River Indian Reservation resource inventory.

<u>Beaver Creek</u>

The Beaver Creek watershed has a drainage area of 283 square miles in southern Fremont County. Beaver Creek heads in the Wind River Mountains near Atlantic City and flows into the Little Wind River south of Riverton.

The SCS prepared a watershed investigation report in 1970 for the Upper Beaver Creek watershed. The primary problem in the Beaver Creek watershed is the lack of late-season irrigation water. In addition, some flood and sediment damages to canals, fences, and irrigation structures occasionally occur.

There are about 916 irrigated acres along Beaver Creek which receive a short supply. Of three potential reservoir sites identified, a multipurpose reservoir located in Sec. 15, T. 30 N., R. 97 W. appeared to be the most feasible. The 125-foot dam would form a reservoir of 14,500 acre-feet capacity, including 9,400 acre-feet for irrigation, 1,600 acre-feet for sediment control, and 3,500 acre-feet for flood control. Other structures would include an enlargement and extension of the Samuel P. Large Canal.

The acreage served by this project includes 2,800 acres of presently and potentially irrigated lands (1,213 acres to receive a supplemental supply, 821 acres of dry cropland, and 766 acres of new lands to receive a full supply). The total installed project cost would be $968,800 with an annual cost of $55,660. The annual benefits were estimated to be $109,735 ($92,750 for agriculture, $1,600 for flood and sediment reduction, and $15,385 of secondary benefits). The benefit-cost ratio of this project is 2.0 to 1.0.

Badwater Creek

The Badwater Creek watershed has a drainage area of 808 square miles and flows directly into Boysen Reservoir from the east. Badwater Creek dumps an estimated annual sediment load of 304,800 tons into Boysen Reservoir. Along with sediment and erosion problems, the 3,139 acres of irrigated land along Badwater Creek and its tributaries have severe water shortages. In studying the Badwater drainage the SCS divided the watershed into four subbasins including Upper Badwater, Alkali Creek, Bridger Creek, and Lower Badwater Creek. Only two reservoir sites capable of serving the needs of the basin were found. Both were in the Upper Badwater drainage.

The Watershed Investigation Report for Upper Badwater Creek indicated that water rights for over 4,400 acres are recorded in the Upper Badwater Watershed, but only 1,700 acres are currently being irrigated. These lands experience severe shortages, and a full-season water supply cannot be provided even with reservoir storage. A 1,770-acre-foot multipurpose reservoir would extend the annual irrigation season an average of 1 month. This is equivalent to a 70-percent-chance water supply. The associated capacities of the Badwater Creek Reservoir, located in Sec. 28, T. 39 N., R. 88 W., would be 850 acre-feet for irrigation, 770 acre-feet for flood control, and 150 acre-feet for sediment control.

The installed cost of this project is estimated to be $546,000 with an annual cost of $30,675. The estimated average annual benefits are $39,120 ($31,080 for agriculture, $4,085 for flood and sediment damage reduction, and $3,955 for secondary benefits). The benefit-cost ratio of this project is 1.3 to 1.0.

Little Wind River Unit

The BIA has suggested the construction of a reservoir on Raft Lake to furnish a supplemental supply to the lands irrigated in the Little Wind River Unit. The Bureau of Reclamation has also investigated the possibility of constructing a reservoir at this site to furnish a water supply for the lands potentially irrigable in the Winchester Unit (Big Horn Flat Unit). A proposed reservoir with an active capacity of 50,000 acre-feet would serve approximately 21,120 acres in the Little Wind Unit with a supplemental supply and 9,680 potentially irrigable acres in the Winchester Unit with a full supply. The storage in Raft Lake would be allocated 35,000 acre-feet for supplemental supply and 15,000 acre-feet for the Winchester Unit. Because of the lack of good fill material, the dam was proposed to be a 133-foot concrete arch structure. The estimated capital cost at January 1963 prices was estimated to be $5,250,000, and a capital cost of $105 per acre-foot of storage capacity was also estimated.

Riverton Project Extension

The USBR has placed 18,500 acres of the Riverton Project in a deferred status. About 8,700 acres of the total are on Muddy Ridge, and 9,800 acres are on Cottonwood Bench. These lands could be brought under irrigation by extending the existing canal system. Additional storage would be required to supply these lands a full supply, but no definite plan has been proposed for the development.

Midvale

The lands that were proposed to be irrigated by the SCS in the Midvale Watershed Report of July 1970 could serve as an alternate to the development of the Riverton Project Extension. The Midvale watershed includes all of the Riverton

Reclamation Project except the lands in the North Portal and along Cottonwood Bench of the Third Division. About 250 farm units in the watershed irrigate a total of 62,070 acres. Because of modern technology the size of the farm units can and should probably be increased for economic efficiency. With the development of 15,580 acres (4,880 acres on Airport Bench, 1,950 acres on Big Ridge, and 8,750 acres on Muddy Ridge) the average size of the 250 farm units could be increased 60 acres. The SCS assumed that no additional reservoir storage would be necessary to supply these lands. The increased water demand could be supplied by increasing the efficiency of irrigation and by canal rehabilitation. The lands proposed to be irrigated on Airport Bench and Big Ridge would be supplied by pumping out of the existing Pilot Canal with a pump lift of 107 feet. The lands on Muddy Ridge could be supplied by the existing Wyoming Canal which presently has sufficient capacity to serve the lands.

The estimated installed cost for this project is $2,490,730 with an estimated annual cost of $225,860. The annual benefits derived from the project are estimated to be $580,550 including $420,200 for agriculture and $160,350 for secondary benefits. The benefit-cost ratio is 2.6 to 1.0.

North and South Crowheart, Winchester, Coolidge Extension, and Shoshone Units

The USBR has concluded that combining the North and South Crowheart, Winchester, Coolidge Extension, and Shoshone Units into one project would be more advantageous than developing the units separately. Under the USBR plan 30,580 acres would be brought under irrigation. Water would be regulated by two new reservoirs, Wiggins Reservoir and Raft Lake, and an enlargement of the existing Bull Lake Reservoir.

The proposed 80,000 acre-foot Wiggins Reservoir is located on East Fork at the junction of Wiggins Fork and East Fork. The 192-foot high dam would be about 6.5 miles upstream from the mouth of East Fork. The maximum surface area of this impoundment would be 1,290 acres. Water would be released from the reservoir to the Wind River and diverted into the 73.5-mile long North Crowheart Canal to supply 11,600 acres in the North Crowheart Unit. The diversion dam is located on the Wind River about 13 miles upstream of Bull Lake Creek and west of Crowheart Butte. Most of the lands to be served by the North Crowheart Canal are within the Fivemile and Muddy Creek drainages, but there are scattered areas in the upper reaches of the drainage and along Cottonwood Creek.

Raft Lake would be enlarged by a 133-foot high concrete arch dam to a controllable capacity of 50,000 acre-feet (35,000 acre-feet to furnish a supplemental supply to the existing Little Wind River Unit and 15,000 acre-feet of capacity to supply the Winchester Unit). At present, Raft Lake has a natural capacity of 40,000 acre-feet; thus, the total enlarged reservoir capacity would be 90,000 acre-feet. The maximum surface area of the enlarged lake would be 9,273 acres. A diversion dam on the North Fork Little Wind River about 16 miles downstream from Raft Lake would divert the water into a 30.8-mile Winchester Canal to irrigate 9,680 acres enroute. These irrigable lands are east of Bull Lake Creek between the Wind River and Sage Creek.

Bull Lake would be enlarged 50,000 acre-feet from a capacity of 152,000 acre-feet to a capacity of 202,000 acre-feet. The earthfill dam would be raised 22 feet to a total height of 82 feet. The stored water would be released into Bull Lake Creek and diverted along with direct flow by the existing Wind River Diversion Dam into the Wyoming Canal. Water for the South Crowheart Unit, Coolidge Extension Unit, Shoshone Unit, and replacement water for the Winchester Unit would be conveyed in the South Crowheart Canal branching from the Wyoming Canal, 7 miles downstream from the Wind River Diversion Dam. The South Crowheart Canal would irrigate the 4,260-acre South Crowheart Unit, south of the Wind River. The Little Wind Supply Canal would divert from the South Crowheart Canal and deliver Wind River water to the Little Wind River to replace water diverted upstream out of priority for the Winchester Unit. The Little Wind Supply Canal would also deliver water for the 2,030-acre Coolidge Extension Unit and for the 3,010-acre Shoshone Unit, which would be served by the Coolidge Extension Canal and the Shoshone Canal. These two canals extend 66 miles from the Little Wind River, roughly paralleling the Little Wind and Wind Rivers.

The Indian tribes have reportedly investigated a potential sprinkler irrigation unit of about 7,000 acres located between the Little Wind River and the Popo Agie River. This project is apparently in the vicinity of the proposed Coolidge Extension Unit. The water supply for the project would be pumped from both the Little Wind River and the Popo Agie River.

Boysen Reservoir M & I Water Supply

Boysen Reservoir is strategically located to provide a municipal and industrial (M & I) water supply for use either adjacent to the reservoir, or in demand areas to the east of the Wind River Basin. Under the present power and irrigation operation of Boysen Dam, a considerable water supply would appear to be available. However, the amount of M & I water supply that Boysen Reservoir can provide depends upon the amount of future upstream water resources development, the amount of downstream irrigation development, and the level of sustained streamflows to be maintained in the Wind River Canyon. Irrigation season releases of water from Boysen Dam considerably exceed the desired sustained flow levels of 400 cfs and 250 cfs minimum, currently in the operating plan. The sustained flow criteria apply primarily to nonirrigation season releases.

The USBR, in studies done in 1968 and 1971, assumed 56,000 acres of new irrigation above Boysen, releases for existing irrigation below Boysen, and a sustained flow of 250 cfs. Under these conditions an estimated M & I water supply of 135,000 acre-feet per year could be diverted from Boysen Reservoir.

The Wyoming Water Planning Program conducted studies to determine the range of water supplies available under various assumptions. New irrigation development above Boysen Reservoir was assumed to be 68,500 acres. Assuming the irrigation below Boysen Dam of 59,500 acres, which is the present irrigation and the Bighorn Unit, with current irrigation efficiencies and provision of no winter streamflow maintenance below Boysen Dam, an M & I water supply of 268,000 acre-feet per year could be diverted from Boysen Reservoir. As in the USBR studies, Boysen Reservoir was assumed to operate between maximum capacity, 802,000 acre-feet, and the minimum power pool, 252,000 acre-feet. This first assumption recognizes there is no water right in the Boysen system for a minimum or sustained flow release.

In an attempt to provide for minimum flows and recognizing that such provision would limit the M & I water supply, a relationship between water in storage and amount of winter streamflow release was devised. The second assumption was the same as the first except that streamflow maintenance releases of 250 cfs would be made when the active content of the reservoir is between three-fourths full and full, 188-cfs-release when the reservoir is between half and three-fourths full, 125 cfs when the reservoir is between one-fourth and half full, and 63 cfs when the reservoir level is between the minimum pool and one-fourth full. Using this criteria, a 217,000 acre-foot per year M & I water supply could be diverted from Boysen Reservoir.

In the third assumption, irrigation releases were for 74,500 acres, the water right acreage and the 1,730-acre Bighorn Unit, and no winter releases for streamflow maintenance were provided. Operation of Boysen Dam under these circumstances would yield an M & I water supply of 175,000 acre-feet per year.

For a fourth assumption the irrigation was assumed to be at the level of the third assumption, and the minimum flows of the second assumption were assumed. The M & I water supply was found to be 124,000 acre-feet per year. In the 17-year study period, 1952-1968, winter streamflows of assumptions two and four would have been 250 cfs in 9 years, 188 cfs in 4 years, 125 cfs in 3 years, and 63 cfs in 1 year.

Providing winter streamflows below Boysen Dam reduces annual M & I water supplies approximately 50,000 acre-feet between assumptions one and two and between three and four. If greater minimum flows were provided, the M & I water supply would be reduced accordingly. An analysis of the level of desirable streamflows in Wind River Canyon is now being scheduled by Federal agencies. The studies reported herein were not based on field data and were only for defining quantities of water available. The desirability of sustained streamflow is recognized, and it is anticipated that a reasonable compromise of sustained flow, irrigation, and M & I water supply can be reached along with a recommended repayment plan for all of the uses. An obvious way of elimating the conflict is to deliver the M & I water down the Wind-Bighorn River for diversion downstream.

It should be emphasized that there are no legal provisions under existing Wyoming law which require a minimum flow below a dam. Although hydropower releases currently provide a sustained flow below Boysen Dam, these releases would not necessarily continue if the water is committed to beneficial consumptive uses. Storage water could be provided for the sustained streamflow if the cost of providing the storage capacity is repaid.

## Study Area 2 -- Bighorn River

The Soil Conservation Service has identified 642,811 acres of potentially irrigable land in Study Area 2. The limiting factor in developing these lands is the lack of a dependable water supply on most of the streams. Where adequate water supplies are available for smaller developments, private developments will probably bring the land into production. Along the major rivers, private interests are reportedly considering the feasibility of pumping out of the rivers and existing canals. Such projects would include Banjo Flats, Schuster Flats, Hanover Units, Red Flats Unit, the Cody and Ralston Pumplifts, and others. Larger projects including Polecat Bench, Shoshone Extension South, Bighorn Unit, the Nowood River Unit, etc. would probably be Federal or State projects.

The following sections describe some of the potential projects to develop new lands and furnish supplemental supplies to existing irrigation in Study Area 2.

### Nowood River

The Nowood River drains 2,080 square miles before it empties into the Bighorn River near the town of Manderson. The average flow of the Nowood River at the mouth is estimated to be about 252,100 acre-feet per year. About 19,170 acres are currently being irrigated along the Nowood River and its tributaries.

The SCS published a Watershed Investigation Report for the Nowood River in May 1971. Minor irrigation shortages exist in the upper reaches of the Nowood River; however, the major problem is flooding and related damages which occur almost annually along this river. The average annual flood damages along the Nowood River are estimated to be $19,500 above Tensleep Creek, $26,500 between Tensleep and Paint Rock Creeks, $19,500 from Paint Rock Creek to the town of Manderson, and $39,500 to the town of Manderson, for a total of $105,000 annually. About 60 percent of the damage in Manderson is caused by the Nowood River and 40 percent by the Bighorn River. Some flood damages have occurred along Canyon, Tensleep, and Paint Rock Creeks, but these damages are minor compared to those along the Nowood River. Streambank erosion and sediment damage associated with flooding are other serious problems. It is estimated that 1 out of every 10 miles of irrigated land along the river is subject to erosion and sediment damage. Annually, about 8.5 acres of irrigated cropland are lost to streambank erosion, and many more are damaged by sedimentation.

The SCS has identified three potential structural measures to benefit the Nowood River Basin. These include (1) a multipurpose reservoir; (2) a 7-mile streambank stabilization program; and (3) a flood prevention levee system encircling the town of Manderson. The multipurpose reservoir located near Big Trails (Sec. 6, T. 43 N., R. 87 W.) would have a capacity of 18,500 acre-feet. The associated storage capacities are 6,000 acre-feet for irrigation, 5,500 acre-feet for sediment control, and 7,000 acre-feet for flood control. The 95-foot high earthfill dam would have a maximum surface area of 550 acres. The 6,000-acre-foot irrigation pool would provide a full-season water supply to 3,000 acres of new lands.

The capital cost for the entire project would be $1,127,500 with an annual cost of $103,920. The estimated average annual benefits are $200,370 ($126,970 for damage reduction, $44,490 for irrigation, and $28,910 for secondary benefits). The benefit-cost ratio for the development of the three structural measures is 1.9 to 1.0. The benefit-cost ratio for the reservoir and the levee system are each 2.4 to 1.0, and the individual benefit-cost ratio of the streambank stabilization program is 1.2 to 1.0.

The Wyoming Water Planning Program has identified a potential flood control and M & I water supply project for the lower Nowood River drainage. Other functions might also be included in the project. A potential reservoir site on the Nowood River located in Sec. 5, T. 48 N., R. 90 W. could develop the dependable flows of both the Nowood River and Paint Rock Creek. The average annual available streamflow at the reservoir site surplus to downstream irrigation water rights is 257,000 acre-feet, 165,500 acre-feet of which is from the Nowood River and 91,500 acre-feet is from Paint Rock Creek. A diversion dam located on Paint Rock Creek and a canal from the diversion dam to the Nowood River Reservoir would be required to divert the flow from Paint Rock Creek into the potential Nowood Reservoir.

The Nowood Dam could provide a source of M & I water supply. One alternative would be to construct a 175,000-acre-foot reservoir to develop 175,000 acre-feet of firm M & I water. The associated capacities of this reservoir would be 50,000 acre-feet for silt storage and a minimum pool, 58,000 acre-feet for M & I storage, 31,200 acre-feet for flood control, and 35,000 acre-feet of spillway surcharge. The earthfill dam would be 120 feet high and the maximum surface area of the impoundment would be 4,250 acres.

The estimated capital cost of the Nowood River Dam and Reservoir and the Paint Rock Creek diversion works is $13,700,000 with an estimated annual cost of $1,100,000 or $6.25 per acre-foot per year. To deliver this water to the Gillette area, the Wyoming Water Planning Program considered a plan to pump the water from the Nowood River Reservoir into an aqueduct through the Big Horn Mountains to Gillette. The preliminary plan has a total aqueduct length of 117 miles, including a 40-mile tunnel through the Big Horn Mountains southwest of Buffalo. The estimated capital cost of construction, including the cost of the Nowood River Reservoir and Paint Rock Creek diversion works, to deliver water to Gillette was $210 million. The annual cost to deliver the proposed 175,000 acre-feet of water per year was $108 per acre-foot.

Gooseberry Creek

The SCS released a Watershed Investigation Report for Gooseberry Creek in July 1971. Gooseberry Creek originates in the foothills of the Absaroka Mountains and drains about 363 square miles before it empties into the Bighorn River at Neiber. There are about 8,450 acres of adjudicated water rights in the Gooseberry drainage, only 45 percent of which, or 3,800 acres, are currently being irrigated. An estimated 500 acres receive a full water supply under the existing conditions in an average year.

It is estimated that 20,600 acre-feet of water per year are required to provide the 8,450 acres a full water supply. The average annual yield of the Gooseberry Creek drainage is 7,600 acre-feet and the 80-percent-chance supply is 4,300 acre-feet. Because this is an extremely water-short area, the SCS concluded only 1,600 acres (less than half of the presently irrigated lands) could receive a full supply in an 80-percent-chance year.

Due to the severe water shortages along Gooseberry Creek, several other studies have been undertaken to devise means of supplying these irrigated lands a full supply. Early interests tried unsuccessfully to obtain a water right from the Wood River, a tributary of the Greybull River. The Wood River is a few miles west of the upper reaches of Gooseberry Creek. This scheme would give the irrigated lands along Gooseberry Creek a supplemental water supply as well as develop new irrigable lands on Schuster Flats. A water right permit for this project was filed in 1939. The permit was cancelled by the State Engineer in 1963.

The Bureau of Reclamation has tried to find a feasible project or projects to supply the irrigated land along Gooseberry Creek a supplemental water supply as well as develop new land along Gooseberry, Cottonwood, and Grass Creeks. These areas suffer from extreme water shortages, and all of the Bureau's proposals involved a diversion out of the Wood River. None of the projects were found feasible.

In the most recent studies the SCS proposed an off-channel reservoir located near the confluence of Gooseberry and Buffalo Creeks in Sec. 26, T. 47 N., R. 98 W. The 70-foot high earthfill dam would have a capacity of 3,690 acre-feet, 25 acre-feet for sediment control, 25 acre-feet for flood detention storage, and 3,640 acre-feet for irrigation storage. The maximum surface area of the reservoir would be 175 acres. The proposed reservoir would be filled by a diversion from Gooseberry Creek in Sec. 28, T. 47 N., R. 90 W. The diversion canal would be 2 miles long and have a 100 cfs capacity. The stored water would be released from the reservoir and flow into Gooseberry Creek to supply 2,610 presently irrigated acres a full supply in a 50-percent-chance year.

The capital cost of this project was estimated to be $832,000 with an annual cost of $47,300. The estimated average annual benefits are $71,000 ($59,000 for irrigation and $12,000 for secondary benefits). The benefit-cost ratio of this project is 1.5 to 1.0.

With the construction of the Lower Sunshine Reservoir, the potential of having a direct diversion out of the Wood River has probably been eliminated. There is a water right permit filed in the State Engineer's Office to divert 6,445 cfs out of the Wood River to fill the Lower Sunshine Reservoir. However, the opportunity now exists to purchase water from the Lower Sunshine Reservoir, either directly or by exchange.

As an alternative to the off-stream reservoir near the confluence of Gooseberry and Buffalo Creeks, the SCS considered a diversion out of the Wood River. With the construction of the Lower Sunshine Reservoir, the irrigators along the Wood and Greybull Rivers are assured of having a more dependable water supply, and they may not oppose this potential development. By purchasing 8,000 acre-feet of storage in Lower Sunshine Reservoir and constructing a 14-mile canal from the Wood River to Gooseberry Creek, the presently irrigated lands (3,800 acres) would receive a full-season water supply in an 80-percent-chance year. For this alternative the estimated average annual benefits and costs were $140,450 and $57,050 respectively, resulting in a benefit-cost ratio of 2.5 to 1.0.

It is physically possible to divert water from the Clarks Fork into the Shoshone River, and to continue diverting south to the Greybull River and into the Gooseberry Creek-Grass Creek areas by diversion and exchange of water. This type of diversion plan could firm up water supplies for presently irrigated land and enable new lands to be irrigated. Such a plan has not yet been investigated because costs would be high.

Greybull River

The Greybull River drains about 1,120 square miles before it empties into the Bighorn River near Greybull. The average flow at the mouth of the Greybull River is about 124,000 acre-feet per year. About 65,260 acres are currently being irrigated from the Greybull River and its tributaries, including the irrigated lands along Dry Creek.

A 1972 SCS Watershed Investigation Report for the Lower Greybull River basically covers the 45,233 acres being irrigated by the Greybull Valley Irrigation District. The area has two major problems: (1) damaging floods that can be expected 2 out of 10 years, and (2) drainage problems that have adversely affected about 31,600 irrigated and irrigable acres. The SCS did not find a means of reducing the estimated average annual flood damages of $50,000. No flood control reservoir sites along the main stem of the Greybull River could be found. Potential off-stream reservoir sites were identified, but the cost of the required diversion works rendered these sites infeasible.

A project to drain the wet lands by the use of open and closed drains was proposed by the SCS. The lands to be included in the project are located in two areas (Emblem Bench with 1,000 acres and Burlington-Otto area with 20,200 acres). Drains constructed for the Emblem Bench would carry drainage water into Dry Creek, and drains for the Burlington-Otto area would carry drainage water into the Greybull River. Closed drains consisting of tile lines ranging in size from 6 to 12 inches would be incorporated into the existing drainage system whenever possible. Open drains would be installed to intercept the flow from the closed drains and carry the water to either Dry Creek or the Greybull River. The existing open drains would be rehabilitated and incorporated into the project. Trees and other vegetative cover would be established along the open drains to provide suitable wildlife habitat. A right-of-way along these drains could be fenced and maintained as public access for hunting.

The total installed cost for this project is estimated to be $3,900,000 with an average annual cost of $247,730. The average annual benefits would be $821,000, with a resulting benefit-cost ratio of 3.3 to 1.0.

The Greybull Valley Irrigation District has just completed constructing the Lower Sunshine Dam and Reservoir. Lower Sunshine Reservoir will be a companion to the 53,000-acre-foot Upper Sunshine Reservoir in providing regulation of water supply for irrigation on the 50,000-acre irrigation district. Lower Sunshine Reservoir will have a capacity of 56,850 acre-feet, including 1,900 acre-feet of dead space, 44,950 acre-feet for irrigation and flood water storage, and 10,000 acre-feet for M & I water supply. The reservoir will be filled from two sources. Greybull River water will be diverted through Upper Sunshine Reservoir into the lower reservoir, and Wood River water will be diverted by a new canal from the Wood River to Lower Sunshine Reservoir.

Releases of water from Lower Sunshine Dam will reach the Greybull River via Sunshine Creek. Existing ditches will divert the reservoir water from the Greybull River for delivery to the land. The M & I water use is contemplated to be via an exchange of Lower Sunshine Reservoir water for Wood River water used out of priority at a potential copper mine at Kirwin, near the headwaters of Wood River.

The total cost of the Lower Sunshine Dam and Reservoir project is estimated to be $4.25 million.

<u>Shell Creek</u>

Shell Creek drains about 583 square miles before it empties into the Bighorn River near Greybull. The estimated average annual flow at the mouth of Shell Creek is 89,700 acre-feet. Shell Creek and its tributaries have about 10,493 acres that are currently being irrigated.

A 1972 Watershed Inventory Report for Lower Shell Creek by the SCS covers 320 square miles of the Shell Creek drainage basin from the town of Shell to the confluence of Shell Creek and the Bighorn River near Greybull. Frequent flooding occurs along Shell Creek and its tributaries, but the damages are relatively small. The major problem in the Basin is the lack of early spring and fall irrigation water supplies. Of the 9,725 acres irrigated in the Lower Shell Creek Basin, 2,487 acres receive irrigation shortages. All the 547 acres irrigated from Horse Creek, 660 of the 1,866 acres irrigated from Beaver Creek, and 1,280 of the 7,292 acres served by the Shell Canal extension experience early spring and fall irrigation shortages. Another 150 acres on Horse Creek are irrigated only 1 out of 5 years because of an insufficient water supply. Some of the lands irrigated by Beaver Creek currently receive a supplemental water supply from Leavett Reservoir.

The SCS identified two potential reservoir sites to supply supplemental water to Beaver Creek and the Shell Canal extension. A potential reservoir located in Coyote Basin, Sec. 30, T. 54 N., R. 91 W. would provide a supplemental water supply to all the water-short acres on Beaver and Red Canyon Creeks. The 59-foot-high earthfill dam would have 1,385 acre-feet of capacity (65 acre-feet for sediment storage, 50 acre-feet for flood storage, and 1,270 acre-feet for irrigation storage).

The reservoir would be filled by a diversion from Beaver Creek. The second reservoir, located in Scharen Draw, Sec. 17, T. 52 N., R. 92 W., would provide a supplemental supply to 1,280 acres irrigated by the Shell Canal extension. The potential reservoir would be filled during the nonirrigation season by the existing Shell Canal. A 40-foot earthfill embankment would provide 2,100 acre-feet of storage (50 acre-feet of sediment storage, 50 acre-feet of flood control storage, and 2,000 acre-feet for irrigation storage).

The estimated installed cost of the project would be $546,900 with an average annual cost of $28,210. The average annual benefits would be $51,500, including $45,500 for irrigation and $6,000 for secondary benefits. The resulting benefit-cost ratio is 1.8 to 1.0.

Sage Creek

Sage Creek heads in the Pryor Mountains in Montana and initially flows in a northwesterly direction. The creek then turns and flows in a southeasterly direction across the Montana-Wyoming State line and empties into the Shoshone River near Lovell. Sage Creek drains about 393 square miles, of which 235 square miles are in Montana, and 158 square miles are in Wyoming. Of the 24,958 acres irrigated in the watershed, 23,509 acres are irrigated by the Deaver, Frannie, and Sidon Canals in Wyoming, and 1,449 acres are irrigated on Bowler Flats in Montana.

The major problems identified in the SCS watershed investigation in Wyoming are irrigation shortages, inadequate drainage, and streambank erosion. The irrigation shortages are attributed to several factors including the reduced capacity of the 6-mile-long Corbett diversion tunnel and the deterioration of the distribution system due to siltation and vegetative and moss growth in the canals and laterals. Because of salt problems, 7,008 acres in the Basin require drainage facilities; of these, 1,168 acres are not drainable, 3,788 acres have already been drained, and 2,052 acres could be benefited by a drainage project. Streambank erosion has taken out of production an estimated 13 acres per year along Sage and Polecat Creeks because of releasing tail water into these creeks without proper control structures.

The SCS has identified four potential reservoir sites, two off-channel and two sites along the main stem of Sage Creek, to provide supplemental water supplies to existing irrigation. The two main stem reservoir sites would help reduce the streambank erosion but would not have the advantage of regulating the water supply close to the irrigation. One of the off-channel reservoirs could be filled by pumping from the Frannie Canal and the other could be filled by an extension of the Frannie Canal. Both of the off-channel sites would provide regulation of the irrigation water supply because of their location relative to the irrigation.

The SCS selected an off-channel dam located in Sec. 35, T. 58 N., R. 97 W. The 25-foot-high earthfill dam would provide 1,580 feet of storage capacity, 1,300 acre-feet for irrigation, 100 acre-feet for sediment control, and 180 acre-feet for detention storage. Water would be diverted into the proposed reservoir through a 1-mile-long extension of the Frannie Canal and diverted from the reservoir through a 5-mile-long canal using grade control structures. The 1,300 acre-foot irrigation pool would provide a full-season water supply to 4,000 irrigated acres during an average year.

The SCS concluded that 852 acres of irrigated land could be feasibly benefited by constructing 14.2 miles of tile drains. The remaining 1,200 acres of land that need draining had an unfavorable benefit-cost ratio.

The capital cost of the reservoir and drainage structures would be $1,063,770 with an average annual cost of $65,580. The average annual benefits resulting from the project would be $122,180 resulting in a benefit-cost ratio of 1.86 to 1.0.

Shoshone River

The Shoshone River drains 2,989 square miles before it empties into Bighorn Lake, a State-line reservoir on the Bighorn River formed by Yellowtail Dam. The average annual discharge at the mouth of the Shoshone River is 847,800 acre-feet. About 148,724 acres are currently irrigated from the Shoshone River and its tributaries. The 421,300 acre-feet of storage in Buffalo Bill Reservoir provide a potentially full water supply for all the lands irrigated in the Shoshone Project.

Buffalo Bill Dam was completed in 1910 using design criteria considered adequate until the last few years. Present USBR spillway design criteria require that a spillway pass the maximum probable flood. In order to pass this potential flood without overtopping the dam, the spillway needs to be enlarged, or the dam needs to be raised to increase the surcharge capacity. The USBR has been investigating several alternatives to modify the dam so it can safely pass the design flood. A USBR report has not been released, but preliminary data from the studies were provided for this report. The alternatives are to rehabilitate and enlarge the existing spillway or raise the dam 25 feet and modify the spillway. Associated with raising the dam 25 feet, the Bureau has studied four reservoir operation alternatives. By raising the dam 25 feet, the storage capacity of Buffalo Bill Reservoir would be increased to 710,200 acre-feet.

Plan 1 emphasizes irrigation development with some M & I development. With this plan irrigation water would be supplied to 19,200 acres on Polecat Bench and 17,300 acres on the Shoshone Extension South and the lands irrigated by the Cody Canal and/or Lakeview Canal would receive a supplemental irrigation supply. Also about 50,000 acre-feet of water could be developed for M & I purposes and released into the Shoshone River for joint use to provide sustained streamflows and power generation. The minimum flow during the nonirrigation season below Buffalo Bill Reservoir and the Heart Mountain Powerplant would be 68 cfs. In Plan 1, Buffalo Bill Reservoir would be operated between 695,400 and 48,200 acre-feet of capacity.

In Plan 2 irrigation water would be supplied to Polecat Bench and 1,470 acres of new land on Sage Creek east of Cody, Wyoming. With this plan a supplemental water supply would be provided for the lands irrigated under the Cody Canal and/or the Lakeview Canal, and between 125,000 and 140,000 acre-feet of M & I water could be developed at the reservoir. The M & I water released into the Shoshone River would also provide fishery enhancement and power generation. The sustained flow below the Reservoir and below the Heart Mountain Powerplant would be 100 cfs. In Plan 2 Buffalo Bill Reservoir would be operated between 642,200 acre-feet and 48,200 acre-feet.

Plan 3 emphasizes the recreational benefits of Buffalo Bill Reservoir. Plan 3 provides for the supplemental water supplies for the Cody Canal and/or the Lakeview Canal and the development of Polecat Bench but excludes M & I and additional new irrigation developments. This plan provides for a large recreation pool and sustained flow releases below Buffalo Bill Reservoir. The sustained flow below Buffalo Bill Reservoir would be 100 cfs, and below the Heart Mountain Powerplant the minimum flow ould be 208 cfs during the nonirrigation season, November through March. The reservoir capacity would not be drawn below 200,000 acre-feet from a maximum capacity of 642,200 acre-feet.

Plan 4 emphasizes power development with a 20-megawatt Shoshone Powerplant. The project would also provide a supplemental water supply to the Cody Canal and/or the Lakeview Canal, a sustained flow for fish enhancement, and an irrigation supply to the Polecat Bench Project and 1,470 acres in Sage Creek Valley (see Figure V-2). Buffalo Bill Reservoir would be operated between the capacities of 642,000 and 48,200 acre-feet. The minimum flow below Buffalo Bill Reservoir and the Heart Mountain Powerplant would be 100 cfs and 321 cfs respectively.

The Wyoming Water Planning Program, in addition to studying the Bureau's alternatives, investigated a potential diversion into the Shoshone River from the Clarks Fork. This potential project would maximize the water use in the Shoshone River and develop a portion of Wyoming's compact allocation from the Clarks Fork. By diverting water into the Shoshone River from the Clarks Fork, potentially irrigable lands in the Bighorn Basin could be developed while providing a larger minimum pool in Buffalo Bill Reservoir and while providing a substantial sustained flow below the reservoir to maintain fishery and downstream water quality. The project could include irrigation in the Clarks Fork Basin. Clarks Fork water used on Polecat Bench Project and on 25,000 acres presently irrigated from the Shoshone River would provide an exchange for Shoshone River water.

Features of the plan, shown on Figure V-2, would include (a) a dam on the Clarks Fork; (b) irrigation of 19,800 new acres in the Clarks Fork Basin; (c) a diversion into the Shoshone River Basin to supply Polecat Bench, and 25,000 acres on the Shoshone Project for exchange of Shoshone River, and to deliver M & I water to the Shoshone River; and (d) raising Buffalo Bill Dam to provide a larger minimum pool for recreation, irrigation of existing lands and Shoshone Extension South, M & I water, and sustained streamflow below the dam for fishery and water quality improvement for the entire Shoshone River.

A potential 265-foot-high earth dam on Clarks Fork in Sec. 14, T. 56 N., R. 103 W. and a 168-foot dike on Lake Creek in Sec. 35, T. 57 N., R. 103 W. would provide 750,000 acre-feet of storage capacity, 185,000 acre-feet for a recreation pool and a head for diverting to the Cyclone Bar area, 50,100 acre-feet of storage to provide a firm sustained streamflow release into Clarks Fork, 140,500 acre-feet for irrigation, 317,700 for M & I water supply, and 56,700 acre-feet for spillway surcharge. The 50,100 acre-feet of storage for sustained flows would provide 168 cfs (10,000 acre-feet per month) below Clarks Fork Reservoir. The 140,500 acre-foot irrigation pool would provide a full irrigation supply for the 4,600 acres presently irrigated below the reservoir, 19,200 acres of new land on Polecat Bench, the 25,000 acres on the Shoshone Project for exchange, 11,000 new acres on Chapman and Kimball Benches, 8,800 new acres on the Cyclone Bar, and provide supplemental water as needed to the 5,300 acres presently irrigated on Pat O'Hara Creek and on Cyclone Bar. The 317,700-acre-foot M & I pool would develop an M & I water supply of 127,100 acre-feet per year that would be diverted to the Shoshone River. The M & I water supply would be increased to 337,000 acre-feet per year by adding Shoshone River water from Buffalo Bill Reservoir.

Irrigation water would be released through the outlet works in the Lake Creek Dike to irrigate 8,800 acres of new land on Cyclone Bar and provide the presently irrigated lands on Cyclone Bar a supplemental water supply directly or by providing exchange water. The outlet works in Clarks Fork Dam would release water into the Clarks Fork River to provide the sustained flow on Clarks Fork, M & I, and irrigation and supplemental water supply for 56,200 acres in the Clarks Fork, Shoshone, and Greybull River Basins. The M & I and irrigation water would be pumped directly out of the Clarks Fork below Paint Creek (Sec. 12, T. 57 N., R. 103 W.).

A network of pipelines would provide a supplemental water supply to 5,300 acres presently irrigated from Pat O'Hara Creek, provide a full water supply to 11,000 acres on Kimball and Chapman Benches, 25,000 acres on the Shoshone Project, and 19,200 acres on Polecat Bench, and deliver a firm annual M & I water supply of 127,100 acre-feet to the Shoshone River. The M & I water supply and the irrigation water supply for the Shoshone Project and Polecat Bench Unit would be pumped into Heart Mountain Canal in Sec. 4, T. 55 N., R. 101 W.

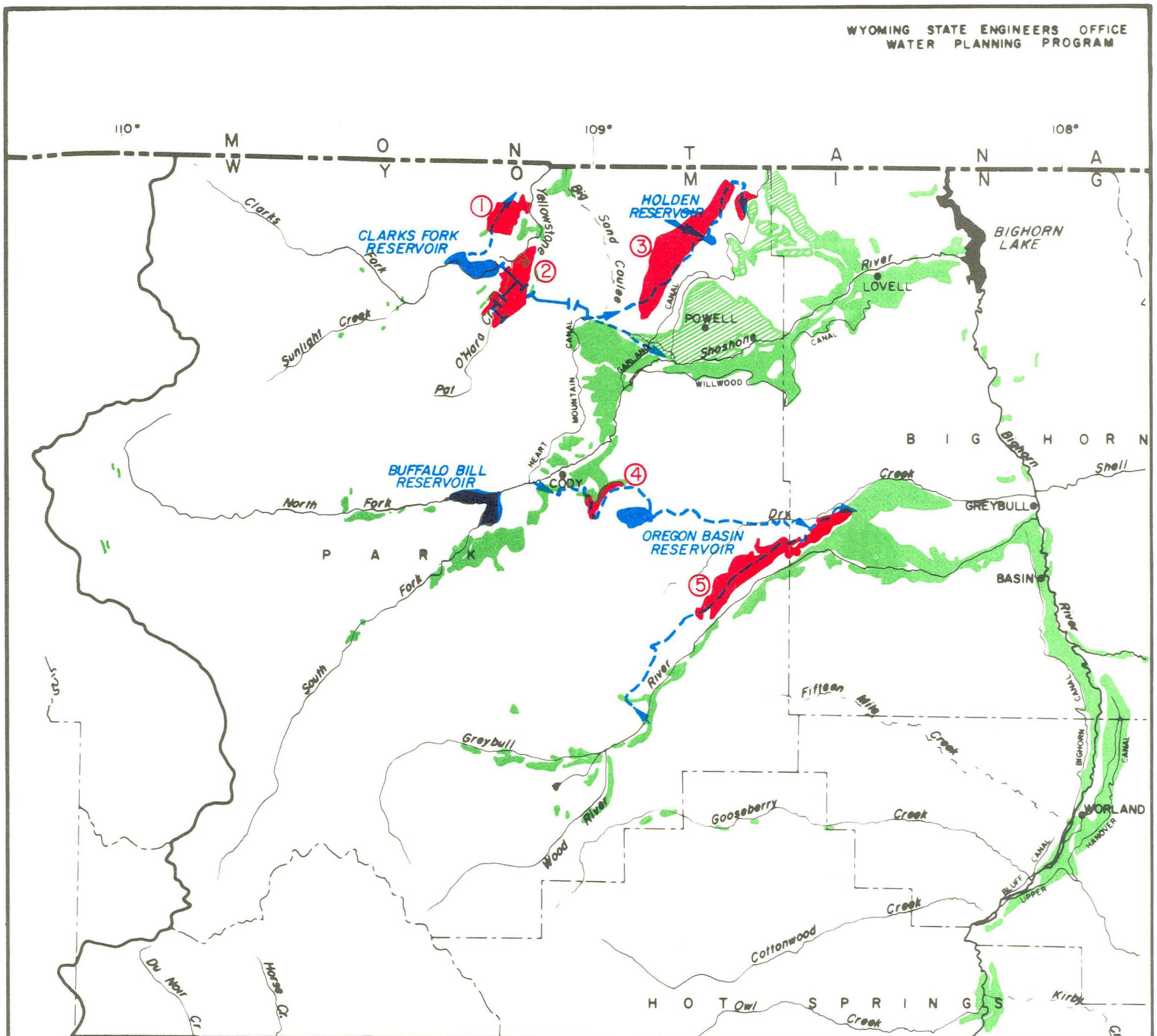
The Polecat Bench Unit would be developed under the Bureau of Reclamation plan, using Clarks Fork as the source of water supply instead of the Shoshone River. Shoshone River water could be used to develop Polecat Bench, and the imported Clarks Fork water could be used as a later exchange in order to develop the Buffalo Bill Reservoir M & I water and to provide other benefits. The 18,000 acres on Polecat Bench and 1,200 acres in the Frannie Loop would receive water through an extension of the Heart Mountain Canal. This could be accomplished by a series of siphons and a short tunnel. A small pumping plant at the inlet to the tunnel would be required to serve the potentially irrigable acreage on the highest portion of the bench. The proposed 9,900-acre-foot Holden Reservoir near the midpoint of Polecat Bench was proposed to reregulate the flow and supply the lands in the lower portion of the Bench and the acreage in Frannie Loop.

Exchange water developed at Clarks Fork Reservoir would be pumped to the Heart Mountain Canal to provide a full-season water supply for 25,000 acres on the Shoshone Project. The present canal and lateral system would be used wherever possible; however, in some instances additional supply canals may be desired to more beneficially utilize the imported water.

The 127,100 acre-feet of M & I water developed at the Clarks Fork Reservoir would be delivered to the Heart Mountain Canal in conjunction with delivering irrigation water to more fully utilize the pipeline and pumping plant capacities. The basic M & I water delivery period would be March through October, except no M & I water would be delivered in July and August because of the high irrigation demand in those months. The M & I water pumped into the Heart Mountain Canal would be conveyed down Alkali Creek and then released into the Shoshone River near Ralston. Releases from Buffalo Bill Dam would be scheduled to provide a steady, year-round M & I water supply that could be diverted below Ralston. If the M & I water were diverted from Bighorn Lake rather than from the Shoshone River the water quality of the entire Shoshone River would be enhanced. The combination of irrigation releases and M & I water releases from Buffalo Bill Dam would provide a sustained flow below the dam of 325 cfs in October and 415 cfs or more the rest of the year. Sustained flows in the Shoshone River below Ralston would always be 415 cfs or more.

The Clarks Fork water exchanged for Shoshone River water would enable an enlarged Buffalo Bill Reservoir to serve the existing Shoshone Project (except the 25,000 acres served by exchange) and the Shoshone Extension South, to provide increased recreation with an enlarged minimum pool and develop 209,900 acre-feet of M & I water per year. The plan would include enlarging Buffalo Bill Dam by 25 feet and the reservoir capacity to 710,200 acre-feet. The reservoir allocation could include 200,000 acre-feet minimum pool, 442,200 acre-feet conservation pool, and 68,000 acre-feet spillway surcharge capacity.

The Shoshone Extension South would be developed as proposed by the Bureau of Reclamation. The 17,300 acres in the Oregon Basin-Dry Creek Areas and on YU Bench would be supplied water directly from the Shoshone River through the Shoshone Canyon Conduit and the proposed Dry Creek and Oregon Basin Feeder Canals. The Oregon Basin Feeder Canal would supply 1,470 acres in the Dry Creek Valley enroute to the




# FIGURE V-2
## Potential Clarks Fork-Shoshone River Development

LEGEND

**Potential Project Lands**

1. Cyclone Bar Area
2. Chapman & Kimball Benches
3. Polecat Bench
4. Sage Creek Valley
5. Shoshone Extension South

**Presently Irrigated Lands**

- Irrigated Lands
- Shoshone Project Lands Potentially Supplied By Clarks Fork Water

**Potential Project Facilities**

- Pipeline
- Potential Reservoir
- Potential Canal

N

proposed 167,000-acre-foot Oregon Basin Reservoir, 120,000 acre-feet of which is conservation storage, and the remainder is fish and wildlife storage. Dry Creek Canal would begin at Oregon Basin Reservoir and extend to the Greybull River. Dry Creek Canal would supply water for 4,240 acres on Emblem Bench and in Dry Creek Valley and deliver replacement water to the Greybull River for the 11,560 acres irrigated on YU Bench and adjacent benches. The irrigable lands on the YU Bench and adjacent benches would receive water supplies from the Greybull River through the potential YU Canal.

A complete analysis of the costs and benefits of the Clarks Fork-Shoshone River project has not been done. The modification of Buffalo Bill Dam and the associated irrigation, M & I water supply, recreation, and hydropower facilities is under feasibility investigation by the USBR and up-to-date figures are not available. The latest cost estimate for the Polecat Bench Project is $30.3 million, and the ratio of total benefits to costs is 1.2 to 1.0.

A reconnaissance estimate of the Buffalo Bill Dam enlargement was $4.2 million in 1968. Recreation and hydropower-plant costs were an additional $5.2 million. The estimated cost of the Shoshone Extension South was reported to be $24.3 million in 1968.

Clarks Fork Dam and conveyance works from Clarks Fork to the Shoshone River were estimated to cost over $101 million. Additional costs not estimated would include conveyance structures to deliver irrigation water on Cyclone Bar, Pat O'Hara Creek, Chapman Bench, and Kimball Bench. The estimated average cost of water developed for all purposes is $17 per acre-foot per year. The feasibility of the project would depend upon how the costs were allocated among the various project purposes.

Main Stem Bighorn River

Irrigation. Several potential irrigation projects along the Bighorn River have been identified by the USBR and others. Many of these projects appear suitable for private development. Descriptions of these projects are from USBR reports or other sources. The Greybull Flats Unit near the town of Greybull contains 980 acres which could potentially be irrigated by pumping out of the Bighorn River. In a USBR plan to irrigate these lands, two 10-cfs pumps would lift the irrigation water 133 feet and dump it into a 3.2-mile-long canal. This project may be under consideration for private development and may include additional acreage.

The Bighorn Unit, which is located above the Bighorn Canal north of Worland, contains 1,730 acres of irrigable land in two separate tracts. Water would be pumped from the Bighorn Canal by three proposed pumping stations. About 860 acres could be served by two pumps with a 17-cfs capacity and pumping against a 68-foot static head. The second area containing 870 acres would be supplied by two pumping plants each containing two pumps. One pumping plant would contain two pumps with a total capacity of 12 cfs and pumping against a 134-foot static head, and the other pumping plant would contain two pumps with a total capacity of 8.6 cfs and pumping against a 26-foot static head. To supply the Bighorn Unit, about 26 miles of the Bighorn Canal would have to be enlarged to carry an additional 35 cfs.

Two other units near Worland include Schuster Flats, containing about 6,300 acres located west of the Bighorn River, and Banjo Flats, reportedly containing about 4,000 acres located southeast of Worland. Water for Schuster Flats might be pumped from the Bighorn River or diverted from Gooseberry Creek (supplied from a diversion into the creek from outside sources). Banjo Flats could be served from the Upper Hanover Canal, which would probably have to be enlarged.

Four other units formerly identified by the USBR have undergone partial development by individuals. About 1,700 acres could still be developed on the Kirby, Red Flats, Beaver Flats, and Kane Units.

These identified potentially irrigable units are examples of units that have been identified throughout the Bighorn River Study Area. At least 2,000 acres could be developed in the Shoshone River Basin, and over 3,000 acres could be developed privately in the Greybull River Basin if water is available. On most tributaries the dependable water supply and suitability of land are the restrictions on the potentials.

M & I Water Supply. Beginning in 1967 industrial companies began looking for water supplies for use in developing the energy resources of Southeastern Montana and Northeastern Wyoming. The USBR entered into option agreements with companies for water supplies that could be made available by regulation provided by Boysen and Yellowtail Dams on the Bighorn River. Table V-4 summarizes information about the contracts between the USBR and the companies.

The water supply available for industrial uses from Boysen and Bighorn Lake Reservoirs was estimated by the USBR in 1968, and the estimate was revised in 1971. The State of Wyoming conducted studies in 1971 to determine the probable range of the water-supply estimates depending upon assumptions used in the operation studies. The results of the Boysen Reservoir studies have been previously described.

The USBR estimated that Bighorn Lake could be regulated to produce an M & I water supply of 951,300 acre-feet per year. The assumptions used in operation studies to make the estimate are complex. Basically the assumptions include: (1) the correction of the estimated inflow to Bighorn Lake for assumed future operation of Boysen Reservoir, future supplemental irrigation water supply projects, and depletions on 96,060 acres of assumed new irrigation in Wyoming; (2) operation of Bighorn Lake between capacities of 1,116,000 acre-feet and 734,200 acre-feet; (3) annual releases from Bighorn Lake of 271,800 acre-feet for irrigation in Montana, 144,800 acre-feet for sustained streamflows at Hardin, Montana, and the M & I water supply of 951,300 acre-feet.

The Wyoming Water Planning Program conducted two hydrology studies to determine the probable range in the Bighorn Lake M & I water supply. Assumptions used in the studies included: (1) Bighorn Lake inflow was corrected for Boysen Reservoir operation assumption one, described on page 165, future supplemental irrigation water supply projects, and depletions on 122,700 acres of assumed new irrigation in Wyoming; (2) operation of Bighorn Lake between capacities of 1,116,000 acre-feet and 502,300 acre-feet, the minimum power pool; (3) annual releases of (a) 271,800 acre-feet per year or (b) 554,900 acre-feet for irrigation in Montana and M & I water release. The range in the Bighorn Lake M & I water supply was found to be between 648,000 and 1,002,000 acre-feet per year.

In a third study it was estimated that an M & I water supply of 672,000 acre-feet per year could be provided from Bighorn Lake. Assumptions for this study included: (1) Boysen Reservoir operation assumption 2; (2) operation of Bighorn Lake between minimum power pool and full capacity; and (3) the larger Bighorn Lake irrigation release. Under these assumptions a sustained flow could be maintained below Boysen Dam, the projected new irrigation in Wyoming could be developed, the larger Montana irrigation water supply could be provided, and the Bighorn Lake M & I release would provide sustained streamflows below Yellowtail Dam to the point of diversion of the water. With this kind of river operation, annual M & I water supplies of 217,000 acre-feet and 672,000 acre-feet would be available from Boysen Reservoir and Bighorn Lake respectively.

From the hydrology studies it is concluded that the amount of water contracted by the USBR listed in Table V-4 is within the limits of available water supplies, and additional water supplies are available from both Boysen Reservoir and Bighorn Lake. Constructing additional storage at Buffalo Bill Dam, or on the Nowood River, or at other sites could increase the total available firm water supply.

The Bureau of Reclamation has conducted reconnaissance investigations of alternative pipelines or aqueducts to convey the water into Northeastern Wyoming and Southeastern Montana. The routes are shown on a map on page 191. The farthest downstream alternative is a diversion of 694,000 acre-feet per year at Miles City, Montana below the confluence of the Tongue River and the Yellowstone River. The 173-mile pipeline would be constructed from that point through Montana, into Wyoming, and the Gillette area. Under this plan 382,000 acre-feet per year would be delivered in the Gillette area at a cost of $91 per acre-foot. The estimated cost of the project is $564.3 million.

The second USBR alternative is a diversion from the Bighorn River at Hardin, Montana and a pipeline up the Little Bighorn River into Wyoming and across the Tongue and Powder Rivers to the Gillette area. In this plan, a diversion of 694,000 acre-feet of water per year would be delivered to various points in Montana and Wyoming along the 180-mile route. The delivery to the Gillette area would be 312,000 acre-feet per year at a cost of $99 per acre-foot. Other Wyoming water deliveries include 52,000 acre-feet at Ulm for $59 per acre-foot and 52,000 acre-feet at Lake DeSmet for $76 per acre-foot. The total cost of construction is estimated to be $547.2 million.

The third Bureau alternative is an annual diversion of 135,000 acre-feet from Boysen Reservoir, with a 182-mile pipeline to the Gillette area. The Bureau's estimated annual cost of water in this alternative is $124 per acre-foot. Total construction cost is estimated to be $240.7 million.

The Wyoming Water Planning Program considered two additional diversion routes from the Bighorn River to the Gillette area coal fields and a larger diversion from Boysen to Gillette than the USBR reported. The first alternative is a diversion from the Nowood River, a tributary of the Bighorn River, through a pipeline to a tunnel through the Big Horn Mountains and a pipeline to Gillette. The preliminary plan has a total aqueduct length of 117 miles, including a 40-mile tunnel. A rough cost analysis indicates the annual cost of a 175,000 acre-foot per year diversion would be $108 per acre-foot. The capital cost of construction was estimated to be about $210 million.

The second alternative is a diversion from Bighorn Lake through a pipeline to a 16-mile tunnel through the Big Horn Mountains and a pipeline to Gillette. Water could also be delivered to the Tongue River and Lake DeSmet areas. The total aqueduct length would be about 202 miles, including the tunnel. If 40,000 acre-feet per year were delivered to the Tongue River and 175,000 acre-feet per year were delivered to Gillette, the cost of construction was estimated to be $268 million. The annual cost of water delivered would be $43 per acre-foot at Tongue River and $140 per acre-foot at Gillette. A 382,000 acre-foot per year diversion to Gillette would cost an estimated $452 million. The annual water cost at Gillette

TABLE V-4--Status of Industrial Water Service Contracts, December, 1971

| Contractor | Contract Date | Annual Water Service, Acre-Feet and Location of Use | | |
|---|---|---|---|---|
| | | Total | Wyoming | Montana |
| YELLOWTAIL UNIT | | | | |
| 1. Kerr-McGee Corp. | 11/9/67 | 50,000[1] | 50,000 | - |
| 2. Shell Oil Co. | 11/22/67 | 28,000[1] | - | 28,000 |
| 3. Humble Oil Co. | 12/14/67 | 50,000[1] | - | 50,000 |
| 4. Peabody Coal Co. | 5/24/68 | 40,000 | - | 40,000 |
| 5. Reynolds Mining Corp. | 6/19/69 | 50,000 | 50,000 | - |
| 6. John S. Wold | 6/20/69 | 50,000 | 50,000 | - |
| 7. Gulf Mineral Resources Co. | 1/20/70 | 25,000 | 25,000 | - |
| 8. Gulf Mineral Resources Co. | 3/ 2/70 | 50,000 | - | 50,000 |
| 9. Peabody Coal Co. | 5/22/70 | 40,000 | - | 40,000 |
| 10. Colo-Interstate Gas Co. | 9/ 4/70 | 30,000 | 30,000 | - |
| 11. Ayrshire Coal Co. | 1/20/71 | 30,000 | 30,000 | - |
| 12. Panhandle Eastern Pipeline Co. | 1/11/71 | 30,000 | 30,000 | - |
| 13. Shell Oil Co. | 2/10/71 | 20,000 | - | 20,000 |
| 14. Westmoreland Resources | 3/ 1/71 | 30,000 | - | 30,000 |
| 15. Norsworthy & Reger, Inc. | 4/21/71 | 50,000 | 50,000 | - |
| 16. Cardinal Petroleum Co. | 5/ 7/71 | 50,000 | 50,000 | - |
| Total - Yellowtail Unit | | 623,000 | 365,000 | 258,000 |
| BOYSEN UNIT | | | | |
| 1. Sun Oil Co. | 8/15/69 | 35,000 | 35,000 | - |
| 2. Mobil Oil Corp. | Pending | 50,000 | 50,000 | - |
| Total - Boysen Unit | | 85,000 | 85,000 | |

[1] State of intended use not specified in contract. Based upon coal resource explorations, it is expected that water will be used in the location shown.

Source: U. S. Bureau of Reclamation.

would be $119 per acre-foot.

A diversion of 175,000 acre-feet per year, 194 miles from Boysen to the Gillette coal fields, was estimated to cost $188.5 million. The annual water cost at the coal fields would be $113 per acre-foot. Water could also be diverted from Boysen Reservoir to meet the 30,000-acre-foot water demand projected for the Bighorn River Basin coal industry.

Another source of water for importation into Northeastern Wyoming is the Green River, a tributary of the Colorado River. Interstate stream compacts allocate to Wyoming 1,043,000 acre-feet of water per year from the Colorado River Basin. This allocation depends upon repetition of hydrologic conditions estimated at the time the compacts were agreed upon. More recent studies indicate that unless the Colorado River is augmented, something less than the total water supply would be available to Wyoming under the compacts. After accounting for the present uses and the projected water needs in the Green River Basin, it is estimated that between 93,000 and 272,000 acre-feet of water per year could be utilized outside of the Green River Basin in Wyoming. The larger figure assumes Wyoming's full allocation of water will ultimately be available for use in the State. In the aqueduct studies reported by the Billings office of the Bureau of Reclamation, a diversion from the Green River to Gillette of 239,000 acre-feet was assumed. The estimated annual cost of this water is $132 per acre-foot, and the total construction cost is estimated to be $334.2 million.

There are several factors that need to be considered regarding the proposals for transbasin diversions. One is the language of the Yellowstone River Compact: "No water shall be diverted from the Yellowstone River Basin without the unanimous consent of all the signatory states." This consent is needed if water is to be delivered to the coal beds in the Belle Fourche and Cheyenne River Basin. In order to get consent it would appear that regional factors must be considered so that the states can agree that a transbasin diversion can be made. In view of this, perhaps one of the downstream diversions that provide water for industries in both Montana and Wyoming may be a logical approach. The Colorado River Compacts do not contain any restrictions regarding transbasin diversions, and Wyoming may find use of Green River water in Northeastern Wyoming to be an attractive alternative.

Another consideration is the large construction cost of an aqueduct. A large diameter pipeline can deliver water at a cheaper cost per acre-foot although the total construction cost will be greater than a smaller diameter pipeline. Unless large-quantity water sales can be made in a reasonably short period of time, however, interest costs may offset savings achieved during construction. Thus, a stage-development plan of water resources may be attractive from a cost standpoint. Such a stage-development plan might include initial construction of water projects on the Tongue and Powder Rivers, and segments of pipelines that would fit into an ultimately constructed aqueduct system from either the Bighorn River or the Yellowstone River to the Gillette area. Reservoirs on the Tongue and Powder Rivers could be sized to reregulate the imported water so as to assist in the overall water management. Dams might be designed to accommodate staged enlargements as the system water-management needs increase.

## Study Area 3 -- Little Bighorn River

There is no interstate agreement between Wyoming and Montana dividing the use of water in the Little Bighorn River. It appears that a water supply could be developed from the main stem of the Little Bighorn River and its principal tributaries, West Fork and Dry Fork. These streams flow through steep canyon terrain.

Reservoir sites are limited and the reservoir capacity that could be developed is also restricted because of the steep terrain. In a 1947 report by the Montana Water Conservation Board, the total acreage of land in Montana irrigated from the main stem Little Bighorn River was stated to be 13,134 acres, and the total potentially irrigable lands were estimated to be 17,711 acres, including the presently irrigated land. The Little Bighorn River flows 102,600 acre-feet per year at the State line. After providing for the Montana irrigation, it appears that a water supply of approximately 50,000 acre-feet per year could be developed with a storage capacity of 50,000 acre-feet in Wyoming constructed on the Little Bighorn River near the State line. The U. S. Bureau of Reclamation identified 40,000 acre-feet of M & I water supply in its Montana-Wyoming Aqueducts Study.

## Study Area 4 -- Clarks Fork

The Clarks Fork and its tributaries drain about 2,660 square miles in Montana and Wyoming. The Clarks Fork heads at Lady of the Lake in Montana and then flows south, entering Wyoming near Cooke City, Montana. About 1,050 square miles are drained in Wyoming by Clarks Fork, before the river flows back into Montana near Chance, Montana. The discharge of Clarks Fork is 778,780 acre-feet per year at the mouth and 689,600 acre-feet at Chance. About 11,120 acres are currently being irrigated from Clarks Fork and its tributaries in Wyoming.

Opportunities for water resource development in the Wyoming portion of the Clarks Fork Basin have been investigated by the USBR and the SCS. The Wyoming Water Planning Program also investigated three alternatives of major resource development to utilize Wyoming's Clarks Fork allocation under the Yellowstone River Basin Compact.

Some years ago the USBR identified the Beartooth Unit as a potential hydropower project on the Clarks Fork. The unit consists of three dams and reservoirs on the main stem of the Clarks Fork, one dam and reservoir on Sunlight Creek, and three hydropower plants and related facilities on the main stem of Clarks Fork. The detail of this unit are explained in Chapter IV in Table IV-27.

The USBR also identified an irrigation potential on Chapman Bench in the Clarks Fork River Basin. Chapman Bench is located about 12 miles west of Polecat Bench along the east side of Pat O'Hara Creek. The USBR plan included the unit as a portion of the Shoshone Extensions Unit. The plan called for irrigation of 3,550 acres with a full water supply and 3,800 acres to be irrigated during the off-peak demand season and used for irrigated pasture. The unit was dropped from inclusion in the Shoshone Extensions Unit by the USBR.

The Watershed Investigation Report for the Cyclone Bar area of the Clarks Fork River Basin was prepared in 1971 by the SCS. The three problems identified on Cyclone Bar by the SCS included: (1) irrigation shortages on Little Rock, Bennett, and Line Creeks; (2) flood damages to irrigation structures and ditches on Little Rock, Bennett, and Line Creeks; and (3) freezing and icing on the lower reaches of Bennett Creek.

Each winter Bennett Creek freezes from the bottom up and develops a sheet of ice 2 to 3 feet thick, one-fourth to three-fourths-mile wide, and up to 2.5 miles long. The land covered by ice is unproductive until mid-summer. While the problem was not studied in detail by the SCS, there may be ways of preventing this massive ice build-up.

The SCS study determined there is little potential for using reservoir storage to provide supplemental irrigation water supplies or for flood control storage.

This is because of a lack of good storage sites and suitable construction materials. The best means identified for reducing flood damages are through channel stabilization and installation of permanent diversion structures. Supplemental irrigation water could be diverted from the Clarks Fork and regulated on Lake Creek with a reservoir to serve lands on Little Rock and Bennett Creeks.

A diversion structure on Clarks Fork (Sec. 12, T. 56 N., R. 103 W.) would divert water through a 3.3-mile-long supply canal into a potential 5,100 acre-foot reservoir on Lake Creek (Sec. 4, T. 56 N., R. 103 W.). A 45-foot-high earth-fill dam would store 4,900 acre-feet of irrigation water and provide 150 acre-feet of sediment storage and 50 acre-feet of flood-detention storage. The irrigation storage would give 2,076 acres a supplemental supply and provide 3,190 acres of nonirrigated grasslands a full supply in an 80-percent-chance year.

The cost of this project was estimated to be $840,000 with an annual cost of $54,400. The average annual benefits were estimated to be $134,320, and the resulting benefit-cost ratio is 2.5 to 1.0.

The Wyoming Water Planning Program investigated three alternative plans for the Clarks Fork. The most comprehensive plan, previously described in the section on <u>Shoshone River</u>, involved irrigation of 19,800 acres of new land in the Clarks Fork River Basin, production of 127,100 acre-feet of M & I water supply to be diverted into the Shoshone River, and the maintenance of a sustained flow in Clarks Fork below the potential 750,000-acre-foot Clarks Fork Reservoir located downstream of Clarks Fork Canyon. The streamflow depletion under this plan would be about 375,000 acre-feet per year out of Wyoming's compact allocation of 429,000 acre-feet per year. The full compact water supply would not be developed in this plan because of the commitment of a portion of the water available at Clarks Fork Dam to sustained streamflow below the dam.

A second plan considered full utilization of Wyoming's compact allocation of Clarks Fork water. In this plan, 19,800 acres of new land would be developed and a 181,600-acre-foot per year M & I water supply could be provided. The Clarks Fork Reservoir would have about 450,000 acre-feet capacity. Sustained winter streamflows below the Clarks Fork Dam could not be provided if the M & I water were diverted into the Shoshone River.

A third plan considered new irrigation only. Approximately 19,800 acres of new land would be developed in the Clarks Fork River Basin. In this plan as in the other two plans it was contemplated that water would be diverted into the Shoshone River for use on Polecat Bench and the Shoshone Project to provide an exchange of water in order that Shoshone River M & I water supply, irrigation, and recreation at Buffalo Bill Dam could be provided. Depletions of Clarks Fork would be about 238,000 acre-feet per year under this plan.

The obvious alternative to diverting Clarks Fork water into Shoshone River for use in the Bighorn Basin would be to divert Wyoming's share of the Clarks Fork, along with other water at Miles City, Montana, into the Miles City-Gillette aqueduct proposed by the USBR.

## POTENTIAL GROUNDWATER DEVELOPMENT

Groundwater will continue to be used extensively for domestic and livestock supplies, and as a significant part of municipal supplies. There are indications that irrigation using groundwater probably will expand, such as the recent (1971) completion of an irrigation well which reportedly flowed about 3,200 gpm (mainly from the Flathead sandstone) from a depth of about 3,900 feet. The well is located between Tensleep and Hyattville (Study Area 2c), in a region where groundwater is used for irrigation and where the largest previously reported well yield was 2,880 gpm from the Madison limestone.[1] More commonly irrigated wells are drilled into the Tensleep-Amsden, the Madison limestone, or the Bighorn dolomite and do not reach the Flathead sandstone. A USGS open-file report of 1962 (12) states that the groundwater development in the area (34 wells in a belt about 48 miles long and 5-10 miles wide, parallel to the Big Horn Mountains and with a total potential yield of 14,500 gpm) apparently has not lowered artesian pressure in the area. This same report mentions that wells with high yields commonly are associated with geologic features and that artesian pressure may locally be great enough to require the installation of a pressure regulator for sprinkler irrigation. The water quality reportedly is suitable for irrigation and stock use, but high iron content makes the water objectionable for domestic use.

The two Flathead wells raise the potential yield to more than 20,000 gpm (assuming other potential well yields have not declined). Some additional irrigated acreages near the Big Horn Mountains and near other uplifted areas may come into being through the use of groundwater from the Flathead sandstone, or the interval from the Tensleep to the granite.

Large yields (600-1,000 gpm) are reported from several wells in the floodplain alluvium and terrace gravels of the Greybull River. A yield of 2,000 gpm is reported from a well in the alluvium of Owl Creek. Alluvial aquifers do not appear to be of adequate extent and thickness anywhere in the report area to support sustained large-scale irrigation, without depleting surface water supplies. Alluvial aquifers probably would provide supplemental supplies many places, particularly where existing irrigation practices have contributed recharge to shallow aquifers. The gravels capping irrigated terraces would supply small to large well yields, perhaps on an annual basis. When new terrace lands are put into irrigated production groundwater supplies will accumulate in the gravels and can be pumped out for beneficial uses.

The entire mountain-front area along the Big Horn Mountains has a potential for development of groundwater in the Madison limestone, Flathead sandstone, or overall Tensleep-granite interval. The SCS has identified several opportunities for the development of groundwater to support irrigation projects. These projects are near the mountains, in places where surface storage sites are scarce or structures are not feasible due to steep topography and an absence of natural basins, or in wide valleys with associated unfavorable embankment storage ratios (33), (37).

In the Shell Creek drainage area (Study Area 2d) a preliminary investigation report points out the possibility of developing water supplies from the Madison limestone at depths of 1,500 to 2,000 feet. The report assumes an artesian flow of 2 cfs per well to provide supplemental irrigation water for 150 acres per well. The lands to receive the water are 544 acres along Trapper Creek, 518 acres along Horse Creek, and 2,300 acres along Beaver Creek and its main tributary, Red Canyon. The SCS considers these acreages suitable for project development.

Another potential groundwater irrigation project identified by the SCS is in the Crooked Creek drainage (Study Area 2e). Crooked Creek flows in a southeasterly

[1] One other irrigation well is known to produce water from the Flathead and reportedly flows 2,700 gpm from a depth of about 2,200 feet.

direction from its headwaters in the Pryor Mountains of Montana, across the state line into Wyoming and Bighorn (Yellowtail) Reservoir. Artesian wells tapping the Madison limestone at depths of 1,200 to 1,350 feet might provide supplemental water for 1,400 acres of irrigable lands. The irrigated lands are located on the floodplains of Crooked Creek and Gypsum Creek and are estimated to require 29 cfs supplemental water during the peak irrigation season. The proposed project calls for up to ten wells installed along the Crooked Creek floodplain in the vicinity of the Montana-Wyoming State line. The Crooked Creek stream channel would be used to convey the well discharges downstream to individual diversion structures. The SCS has also investigated the possibility of additional development, by installing wells on Gypsum Creek to irrigate 240 acres that have been abandoned due to insufficient water supply.

Hundreds of domestic, stock, and municipal wells obtain water from the Wind River formation in the Wind River Basin. Most of the wells are drilled in irrigated areas and obtain much of their water yields as a result of irrigation practices. The deeper Wind River formation wells probably reach aquifers that are recharged by infiltration of direct precipitation occurring near mountainous or uplifted areas and moving down-gradient in the formation to places of discharge. Some increased withdrawals might be anticipated due to projected municipal growth in the Wind River Basin.

The Wind River formation is a source of industrial water in the Gas Hills Uranium District. The use of industrial groundwater can be expected to increase as the amount of processed ore increases.

The petroleum industry has been using groundwater for the secondary recovery of oil for a number of years. This use will probably increase in the near future, and then most likely decline as oil production declines. The petroleum industry can use water of a quality not suitable for some other uses. Due to advances being made in desalting technology, water now considered too mineralized for normal use may become usable in the future.

## ALTERNATIVE WATER RESOURCE DEVELOPMENTS

The objective of this report is to illustrate the possible alternatives of water resource development that would meet the projected water needs of the Bighorn River Basin of Wyoming. Since a large potential industrial water demand in Northeastern Wyoming that will exceed the water supplies of the area has been identified, alternative ways of transporting water to Northeastern Wyoming are also given. The primary factors influencing the development of the Bighorn River Basin are agriculture, minerals development, and tourism-recreation.

The primary alternatives available in the Bighorn River Basin described in this report are: (1) no water resource development; (2) development of irrigation water projects and cooperative Wyoming-Montana M & I water development, and (3) irrigation development and development of M & I water for Wyoming only.

### Alternative 1

A decision by the State for "no development" or "minimum development" for the area could be made in several ways. Air quality standards could be the basis for limiting industry by setting low limits on certain types of stack emissions. Land reclamation requirements or zoning might be ways of limiting strip mining or natural resources activities. State policies on all forms of taxation could limit resources development by making Wyoming development less economically attractive to industry than other areas of the Nation. Various kinds of decisions affecting utilization of water resources could limit other kinds of resource development. Decisions on air, land, and water utilization control and taxation could influence the type and location of development.

Another way in which the development of the area's natural resources can be influenced is through Federal programs, policies, regulation, and laws. Public policy promulgated by the State with respect to Federal planning and development programs could result in higher or lower rates of development for the area.

In addition, discouraging water resource development would cause future development to occur much differently than the projections in this report. Without additional land and water resource development the future agricultural output of the Basin would be restricted to levels below projections. Industrial projections of the Bighorn Basin and Northeastern Wyoming would also be erroneous if water resources are not used in the development of the mineral resources, unless technological advances enable industrial developments without large water requirements.

Under this alternative some private water resource development would probably still occur even without guidance by the State. Water resource undertakings could proceed without assistance from State sponsored projects or Federal projects planned in cooperation with the State. Under a complete "no water resource development" alternative no additional dams would be constructed for water management, flood control, erosion control, silt control, recreation, or related functions.

### Alternative 2

Irrigation projections of 137,000 acres of new land brought into production by the year 2020 would be met in various combinations of units given in Table V-5 and indicated on Figure V-3. Supplemental water supplies for existing irrigation would be developed by projects previously described such as Crow Creek, Beaver Creek, Badwater Creek, Shell Creek, Crooked Creek, Cyclone Bar, Greybull River, Shoshone River, Gooseberry Creek, Pat O'Hara, Sage Creek, the Little Wind River, and other projects. Developments of new lands and supplemental water supplies would increase irrigation consumptive use from 1,029,000 to 1,398,000 acre-feet annually.

The industrial water needs of the Bighorn River Basin would be met by groundwater developments and by water supplies developed at Boysen and Buffalo Bill Reservoir and at reservoirs that might be constructed in the future. Municipal water supplies would be developed as needed by the individual communities of the Basin.

For Alternative 2, it was assumed that Wyoming and Montana would agree to pursue M & I water development on a cooperative basis for the coal fields in the eastern portions of the two states. In this cooperative development, a transbasin diversion from the Bighorn River or the Yellowstone River would be constructed to jointly serve the water needs of the two states. In Figure V-4, the Miles City-Gillette pipeline or the Hardin-Gillette pipeline would be the alternative best suited to serving both states. These pipelines might be constructed as an initial means of serving coal field needs, or they might be constructed as a later stage after developing the water resources of the Tongue and Powder River Basins.

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM

# WYOMING'S BIGHORN RIVER BASIN

SCALE
10 0 10 20 30 40 Miles

## FIGURE V-3
## IRRIGATED AND POTENTIALLY IRRIGABLE LANDS

LEGEND

IRRIGATED LANDS

IRRIGABLE LANDS

(1) NUMBERS REFER TO STUDY AREAS

## POTENTIAL IRRIGATION PROJECTS

| PROJECT | ACRES |
|---|---|
| 1. Indian Development | 50,000 |
| 2. Riverton Extension | 18,500 |
| 3. Beaver Creek | 1,590 |
| 4. Polecat Bench | 19,200 |
| 5. Shoshone Extension South | 17,300 |
| 6. Bighorn Unit | 1,700 |
| 7. Greybull Flat | 1,000 |
| 8. Nowood River | 3,000 |
| 9. Crooked Creek | 250 |
| 10. Clarks Fork | 19,800 |
| 11. Private Surface Water Development | 15,000 |
| 12. Private Groundwater Development | 31,000 |

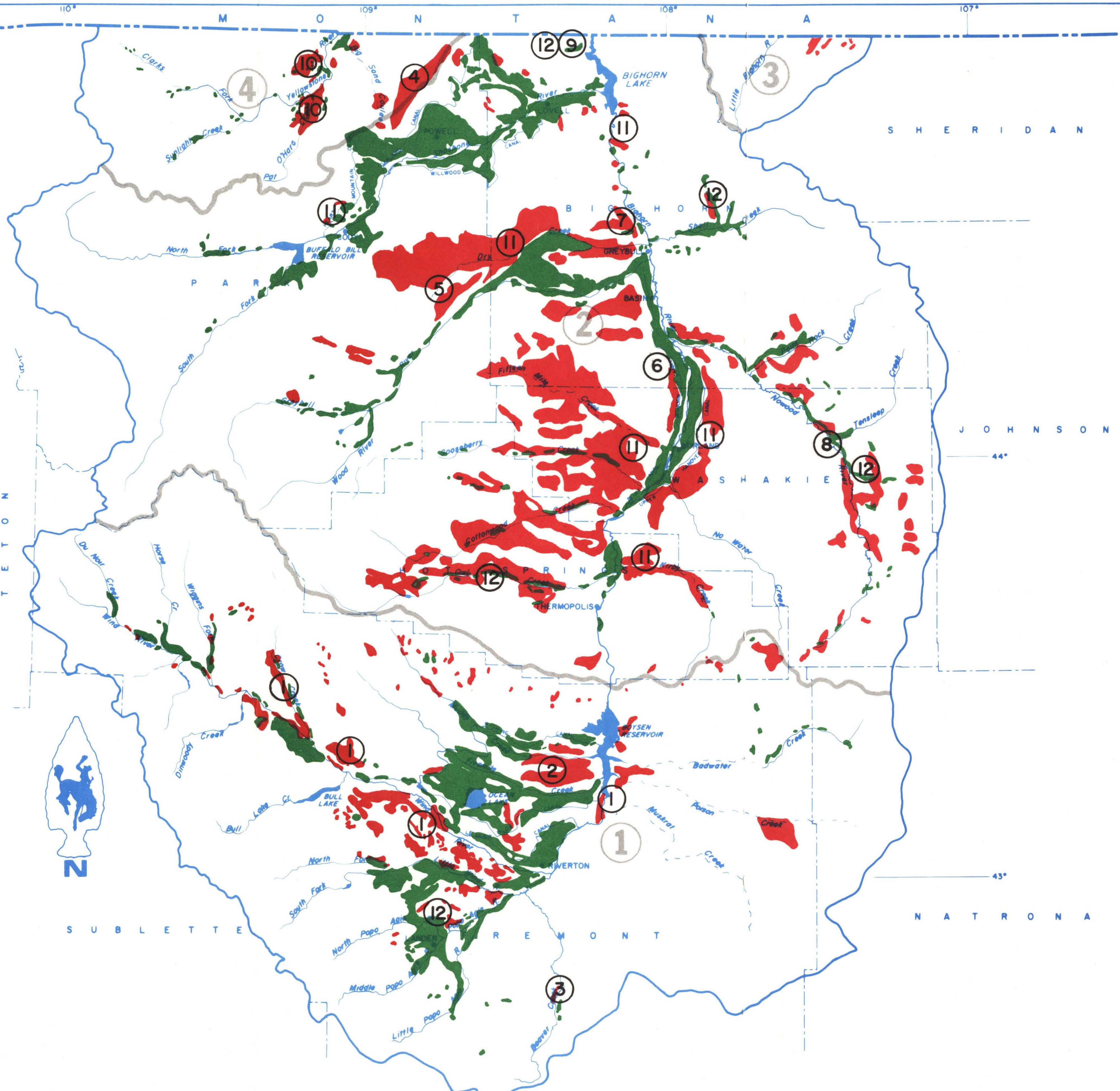



FIGURE V-3

TABLE V-5--Potential New Land Irrigation Project Developments

| Project | | Acres |
|---|---|---|
| 1. | Indian development (miscellaneous projects) | 50,000 |
| 2. | Riverton Extension Project | 18,500 |
| 3. | Beaver Creek | 1,590 |
| 4. | Polecat Bench | 19,200 |
| 5. | Shoshone Extension South | 17,300 |
| 6. | Bighorn Unit | 1,700 |
| 7. | Greybull Flat | 1,000 |
| 8. | Nowood River | 3,000 |
| 9. | Crooked Creek | 250 |
| 10. | Clarks Fork | 19,800 |
| 11. | Private Surface Water Projects | 15,000 |
| 12. | Private Groundwater Projects | 31,000 |
| | Total | 178,340 |

The projected consumptive uses of water in the Bighorn River Basin by the year 2020 are summarized in Table V-6. The total increase in consumptive uses of water in the Bighorn River Basin is projected to be 442,000 acre-feet per year, and a transbasin diversion is projected to be 175,000 to 416,000 acre-feet per year to Northeastern Wyoming. The use of water within the Bighorn River Basin of Wyoming is projected to be greater than the amount of water diverted from the Bighorn River Basin to other areas of Wyoming.

## Alternative 3

Bighorn River Basin water uses for irrigation, industry, and municipal purposes would be the same in Alternative 3 as in Alternative 2. The difference between the alternatives is in the transbasin diversion of water from the Bighorn River into Northeastern Wyoming. If it is not possible or practical for Wyoming and Montana to proceed on a joint water resource development plan, transbasin diversions could be constructed to serve Wyoming needs only. In this case, the Boysen Reservoir to Gillette, Nowood River to Gillette, or Bighorn Lake to Gillette pipeline could be constructed to serve the Wyoming water needs only. These three conveyance routes are shown on Figure V-4. In this alternative it is assumed that ultimately Wyoming

TABLE V-6 -- Wyoming's Consumptive Uses of Bighorn River Basin Water by the Year 2020[1]

| Use | Present | + | Increase by 2020 | = | Total 2020 |
|---|---|---|---|---|---|
| | Annual Consumptive Use--Acre-Feet | | | | |
| Bighorn River Basin | | | | | |
| Irrigation | 1,029,000 | | 369,000 | | 1,398,000 |
| Industrial | 28,000 | | 19,000 | | 47,000 |
| Municipal, Domestic, and Stock | 13,000 | | 14,000 | | 27,000 |
| Reservoir Evaporation[2] | 105,000 | | 40,000 | | 145,000 |
| Subtotal | 1,175,000 | | 442,000 | | 1,617,000 |
| Transbasin Diversion | | | | | |
| Projected | 0 | | 175,000 | | 175,000 |
| (Maximum USBR Plan) | -- | | (416,000) | | (416,000) |
| Total | 1,175,000 | | 617,000 to | | 1,792,000 to |
| (Total with Maximum USBR Transbasin Diversion) | | | (858,000) | | (2,033,000) |

[1] Includes groundwater uses.

[2] Excludes Bighorn Lake.

would divert Clarks Fork water into the Shoshone River for utilization in Wyoming, since the water would not be diverted lower on the Yellowstone River.

The Wyoming water uses under this alternative for the year 2020 are the same as under alternative 2 and are listed in Table V-6.

In both Alternatives 2 and 3 the transbasin diversion of water to Northeastern Wyoming may stop somewhat short of Gillette, Wyoming because of the Article X limitation in the Yellowstone River Compact or out of basin diversion. The cost of conveying water from the Yellowstone River would be reduced somewhat from the estimated costs of delivering directly into the Gillette area coal fields. It may be necessary to transport a portion of the Gillette area coal into the Yellowstone River Basin for processing in this case.

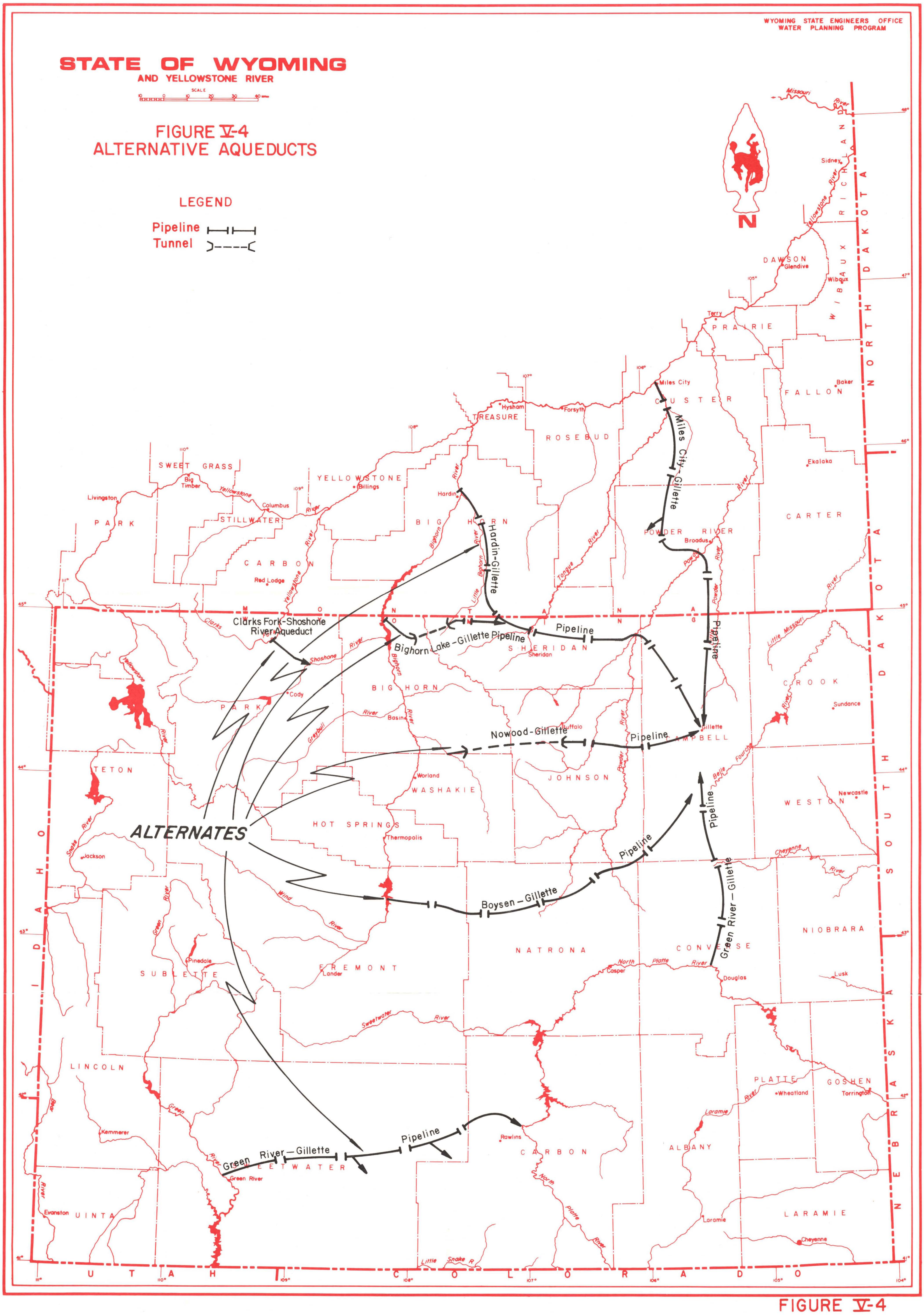

WYOMING STATE ENGINEERS OFFICE
WATER PLANNING PROGRAM
STATE OF WYOMING
AND YELLOWSTONE RIVER
SCALE
FIGURE V-4
ALTERNATIVE AQUEDUCTS
LEGEND
Pipeline
Tunnel
N
ALTERNATES
Clarks Fork-Shoshone River Aqueduct
Bighorn Lake-Gillette Pipeline
Hardin-Gillette
Miles City-Gillette
Pipeline
Nowood-Gillette
Boysen-Gillette
Green River-Gillette
M O N T A N A
I D A H O
U T A H
C O L O R A D O
N E B R A S K A
S O U T H D A K O T A
N O R T H D A K O T A
PARK
TETON
SUBLETTE
LINCOLN
UINTA
SWEETWATER
FREMONT
HOT SPRINGS
WASHAKIE
BIG HORN
SHERIDAN
JOHNSON
CAMPBELL
CROOK
WESTON
NATRONA
CONVERSE
NIOBRARA
CARBON
ALBANY
PLATTE
GOSHEN
LARAMIE
SWEET GRASS
STILLWATER
YELLOWSTONE
TREASURE
ROSEBUD
CUSTER
POWDER RIVER
CARTER
FALLON
PRAIRIE
DAWSON
WIBAUX
RICHLAND
Livingston
Big Timber
Columbus
Billings
Red Lodge
Hardin
Hysham
Forsyth
Miles City
Terry
Glendive
Sidney
Baker
Ekalaka
Broadus
Cody
Basin
Worland
Thermopolis
Sheridan
Buffalo
Gillette
Sundance
Newcastle
Lusk
Douglas
Casper
Lander
Pinedale
Jackson
Kemmerer
Evanston
Green River
Rawlins
Laramie
Cheyenne
Wheatland
Torrington
Missouri River
Yellowstone River
Bighorn River
Shoshone River
Wind River
Green River
Sweetwater River
North Platte River
Powder River
Tongue River
Belle Fourche
Cheyenne River
Little Missouri River
Little Snake R.
Snake River
Clarks Fork

FIGURE V-4

## ENVIRONMENTAL CONSIDERATIONS

The Bighorn River Basin area of Wyoming described in this report is characterized by vast open spaces, rolling hills, badlands, benchlands, prairies, foothills, and mountains. The area consists primarily of two basins--the Wind River Basin and the Bighorn Basin--ringed with mountains. The majority of the area is semiarid to arid, and vegetative cover varies from saltbush to scattered yellow pine to juniper trees along ridges and in river breaks. Cottonwood trees grow along streams in the lowlands and willows occupy mountain streambanks. Coniferous forests prevail in the mountains where precipitation is much more abundant than on the lowlands.

Water is a prime factor in the habitation of the area, and most of the land area is used for livestock grazing. This is supported with irrigated hay and pasture where water is available. Intensive farming is also practiced along streams where irrigation water is available. Other habitations by man and uses of the land are found in the scattered minerals and timber industries, built-up areas, and occasional towns, farms, ranches, mountain cabins, and recreational areas. Wildlife is found throughout the area, which is well-known for its abundance of antelope, deer, elk, moose, black bear, bighorn sheep, upland game, and small game. This wildlife, many other animal species, birds, and waterfowl are dependent upon the land and water for habitat.

Streams, lakes, reservoirs, and stock ponds in the area provide habitat for many varieties of fish and aquatic life. These resources provide fishing for a considerable number of anglers, with most fishing pressure concentrated in the mountainous areas.

The projected development will have impacts on the natural environment as well as on man's economic and social environment. Objectives of detailed planning should include identification and consideration of these impacts. This report describes several alternatives for overall water development, and within the alternatives there are many alternate water projects that could be constructed or utilized. A detailed environmental impact analysis of each alternative would be required in conjunction with a feasibility study. An adequate environmental analysis is not practical in an assessment of the type presented in this report. Some general comments can be made, however, about the environmental considerations of water resource projects.

### Reservoirs

Many of the water resource projects described previously in this report would require construction of new reservoirs for irrigation water supplies, M & I water supplies, and related purposes such as flood, sediment, and silt control, fish and wildlife, and recreation. Careful multiple purpose planning can minimize the environmental impacts of new reservoirs. Environmental factors associated with reservoir development which should be considered during project planning include:

1. Selection of the reservoir site least detrimental to stream fishery and wildlife habitat if feasible alternatives are available.

2. Effects of altered streamflow patterns on fish spawning, movement, and survival.

3. Effects of altered water surface levels of existing reservoirs and recreational uses on fish production.

4. Development of seasonal reservoir operating plans compatible with fish production, waterfowl utilization, and water-based recreation.

5. Importance of potential impoundment areas as wildlife habitat.

6. Environmental effects in design, construction, and operation of new reservoirs.

Some of the projected water needs of the Bighorn River Basin and other areas of Wyoming can be met by utilizing water resources available from existing reservoirs. Existing reservoirs regulating water that could be put to additional uses include Bighorn Lake, Boysen, and Buffalo Bill. As previously stated, the future operations of these reservoirs may enhance or detract from the current conditions of reservoir fluctuations, minimum reservoir pools, and sustained streamflows below the dams. For example, if M & I water is diverted from the Yellowstone River at Miles City, Montana, for delivery to coal industries in southeastern Montana and northeastern Wyoming, the Bighorn River reservoir system can be operated to enhance streamflows in the Bighorn River throughout Wyoming and Montana and in the Yellowstone River to Miles City. In addition, Wyoming's share of Clarks Fork water would be available for diversion at Miles City rather than being diverted in Wyoming. If, however, it is impractical for the states to agree on a common diversion for M & I water, then it may be necessary for Wyoming to divert its M & I water at upstream locations such as at Boysen Reservoir and at Bighorn Lake. In the latter case, it would be necessary to determine the alternative values of sustained flows below dams versus diverting the water for consumptive uses. It would be necessary to work out compromises in the amount of water supplied for diversion and for sustained flows or to construct other facilities to make these water uses compatible. Repayment plans would also have to be devised to reimburse the costs of providing sustained flows below dams.

There are no wild, scenic, or recreation rivers currently designated in Wyoming under either a Federal or State system. Rivers in the Basin that have been mentioned for consideration include the Wind River, North and South Forks of the Shoshone River, and the Clarks Fork in the Clarks Fork Canyon. The State of Wyoming has established the Sinks Canyon State Park, and the upper Popo Agie River has been suggested for State designation as a scenic river.

## Canals and Pipelines

Assuming that water resource development occurs as projections in this report indicate, new lands would be brought into production, and several new canals and pipelines would be constructed. Environmental factors to be considered in the planning for these projects include:

1. Provisions for fish screens, rough fish control, and silt-settling basins for water quality control for fisheries management purposes.

2. Water conservation practices such as ditch linings, use of sprinkler systems, and other means of efficient application of water to reduce water quality deterioration.

3. Provision of public access to streams and lakes, provisions to replace public use areas where these are affected by project development.

4. Minimization of effects on big game wintering areas, or replacement of big game wintering areas.

5. Protection of big game migration routes by providing bridges across canals, inverted siphons across draws and streams, and other provisions to enable wild game to cross water conveyance structures.

## Potential Watershed Projects

Environmental considerations were noted in each of the watershed investigation reports resulting from the Wind-Bighorn-Clarks Fork River Basin Survey. A brief summary of the preliminary findings is presented in Table V-7.

TABLE V-7 -- Environmental Considerations in Potential Watershed Projects

| Study Area | Watershed | Environmental Considerations |
|---|---|---|
| 1 | Upper Beaver Creek | Provide a 7-mile fishery benefit; impoundment would provide a resting place for waterfowl; improve sage grouse habitat; inundate 400 acres winter range for deer and elk. |
| 1 | Upper Badwater Creek | Reduce streambank erosion benefiting fishery and wildlife habitat; impounded water would benefit chukar population and provide a resting place for waterfowl; might be detrimental to fishery because reservoir releases might warm streamflows downstream. |
| 1 | Crow Creek | None reported. |
| 1 | Midvale | Provide additional habitat for pheasants, chukars, small birds, and cottontails; marshes formed in depressions by return flow could be developed for waterfowl. |
| 2 | Gooseberry Creek | Benefit upland game and small game by increased forage, provide waterfowl resting place, reduced flooding and streambank erosion; minor restriction of wildlife movement. |
| 2 | Nowood River | Enhance fishery and water quality by reducing sediment. |
| 2 | Sage Creek | Provide antelope drinking water; resting place for waterfowl on the reservoir, limited recreation potential; reduced grazing by wildlife on sagebrush in reservoir area; small reduction in nesting habitat of ducks and pheasants by using closed drains. |

| | | |
|---|---|---|
| 2 | Crooked Creek | None reported. |
| 2 | Lower Shell Creek | Allow public access to scenic areas for fishing and hunting; provide early summer recreation and fishing; habitat for waterfowl, and watering facilities for wildlife by the impoundments; adverse effect would be sediment buildup in the reservoir basin but this will be partially offset by reduction in the downstream sediment load. |
| 3 | Cyclone Bar | Enhance fishery benefits by providing a more reliable streamflow in Bennett Creek; the reservoir would provide a fishery, recreation and waterfowl habitat. |
| 2 | Lower Greybull River | Increase wildlife habitat and public recreation use; provide cleaner and more dependable water supplies of uniform temperature for waterfowl and fisheries; provide open water for wintering flocks of waterfowl; improve water quality of irrigation return flow; adversely change the habitat for small game and birds by changing the use of wetlands and abandoned lands to cropland. |

Source: USDA Watershed Investigation Reports, Wind-Bighorn-Clarks Fork Type IV Survey.

## Water Quality Considerations

Water users are required to comply with water quality standards adopted by the State. These standards are summarized in Chapter II. Treatment of effluents would be required for any new water uses that would cause the quality of water in interstate streams to fall below the standards required for physical, chemical, biological, and radiological characteristics. Future industrial water uses are most likely to be 100-percent consumptive and should therefore have little, if any, effect on water quality. Municipalities will be required to provide sewerage treatment to comply with health regulations and water quality standards.

One effect of water resource development on water quality will be on the total dissolved solids present in the water. An analysis was made of the effects of developments suggested in the alternatives in this report upon the quality of water leaving the State. The table below shows the change in the concentration of total dissolved solids that is estimated to occur with the developments that are included in the projected water developments by the year 2020.

| River | Concentration of Total Dissolved Solids (ppm) (Annual Average) | |
|---|---|---|
| | Present Condition | Developed Condition |
| Clarks Fork at State line | 107 | 186 |
| Bighorn River at State line | | |
| Alternative 2 | 650 | 790 |
| Alternative 3 | 650 | 800 |

Turbidity and sediment are other important water quality factors in many streams in the Basin. The soils of the lower elevations of both the Wind River Basin and the Bighorn Basin are of loamy to clayey texture with sparse desert vegetative cover. These soils are susceptible to erosion from natural runoff which contributes considerable sediment and turbidity to streamflow. Irrigation return flows, where not properly controlled, contribute sediment and turbidity to streams. Continued improvements in grazing practices, irrigation practices, and other conservation measures will alleviate or improve stream sediment and turbidity problems.

# CHAPTER VI

# SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

WATER AND RELATED LAND RESOURCES OF THE BIGHORN RIVER BASIN, WYOMING

# SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## SUMMARY

LOCATION AND CLIMATE

The Bighorn River Basin extends southward from the Wyoming-Montana State line for a distance of approximately 175 miles and eastward from Yellowstone National Park approximately 155 miles to the Big Horn Mountains. Average annual precipitation varies from over 25 inches in the mountains ringing the Basin to less than 7 inches in both the Wind River and Bighorn Basins. Annual snowfall averages from 14 to 40 inches over most of the plains, up to 90 inches over the southern Wind River plains, and much higher over the mountains. The report area includes the drainages of the Wind-Bighorn River, the Little Bighorn River, and the Clarks Fork of the Yellowstone River.

STREAMFLOW

A majority of streamflow results from snowmelt runoff in the May through July period of the year. Reservoir storage is required in most areas to provide dependable water supplies. The estimated streamflow originating in the Basin under natural conditions is about 4,237,280 acre-feet per year. Adding the estimated streamflow entering from Montana, the average annual discharge leaving Wyoming would be 4,384,620 acre-feet per year. Irrigation consumes 1,028,500 acre-feet of surface water in Wyoming. Reservoir and stock pond evaporation consumes 105,300 acre-feet (excluding Bighorn Lake evaporation); 2,210 acre-feet are consumed by industry, and 2,710 acre-feet by municipal and domestic uses. The total consumptive use is about 1,138,720 acre-feet, and the annual depleted streamflow leaving Wyoming is 3,245,900 acre-feet per year. In the 1948-1968 period, recorded streamflows near the State line varied from 52 percent to 148 percent of average. Seventy-five percent of the streamflow is in the Bighorn River, 4 percent is in the Little Bighorn River, and 21 percent is in the Clarks Fork.

Damaging floods have occurred on many streams of the Basin. Flood damage generally is restricted to agricultural developments and machinery, roads, railroad crossings, wildlife habitat, and farm buildings and urban developments on the floodplain.

WATER QUALITY

Generally the quality of interstate waters in the Basin is within the limits of established standards. An informal cooperative program of physical and chemical monitoring has been carried out since the inception of Wyoming's water pollution control program in 1956. The agencies involved are the Wyoming State Engineer's Office, the Wyoming Game and Fish Commission, the State Department of Agriculture, the State Department of Health and Social Services, and the U. S. Geological Survey.

Communities that discharge waste to streams are considered to have adequate treatment facilities so far as waste effects on water quality of interstate streams and subsequent uses are concerned. The one exception is the town of Thermopolis, including Hot Springs State Park. The effluent from Thermopolis' waste water treatment system and the State Park's separate system causes constant violation of the fecal coliform section of Wyoming's Interstate Water Quality Standards. A plan to correct the problem has been devised by the State Department of Health and Social Services. A new facility financed by a Federal grant of $35,000 is expected to be completed in late 1972 and will bring the receiving water quality into compliance with interstate standards.

Only minor pollution problems related to oil fields exist at this time; the water from oil wells many times is the only water available for livestock and wildlife. Oil spills and pipeline breaks have occasionally caused pollution problems, but the Contingency Plan for Spills of Oil and Other Hazardous Materials have effectively reduced these problems.

The specific contribution by agriculture to water pollution is not known. Guidelines for the control of pollution from livestock feedlots have been developed by the Health Department, Agricultural Extension Service, and State Department of Agriculture. All feedlot operators are being urged to adopt the guidelines.

An extensive program of education in regard to proper irrigation practices is being carried on in the State through the University Extension Service, Farm Bureau, Irrigation Districts, and Soil and Water Conservation Districts. Improved irrigation practices should reduce the effects of irrigation on stream salinity, turbidity, and sedimentation.

A large natural source of salinity exists in the Basin. The many hot springs in the Thermopolis area flow mineralized water having 3,500 ppm TDS, and account for approximately 20 percent of the average annual pickup in salt load between Boysen Reservoir and the Kane gaging station.

WATER RIGHTS

Provisions of the Wyoming Constitution allow the appropriation of water for beneficial uses and establish the Office of the State Engineer and the Board of Control to supervise such appropriations. State Statutes establish procedures for the appropriation of water. Priority of appropriation . . . "first in time is first in right" . . . is the basis for Wyoming water law.

Irrigated lands in the Basin total 538,830 acres. There are 962,350 acres with water rights in good standing.

The "reserved water rights doctrine," or the "Winters Doctrine," could affect water resources development in the

Basin. The foundation of the reservation doctrine is the property clause of the United States Constitution. The basic elements of the doctrine are: "If the United States, by treaty. act of Congress, or executive order, reserves a portion of the public domain for a Federal purpose which will ultimately require water, and if at the same time the government intends to reserve unappropriated water for that purpose, then sufficient water to fulfill that purpose is reserved from appropriation by private users. The effect of the doctrine is twofold: (1) when the water is eventually put to use, the right of the United States will be superior to private rights in the source of water acquired after the date of the reservation; hence such private rights may be impaired or destroyed without compensation by exercise of the reserved right, and (2) the Federal use is not subject to state laws regulating appropriation and use of water." (From: Trelease, Frank J., 1972, Federal-State Relations in Water Law, Prepared for the National Water Commission, National Technical Information Service, Springfield, Virginia).

It is evident that a new water user under the reservation doctrine could take water without compensation from an appropriator with a priority under State law established subsequent to the reservation. Federal claims to ill-defined rights to use water would also be a deterrent to further non-Federal development.

Federal legislation has been proposed which would require Federal recognition of state water laws. A recent proposal calls for a "National Water Rights Procedures Act" to foster a cooperative spirit between the states and the Federal government. The Act would promote a policy of recognizing and utilizing the laws of the states relating to creation, administration, and protection of water rights, (1) by establishing, recording, and quantifying Federal water rights in conformity with such state laws as are consistent with and appropriate to the Federal purposes, (2) by protecting and preserving vested water rights held under state law through the elimination of the no compensation features of the reservation doctrine and the navigation servitude, and (3) by providing new Federal procedures for the condemnation of water rights and the settlement of legal disputes. A most important feature of the proposal is the payment of compensation to holders of rights junior to a reservation who are injured by a Federal reserved water use.

Federal reservations in the Bighorn River Basin of Wyoming are the Wind River Indian Reservation (1868), the Shoshone National Forest (1891), and the Bighorn National Forest (1897). In Montana there are the Crow Indian Reservation (1868) and the Custer National Forest (1907). The Indian reservations and national forests predate most of the water rights in the Basin. Water uses in national forests are assumed not to expand beyond existing types of recreational uses. Indian water uses are considered in the same manner as other uses insofar as projections and planning are concerned. Future new Indian water uses are assumed to be a part of the compact allocation of the state in which the uses are made.

INTERSTATE COMPACTS

The Yellowstone River Compact provides a basis for dividing the water of the Yellowstone River between the states of Wyoming, Montana, and North Dakota. Article V of the compact provides for a division of water among the states. All water rights existing as of January 1, 1950 are recognized. Of the unused and unappropriated waters of the interstate tributaries of the Yellowstone River, each state is allocated sufficient water to provide supplemental water supplies to all rights existing as of January 1, 1950. The remaining unused and unappropriated water is allocated to Wyoming and Montana as follows:

Clarks Fork of the Yellowstone River:

Wyoming . . . . . . 60%
Montana . . . . . . 40%

Bighorn River (excluding the Little Bighorn):

Wyoming . . . . . . 80%
Montana . . . . . . 20%

Tongue River:

Wyoming . . . . . . 40%
Montana . . . . . . 60%

Powder River (including the Little Powder):

Wyoming . . . . . . 42%
Montana . . . . . . 58%

Two other salient provisions are:
Article VI, which provides that the compact shall not adversely affect "any rights to the use of the waters of Yellowstone River and its tributaries owned by or for Indians, Indian tribes, and their reservations;" and Article X, which provides that, "No water shall be diverted from the Yellowstone River Basin without the unanimous consent of all signatory States."

AVAILABLE WATER RESOURCES

The amount of water available for use in Wyoming was estimated for the Bighorn River and Clarks Fork under the allocations of the Yellowstone River Compact, and for the Little Bighorn River which is not allocated by an interstate stream compact. Stream-gage records at compact gages were adjusted for the effects of full use of pre-1950 water rights to estimate the unused and unappropriated water. Then supplemental water supplies were estimated, and the remaining unused and unappropriated water apportioned between Wyoming and Montana.

Apportionment of Bighorn River water was calculated by:

1. Correcting the recorded 1948-1968 streamflows at Bighorn, Montana for developments that affected streamflow for only a portion of the study period such as the filling of Boysen Reservoir and Bighorn Lake.

2. Deducting uses of pre-1950 water rights that have not yet consummated, such as the Riverton Project extensions and scattered small irrigation developments, and industrial use of Boysen Reservoir water. The total unused and unappropriated water was determined to average 2.2 to 2.4 million acre-feet per year.

3. Deducting depletions from potential supplemental water supplies for pre-1950 rights. Supplemental irrigation depletions vary, by estimate, from 67,700 to 98,800 acre-feet per year. The remaining unused and unappropriated water is 2.1 to 2.3 million acre-feet per year. Wyoming's 80-percent allocation is about 1.8 million acre-feet per year.

Additional reservoir capacity is required for Wyoming to use her full compact apportionment on a firm basis. Bighorn Lake could provide a part of the water supply regulation.

The estimated average depletable unused and unappropriated water in the Clarks Fork drainage is 714,000 acre-feet per year. Wyoming's 60-percent share is 429,000 acre-feet. Storage is required to develop Wyoming's annual compact share. During a drought period such as 1960, Wyoming's compact uses without reservoir storage would be limited to 295,600 acre-feet, which is about 70 percent of the average compact allocation.

The Little Bighorn River and its tributaries are excluded from the Yellowstone River Compact. Wyoming's development of these supplies is limited to the dependable water supply in Wyoming over and above existing uses. The average streamflow leaving Wyoming from the Little Bighorn River and its tributaries is estimated to be 133,900 acre-feet per year.

GROUNDWATER

The greatest well yields are reported from the Flathead formation, the Madison limestone, the Tensleep sandstone, and the Wind River formation. It is estimated that as much as 928,000 acre-feet of groundwater are available from wells from the unconsolidated alluvium in the report area. By major study area this is:

| Study Area | Acre-Feet Groundwater Available to Wells |
|---|---|
| Wind River | 330,000 |
| Bighorn River | 570,000 |
| Clarks Fork | 28,000 |
| Little Bighorn River | --- |
| Total | 928,000 |

An enormous quantity of water is available in shallow underground storage in bedrock (within 1,000 feet of the surface). It is estimated that 85,000,000 acre-feet of groundwater is available from the uppermost 1,000 feet of Tertiary formations in the report area.

Water quality generally is better near the outcrop (recharge) areas and deteriorates towards the centers of the geologic basins. Sulfate is a common constituent in groundwater in much of the entire report area. Relatively high TDS concentrations are also common. Occurrences of selenium are reported in the Gas Hills Uranium District.

Groundwater is used for domestic, livestock, municipal, industrial, irrigation, and other uses. An estimated 4,000-5,000 acre-feet of groundwater are consumed annually by domestic and livestock uses. The total municipal population in the report area is approximately 43,300 persons. Of this number, about 17,100 persons are entirely dependent upon groundwater for water supplies. The depletion attributed to this use is about 1,700 acre-feet per year.

Industry uses a large quantity of groundwater. The petroleum industry injects about 30,000 acre-feet of groundwater annually into oil-bearing formations to produce oil by secondary recovery methods. The injected water is considered to be consumed. The uranium industry consumes about 1,000 acre-feet annually in the milling process.

Approximately 6,140 acres of irrigated land in the report area used groundwater as the original supply in 1970. An estimated 9,800 acre-feet of groundwater were consumed in this use, and an additional 3,000 acre-feet were consumed as supplemental supplies.

An estimated 16,800 acre-feet of groundwater issuing from springs near the towns of Cody and Tensleep support fish hatcheries in the Basin.

The industrial use of groundwater in the uranium sector is projected to increase 15-fold (to 15,000 acre-feet) by the year 2000. Use by the petroleum industry is projected to decrease. The total amount of groundwater consumptively used annually by industry in the year 2000 is projected to be about 24,800 acre-feet. It is estimated that about 500 acres of new land will be irrigated annually with groundwater, and that there will be a total of 21,000 acres of land in the Basin irrigated with groundwater as the original supply by the year 2000. It is conceivable that geothermal steam, or very hot thermal springs, may be discovered and may be utilized to produce electricity, with potable water as a byproduct.

AGRICULTURE

Agriculture is an expanding industry in the Basin as the result of conservation programs, improved technology, and the use of feed additives, fertilizers, pesticides, and modern farm machinery. There are about 2,600 acres of dry cropland hay and grain and 1,400 acres of summer fallow in the Basin. There are a total of 538,830 acres of irrigated land, of which 29,190 acres are classed as idle. The agricultural enterprises with the greatest potential for future expansion are livestock production, mainly beef, and the feed grains and forage crops needed to support the livestock industry. Projected national needs indicate no additional lamb and mutton production by 1980. An increase in lamb and mutton production by the year 2020 is projected. National beef and veal production is projected to increase by about 142 percent by 2020.

Historical trends and Wyoming's share of national production are the basis for projecting changes in land use and crop distribution. Irrigated acreage is projected to increase from 538,830 acres at present to 675,500 acres by 2020. The number of potentially irrigable acres in the Basin is 875,674.

Most of the water presently used in the Basin is for irrigation. The consumptive use of irrigation water is about 1,029,000 acre-feet per year. This is projected to increase to 1,398,000 acre-feet by 2020. The increased water used would include supplemental supplies for presently water-short lands and uses on new lands.

PETROLEUM

The petroleum industry provides a significant payroll in Wyoming and provides a major tax base for the State. The industry apparently has a finite limit of resources and is projected to decline. In 1967 the industry consumed 26,900 acre-feet of water in the report area. Water uses are projected to decline by 1980.

URANIUM

Approximately 77 percent of the uranium ore mined in Wyoming comes from open-pit mines. Wyoming ranks first in the United States in tons of ore reserves and second in tons mined per year. In 1967 the Gas Hills Uranium District accounted for about 40 percent of Wyoming's total uranium production. The industry consumed almost 1,000 acre-feet of water in 1967 and is expected to consume 15,000 acre-feet per year by 2000. Groundwater sources probably will supply all the water needed.

COAL

At present the coal industry is a minor part of the Basin's mineral industries. Although most of the growth of Wyoming's coal industry will occur in other areas of the State due to larger and more readily available reserves, some growth will occur in the Basin. The two steam electric plants projected for the Basin will require an estimated 30,000 acre-feet of water per year by 2000.

NONFUEL MINERALS AND TIMBER

Gypsum, bentonite, phosphate, and copper are now or are projected to become economically important in the Basin. The development of these minerals and timber will require minor amounts of water.

MUNICIPAL, DOMESTIC, AND STOCK WATER

Nearly 98 percent of the people (43,273 persons) residing in towns in the Basin have municipal water systems. The other 2 percent (980 persons) use private systems. About 61 percent of the people (27,110 persons) in towns use surface water, and 39 percent (17,143 persons) use groundwater. Water requirements for municipal, domestic, and stock uses are:

| | 1970 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Basin Population | 68,427 | 84,100 | 127,300 | 175,300 |
| Municipal and Domestic | | | | |
| Diversion, A-F/year | 13,700 | 16,800 | 25,500 | 35,100 |
| Consumption, A-F/year | 6,900 | 8,400 | 12,700 | 17,500 |
| Stock Water Depletion, Acre-Feet/year | 6,400 | 6,900 | 8,400 | 9,900 |
| Total Depletion, A-F/yr. | 13,300 | 15,300 | 21,100 | 27,400 |

RECREATION AND FISH AND WILDLIFE

Outdoor recreation, including fishing and hunting, is of increasing economic importance in the Basin. The largest fishing pressure, in terms of fisherman-days, occurs on the lowland reservoirs such as Boysen Reservoir, Bighorn Lake (Yellowtail Reservoir), Buffalo Bill Reservoir, and Ocean Lake. The second most popular type of fishing in the Basin is stream fishing, followed in order by alpine lakes, alpine reservoirs, trout farm ponds, lowland lakes, nontrout farm ponds, and mixed farm ponds.

An economic study in 1966 indicated that fishing generated a total income of $3,835,455 to the five counties within the report area. The resident fisherman spends an average of $220 per year and the nonresident fisherman spends $142 annually during his stay in Wyoming. The total annual fishing capacity for sport fishing is estimated to be 80,756.8 fisherman-days for streams and 406,022.3 fisherman-days for lakes, reservoirs, and ponds. The economic study indicated that hunting generated a total annual income $7,786,341 to the five counties of the report area.

The level of fishing in Wyoming is projected to increase 28 percent from 1967 to 1985. Stream fisheries in the Basin could support 3 times the fishing pressure they presently receive without necessitating management changes. Lowland reservoirs could support nearly 4 times the present pressure. Alpine lakes and reservoirs could support 4.3 to 4.8 times the present pressure. The demand for hunting opportunities in the Basin is expected to increase substantially during the next 30 years.

The Wyoming position regarding scenic rivers is given in An Outdoor Recreation Plan for Wyoming, October, 1970: "The State of Wyoming has taken the position that it is the State's responsibility to administer the rivers within its boundaries, and that development of scenic rivers programs and other similar programs affecting the water of Wyoming should be under jurisdiction of the State." The Shoshone, Wind, and Upper Popo Agie Rivers were suggested (1970) in the State Recreation Plan for designation as scenic rivers, and a portion of the Clarks Fork has since been proposed for such designation.

The present consumptive uses assigned directly to recreation and fish and wildlife activities are small. Recreation uses are largely nonconsumptive, although some stock pond evaporation could probably be assigned to wildlife use.

## FLOOD CONTROL

Bighorn Lake has 250,000 acre-feet of storage allocated to joint use which includes flood control. Boysen Reservoir is operated to use 150,000 acre-feet of storage as a joint use including flood control. The water right records of only two reservoirs in the Basin, Bighorn Lake and Tensleep Reservoir, list flood control as a use.

Projects have been completed to alleviate flooding in the towns of Thermopolis and Greybull. Lander has reduced flood damages by improving urban drainage and maintaining levees. Programs have been proposed to alleviate flooding elsewhere in the Basin.

## HYDROELECTRIC POWER

The electrical energy requirements of the Basin are supplied by interconnected power systems with the power being supplied by five Federally operated hydroelectric plants. The combined generating capacity of the five plants is 277,200 kilowatts. If the large increase projected for thermal power is actually realized, additional hydropower developments that may be desired for peaking power could include the existing Buffalo Bill Reservoir in the report area and the proposed Sheep Mountain Dam above Buffalo Bill Reservoir. Another potential hydroelectric unit investigated by the USBR is the Beartooth Unit, which would include three reservoirs on the main stem of the Clarks Fork, one reservoir on Sunlight Creek, and three powerplants and related facilities. A third project proposal is to enlarge Buffalo Bill Reservoir and replace the existing Shoshone Powerplant.

SUMMARY OF WATER RESOURCE REQUIREMENTS

A summary of present and projected consumptive water uses, including both surface water and groundwater, follows:

| | Thousand Acre-Feet/Year | | | |
|---|---|---|---|---|
| Water Uses | Present | 1980 | 2000 | 2020 |
| Irrigation | 1,029 | 1,160 | 1,302 | 1,398 |
| Industrial | 28 | 30 | 56 | 47 |
| Municipal, Domestic, and Stock | 13 | 15 | 21 | 27 |
| Total | 1,070 | 1,205 | 1,379 | 1,472 |

Reservoir and stock pond evaporation consumes an additional 105,300 acre-feet per year, excluding evaporation from Bighorn Lake (Yellowtail Reservoir). If Wyoming makes use of water from this reservoir, a portion of its evaporation might be included in Wyoming's allocation under terms of the Yellowstone River Compact.

Water is available in the Basin to meet future water needs. There are places in the Basin, however, where locally available water supplies are insufficient to meet even the present needs. If a full water supply is to be provided to all present uses, water will have to be conveyed from places of surplus in the Basin to places of need. Boysen Reservoir, Bighorn Lake, and other reservoirs constructed in the Basin could provide dependable water supplies from water surplus to the needs of the Basin, for use in other areas of the State.

POTENTIAL SOURCES OF WATER

The Yellowstone River Compact allocates to Wyoming a considerable water supply in Clarks Fork and the Bighorn River, and water appears to be available for Wyoming uses from the Little Bighorn River. Although there is an abundance of water available in the Bighorn River system, developing a usable, firm supply is dependent upon the availability of storage water and storage sites. Water for new uses is presently available from Buffalo Bill, Boysen, and Bighorn Lake Reservoirs. Use of all of Wyoming's compact allocation would require the construction of additional storage, and at least a portion of the water supply would have to be diverted from Bighorn Lake or from the river system below Yellowtail Dam.

Improved irrigation efficiencies would improve crop yields, and efficiencies can be increased by use of ditch linings, pipelines, sprinkler systems, reorganization of irrigation systems, and by supplying water to lands proportionally to the crop consumptive use rate. Storage is required on most streams to store spring runoff for release during the peak consumptive use period (July and August).

Water could be obtained for preferred uses by change of use of irrigation water rights. This is not particularly desirable because the original use and its accompanying benefits are lost.

Weather modification may provide additional water supplies for new development. At this time it appears that benefits of precipitation management would accrue as supplemental water for existing water rights and uses.

Groundwater resources at shallow depths (to 700 feet below the surface) should be adequate for future domestic, stock, and municipal uses. The aquifer interval from the Tensleep formation downward through the Flathead sandstone may provide water for large yield wells for irrigation along the flanks of the Big Horn and Wind River, Owl Creek, Bridger, and other mountain uplifts. Groundwater is available to supply many industrial uses, the largest of which will be in the petroleum and uranium industries.

POTENTIAL SURFACE WATER PROJECTS

Potential surface water projects have been identified by many individuals and agencies including the Bureau of Reclamation, Bureau of Indian Affairs, and the Soil Conservation Service (and other USDA agencies). The USDA is conducting a river basin survey to assist in identifying potential conservation measures and projects. Data from these studies and additional State studies were used to identify potentials for providing supplemental water supplies and for formulating alternatives for meeting future water needs.

Study Area 1 -- Wind River

Several agencies have identified potential irrigation projects that could include over 200,000 acres of new land. On the basis of water supply studies, it is concluded that the water supply is adequate for existing irrigation and supplemental water, and for 68,500 acres of new irrigation. The development might occur in a combination of several irrigation projects that have been identified: Crow Creek, Beaver Creek, Badwater Creek, Little Wind River Unit, Riverton Project Extension (or the Midvale Project), North and South Crowheart Units, Winchester Unit, Coolidge Extension, and Shoshone Unit.

Boysen Reservoir is strategically located to provide a municipal and industrial (M & I) water supply for use adjacent to the reservoir and/or in demand areas to the east of the Wind River Basin. The amount of water available depends upon the amount of future upstream development, the amount of downstream irrigation development, and the level of sustained streamflows to be maintained in the Wind River Canyon. Considering these factors, the water supply available is between 124,000 and 268,000 acre-feet per year.

There are no legal provisions under existing Wyoming water law which require a minimum flow below a dam. Although hydropower releases currently provide a sustained flow below Boysen Dam, these releases would not necessarily continue if the water is committed to beneficial consumptive uses. Storage water could be provided for the sustained streamflow if the cost of providing the storage capacity is repaid.

Study Area 2 -- Bighorn River

The SCS has identified 642,811 acres of potentially irrigable land in Study Area 2. The limiting factor in developing these lands is a dependable water supply. Potential irrigation projects identified in Study Area 2 include the Nowood Watershed Project, Gooseberry Watershed Project, Greybull Watershed Project, Shell Creek, Sage Creek, additional Shoshone River irrigation--Polecat Bench Project and Shoshone Project Extension South, and Bighorn River potentials--Bighorn Unit, Greybull Flats, Schuster Flats, Banjo Flats, and other small tract units. Buffalo Bill Dam on the Shoshone River can be enlarged to provide water for combinations of uses including irrigation, M & I water supply, recreation, fish and wildlife, water quality control, and hydropower. Clarks Fork water could be imported to the Shoshone River to increase the M & I water supply and provide associated recreation, fish and wildlife, and water quality control benefits.

M & I water supplies can be provided from Bighorn Lake and can be diverted from the lake (Yellowtail Reservoir) or from Bighorn River below Yellowtail Dam, or even further downstream, from the Yellowstone River. The M & I water supply available from Bighorn Lake depends upon the amount of consumptive uses upstream from the reservoir, the amount of operating capacity used at Bighorn Lake, and the amount of water released for other purposes. The Wyoming Water Planning Program estimated the range of available M & I water in the Bighorn Lake to be between 648,000 and 1,002,000 acre-feet per year. It was further estimated that annual M & I water supplies of and storage sites. Water for new uses is presently available from Buffalo Bill, Boysen, and Bighorn Lake Reservoirs. Use of all of Wyoming's compact allocation would require the construction of additional storage, and at least a portion of the water supply would have to be diverted from Bighorn Lake or from the river system below Yellowtail Dam.

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217,000 acre-feet at Boysen and 672,000 acre-feet at Bighorn Lake, or a combined supply of 889,000 acre-feet, would be available. Constructing additional storage at Buffalo Bill Dam, or on the Nowood River or at other sites, could increase the total available water supply.

The U. S. Bureau of Reclamation has conducted reconnaissance investigations of alternative pipelines to convey the M & I water into the southeastern Montana-northeastern Wyoming coal fields:

1. Miles City-Gillette. A diversion of water from the Yellowstone River at Miles City, Montana would be piped 173 miles to Gillette. Besides delivering water in Montana, the pipeline would also deliver 382,000 acre-feet per year of Wyoming's allocated water to Gillette.

2. Hardin-Gillette. Water would be diverted from the Bighorn River, downstream from Yellowtail Dam, near Hardin, Montana. The 180-mile pipeline would parallel the Little Bighorn River into Wyoming, then cross the Tongue and Powder Rivers to Gillette, and would convey 416,000 acre-feet per year to Wyoming.

3. Boysen-Gillette. The Bureau studied an annual diversion of 135,000 acre-feet from Boysen Reservoir on the Bighorn River in Wyoming, 182 miles to Gillette.

The Wyoming Water Planning Program considered four additional alternatives:

a. A diversion of 175,000 acre-feet per year from the Nowood River, piped 117 miles (including a 40-mile tunnel) to Gillette.

b. A diversion of 175,000 to 382,000 acre-feet per year, from Bighorn Lake piped 202 miles (including a 16-mile tunnel) to Gillette.

c. A diversion of 175,000 acre-feet per year, from Boysen Reservoir conveyed 194 miles to the Gillette area coal fields.

d. A diversion of 175,000 acre-feet per year from Wyoming's allocation of Colorado River water. Water would be diverted from the Green River via the Platte River to the Gillette area coal fields.

<u>Study Area 3 -- Little Bighorn River</u>

There is no interstate agreement between Wyoming and Montana dividing the use of water in the Little Bighorn River. After providing for Montana irrigation, it appears that a 50,000-acre-foot-per-year water supply could be developed with a storage capacity of 50,000 acre-feet in Wyoming constructed on the Little Bighorn River near the State line.

Study Area 4 -- Clarks Fork

The Bureau of Reclamation identified the potential Beartooth hydropower project on Clarks Fork, and an irrigation project potential on Chapman Bench. A SCS watershed investigation identified a potential irrigation project on Cyclone Bar. The Wyoming Water Planning Program investigated alternatives to use Wyoming's compacted Clarks Fork water supply. These alternatives all contemplated the construction of a dam and reservoir on Clarks Fork downstream of the Clarks Fork Canyon. Irrigation on Cyclone Bar, Chapman Bench, and Kimball Bench would consume about 238,000 acre-feet of Wyoming's allocation. Diversion of water into Shoshone River with provisions for sustained streamflows below Clarks Fork Dam, located downstream from the Clarks Fork Canyon, would raise the depletion to 375,000 acre-feet per year. Increasing the diversion of water into the Shoshone River could use all of Wyoming's 429,000-acre-foot Clarks Fork allocation, but sustained flows below the dam could not be provided. An alternative to diverting water into the Shoshone River to increase the Bighorn M & I water supply would be to divert Wyoming's share of the Clarks Fork, along with other water at Miles City, Montana, into the Miles City-Gillette pipeline.

POTENTIAL GROUNDWATER DEVELOPMENT

Irrigation using groundwater probably will expand in the future. Potential groundwater projects utilizing water from the Madison limestone have been identified along the western flank of the Big Horn Mountains in the Nowood and Shell Creek drainages, and in the Crooked Creek drainage, west of Yellowtail Reservoir. The Wind River formation is a source of industrial water in the Gas Hills Uranium District.

ALTERNATIVE WATER RESOURCE DEVELOPMENTS

Three alternative approaches for the future water resource development in the Basin are:

Alternative 1 -- No water resource development. Decisions by the State on air, land, and water utilization and control, and taxation could influence development. Public policy promulgated by the State with respect to Federal planning and development programs could influence development. Limiting water resources development would restrict the level of future agricultural output of the Basin, and industrial development in the Basin and in northeastern Wyoming.

Alternative 2 -- Development of irrigation water projects and cooperative Wyoming-Montana M & I water development. Irrigation projections of 137,000 acres of new land brought into production by the year 2020 would be met in various combinations of projects given in Table V-5, and shown on Figure V-3. Supplemental irrigation water would also be provided in previously named projects. M & I water for Bighorn River Basin needs would be developed at Boysen, Buffalo Bill, and other reservoirs, and by groundwater developments. Water for the northeastern Wyoming-southeastern Montana coal fields would be provided for both states by either the Miles City-Gillette Pipeline or the Hardin-Gillette Pipeline shown on Figure V-4. One of these pipelines might be constructed as an initial means of serving coal field needs, or it might be constructed after first developing the water resources of the Tongue and Powder River Basins. The projected consumptive uses of water in the Bighorn River Basin by the year 2020 are summarized in Table V-6. The use of water within the Bighorn River Basin of Wyoming is projected to be greater than the amount of water diverted from the Bighorn River Basin to other areas of Wyoming.

Alternative 3 -- Irrigation development and M & I water development for Wyoming only. This alternative differs from Alternative 2 only in the transbasin diversion of water for northeastern Wyoming. If it is not possible or practical for Wyoming and Montana to proceed on a joint water resource development plan, the Boysen-Gillette, Nowood-Gillette, or Bighorn Lake-Gillette pipeline could be constructed to serve the Wyoming water needs.

In both Alternatives 2 and 3 the transbasin diversion of water to northeastern Wyoming may stop somewhat short of Gillette, Wyoming because of the Article X limitation in the Yellowstone River Compact on out of basin diversion.

ENVIRONMENTAL CONSIDERATIONS

Many of the alternative water resources projects would require construction of new reservoirs. Among other things, reservoir planning should include provisions for minimum reservoir pools and sustained streamflows below dams. The future operation of Buffalo Bill, Boysen, and Bighorn Lake Reservoirs may enhance or detract from current conditions of reservoir fluctuations, minimum reservoir pool, and sustained streamflows below the dams.

Environmental considerations for new canals and pipelines include provisions for fisheries control and measures for maintenance of game migration routes.

The effect of projected future water resource development on the concentration of total dissolved solids is shown in the following tabulation:

| River | Concentration of Total Dissolved Solids (ppm) | |
|---|---|---|
| | Present Conditions | Developed Conditions |
| Clarks Fork at State line | 107 | 186 |
| Bighorn River at State line | | |
| Alternative 2 | 650 | 790 |
| Alternative 3 | 650 | 800 |

Conservation practices can alleviate and improve stream sediment and turbidity problems.

# CONCLUSIONS

1. Agriculture is expanding in the Bighorn River Basin. Continued development of water supplies for supplementing presently water-short areas and for new land irrigation is required for the State and the Basin to maintain a healthy agricultural economy and to furnish Wyoming's share of food and fiber for the Nation.

2. Economic projections indicate expansion of irrigation by 137,000 acres by the year 2020 and increases in production of uranium, coal, gypsum, bentonite, and phosphate. The increased economic activity and population growth will require the consumptive use of an additional 442,000 acre-feet of water per year by 2020.

3. A considerable water supply has been allocated to Wyoming by the Yellowstone River Compact. Although there is an apparent abundance of water supply, much of the surplus water is available only in the lower reaches of the major rivers of the Basin. Storage reservoirs are necessary to control the water supply. Intrabasin water transfers are necessary to supplement water-short streams from nearby streams with water surpluses. Water supplies surplus to the needs of the Basin from compacted allocations of the Clarks Fork and Bighorn River could be made available to water-short areas of Wyoming, such as the coal fields of northeastern Wyoming.

4. Groundwater resources will continue in importance for municipal, domestic, and stock water uses, and will support increasing industrial water needs. Several areas are attractive for irrigation development using groundwater.

5. Water resource development will have beneficial and adverse impacts on the environment. The impacts of water projects on the environment need to be properly considered in design and construction. Proper project planning can result in maximizing beneficial impacts while minimizing adverse impacts.

## RECOMMENDATIONS

1. In formulating a State Water Plan, water needs of the Bighorn River Basin should be considered in conjunction with the water needs of the State of Wyoming.

2. Public opinion should be ascertained regarding the desired levels of development in the Bighorn River Basin, the economic, environmental, social, and other impacts of the alternatives, and the best alternative(s) to follow.

3. Short-range and long-range goals should be established and implementation procedures outlined.

4. Detailed feasibility studies of the desired project-components of the alternatives should be undertaken to evaluate engineering and economic factors, and social and environmental impacts.

5. Steps should be taken to obtain the necessary consent from Yellowstone River Compact states to use Yellowstone River Basin water outside the Yellowstone River Basin in Wyoming.

6. The uses of water reserved for the Wind River Indian Reservation and other Federal reserves should be defined to facilitate future water and related land resources planning.

7. Sources of financing, such as Federal funds, State loans and bonds, private sources, and others, should be reviewed. State laws should be analyzed to determine what legislation would be desirable and necessary for financing of water development projects under different types of financing arrangements.

8. The best plan should be determined from public opinion, feasibility studies, and financial considerations.

9. The type of organization required to implement and operate water development projects should be determined and established.

# CHAPTER VII

# BIBLIOGRAPHY OF SELECTED REFERENCES

# B I B L I O G R A P H Y  O F  S E L E C T E D  R E F E R E N C E S

## C H A P T E R  I


(1) Becker, C. F., Alyea, John, and Eppson, Harold, 1961, Probabilities of Freeze in Wyoming. University of Wyoming Agricultural Experiment Station Bulletin 381.

(2) Bereman, John S., 1965, Water Resources Inventory for Water Division No. 3. Prepared for the Wyoming State Engineer.

(3) Larson, T. A., 1965, History of Wyoming. University of Nebraska Press.

(4) Trelease, Frank J., Rechard, Paul A., Swartz, T. J., and Burman, R. D., 1970, Consumptive Use of Irrigation Water in Wyoming. Wyoming Water Planning Program Report No. 5, Water Resource Series No. 19.

(5) Trenholm, Virginia Cole and Carley, Maurine, 1946, Wyoming Pageant. Prairie Publishing Company.

(6) U. S. Department of Agriculture, Soil Conservation Service, 1972, Wind-Bighorn-Clarks Fork River Basin Type IV Study Summary, Wyoming State Supplement. Preliminary draft.

(7) U. S. Department of the Interior, Bureau of Indian Affairs, Indians of Montana and Wyoming. U. S. Government Printing Office, Washington, D. C.

(8) Whittenburg, Clarice, 1966, Wyoming--Prelude to Statehood. Wyoming Travel Commission and Wyoming State Department of Education.


## C H A P T E R  I I


(1) Bilyeu, Jesse A., Hunter, Carlton L., and Trelease, Frank J., January 1971, Irrigated Lands Inventory for Wyoming. Wyoming Water Planning Program Report No. 7.

(2) Bereman, John S., Consulting Engineer, 1965, Water Resources Inventory for Water Division No. 3. Prepared for the Wyoming State Engineer.

(3) Documents on the Use and Control of Wyoming's Interstate Streams, 1957, Compacts, Treaties, and Court Decrees. Compiled under the direction of Earl Lloyd, State Engineer, and Paul A. Rechard, Interstate Streams Commissioner.

(4) Missouri Basin Inter-Agency Committee, June 1969, Comprehensive Framework Study Appendix, Hydrologic Analyses and Projections. Final Draft.

(5) State Board of Control, April 1963, Tabulation of Adjudicated Water Rights of the State of Wyoming, Water Division No. 2. Supplement, April 1963 to May 1, 1966. Supplement, May 1, 1966 to November 1, 1968.

(6) ___________________, November 1964, Tabulation of Adjudicated Water Rights of the State of Wyoming, Water Division No. 3. Supplement, November 1, 1964 to May 1, 1966. Supplement, May 1, 1966 to November 1, 1968.

(7) Streeter, Robert L., Consulting Engineer, 1965, Water Resources Inventory for Water Division No. 2. Prepared for the Wyoming State Engineer.

(8) Trelease, Frank J., Bloomenthal, Harold S., Geraud, Joseph R., 1965, Cases and Materials on Natural Resources. American Casebook Series.

(9) Trelease, Frank J., Rechard, Paul A., Swartz, T. J., and Burman, R. D., 1970, Consumptive Use of Irrigation Water in Wyoming. Wyoming Water Planning Program Report No. 5, Water Resources Series No. 19.

(10) U. S. Department of Agriculture, July 1971, Gooseberry Creek. Watershed Investigation Report.

(11) ____________________, March 1972, Lower Greybull River. Watershed Investigation Report.

(12) ____________________, March 1971, Cyclone Bar. Watershed Investigation Report.

(13) ____________________, July 1970, Midvale. Watershed Investigation Report.

(14) ____________________, May 1971, Nowood River. Watershed Investigation Report.

(15) ____________________, July 1970, Upper Badwater Creek. Watershed Investigation Report.

(16) ____________________, February 1970, Upper Beaver Creek. Watershed Investigation Report.

(17) ____________________, June 1971, Crooked Creek. Watershed Investigation Report.

(18) ____________________, July 1970, Crow Creek. Watershed Investigation Report.

(19) ____________________, July 1972, Lower Shell Creek. Watershed Investigation Report.

(20) ____________________, October 1969, Middle Popo Agie River Watershed. General Status Report.

(21) ____________________, January 1965, Upper and Lower Shell Creek Watershed. Preliminary Investigation Report.

(22) ____________________, (undated), Riverton Watershed. Preliminary Investigation Report.

## CHAPTER III

(1) Berry, Delmar W. and Littleton, Robert T., 1961, Geology and Groundwater Resources of the Owl Creek Area, Hot Springs County, Wyoming. U. S. Geological Survey Water Supply Paper 1519.

(2) Crawford, James G., Rocky Mountain Oil Field Water, Section 3 - Bighorn Basin.

(3) Hem, John D., 1970, Study and Interpretation of the Chemical Characteristics of Natural Water. U. S. Geological Survey, Water Supply Paper 1473.

(4) Keefer, William R., 1961, Waltman shale and Shotgun members of Fort Union formation (Paleocene) in Wind River Basin, Wyoming, in Bulletin of the American Association of Petroleum Geologists, Vol. 45, No.8.

(5) Love, J. D., 1954, Preliminary Report on Uranium in the Gas Hills Area, Fremont and Natrona Counties, Wyoming. U. S. Geological Survey Circular 352.

(6) Lowry, Marlin E., 1962, Development of Groundwater in the Vicinity of Tensleep, Wyoming. U. S. Geological Survey open file report.

(7) McGreevy, Laurence J., Hodson, Warren G., and Rucker, Samuel J., IV, 1969, Groundwater Resources of the Wind River Indian Reservation. U. S. Geological Survey Water Supply Paper 1576-I.

(8) Montana Water Resources Board, 1969, Groundwater Inventory, Carbon County, Montana.

(9) Morris, D. A. Hackett, O. M., Vanlier, K. E., and Moulder, E. A., 1959, Groundwater Resources of Riverton Irrigation Project Area, Wyoming, with a section on chemical quality of groundwater by W. H. Durum. U. S. Geological Survey Water Supply Paper 1375.

(10) Moulder, E. A., Klug, M. F., Morris, D. A., and Swenson, F. A., 1960 Geology and Groundwater Resources of the Lower Little Bighorn River Valley, Big Horn County, Montana with a section on chemical quality of the water by R. A. Krieger. U. S. Geological Survey Water Supply Paper 1487.

(11) Robinove, Charles J., and Langbord, Russell H., 1963, Geology and Groundwater Resources of the Greybull River - Dry Creek Area, Wyoming 1963. U. S. Geological Survey Water Supply Paper 1596.

(12) Swenson, Frank A., 1957, Geology and Groundwater - Heart Mountain and Chapman Bench Division, Shoshone Irrigation Project, Wyoming, with a section on chemical quality of the water by Herbert A. Swenson. U. S. Geological Survey Water Supply Paper 1418.

(13) Swenson, Frank A., and Bach, W. Kenneth, 1951, Groundwater Resources of the Paint Rock Irrigation Project, Wyoming, with a section on the quality of the water by Herbert A. Swenson. U. S. Geological Survey Circular 96.

(14) Whitcomb, Harold A., and Lowry, Marlin E., Groundwater Resources and Geology of the Wind River Basin Area, Central Wyoming. U. S. Geological Survey Hydrologic Investigations Atlas HA-270.

(15) Wyoming Geological Association, 1952, 7th Annual Field Conference, Southern Bighorn Basin.

(16) Wyoming Geological Survey in cooperation with the Wyoming Department of Economic Planning and Development, 1972, Energy Resources Map of Wyoming.

(17) Wyoming Geological Survey (The Geological Survey of Wyoming), 1966, Mineral Resources of Wyoming: Bulletin No. 50.

## C H A P T E R  I V

(1) Bishop and Spurlock, Consulting Engineers, 1962, Report on Water Resources in the Wind River Basin. Submitted to the Wyoming Natural Resources Board.

(2) Blood, Dwight M. and Phillips, Clynn, 1969, Outdoor Recreation in Wyoming, Volume II--Outdoor Recreation Participation by Out-of-State Visitors in Wyoming. Prepared for the Wyoming Recreation Commission by the Division of Business and Economic Research, College of Commerce and Industry, University of Wyoming, Laramie, Wyoming.

(3) Blood, Dwight M., Phillips, Clynn, and Moewes, David S., 1969, Outdoor Recreation in Wyoming, Volume III - Recreation Boating in Wyoming's Lakes and Reservoirs. Prepared for the Wyoming Game and Fish Commission and the Wyoming Recreation Commission by the Division of Business and Economic Research, College of Commerce and Industry, University of Wyoming, Laramie, Wyoming.

(4) Cameron Engineers, 1969, Review and Forecast--Wyoming Mineral Industries. A report prepared for the Wyoming Natural Resource Board and the State Water Planning Program.

(5) Morgan, William E., Pearl, Margaret W., and Barker, Florence F., December 1969, Demographic Study of Wyoming, Population in Transition. University of Wyoming.

(6) North Central Power Study, Report of Phase I, Volume I, October 1971. Prepared under the direction of Coordinating Committee, North Central Power Study.

(7) Olson, Carl E., Morgan, William E., and Marquardt, Raymond A., August 1971, University of Wyoming.

(8) U. S. Army Corps of Engineers, January 1969, Water Resource Developments in Wyoming.

(9) U. S. Department of Agriculture, July 1971, Gooseberry Creek. Watershed Investigation Report.

(10) ________________, March 1972, Lower Greybull River. Watershed Investigation Report.

(11) ________________, March 1971, Cyclone Bar. Watershed Investigation Report.

(12) ________________, July 1970, Midvale. Watershed Investigation Report.

(13) ________________, May 1971, Nowood River. Watershed Investigation Report.

(14) ________________, July 1970, Upper Badwater Creek. Watershed Investigation Report.

(15) ________________, February 1970, Upper Beaver Creek. Watershed Investigation Report.

(16) ________________, June 1971, Crooked Creek. Watershed Investigation Report.

(17) ________________, July 1970, Crow Creek. Watershed Investigation Report.

(18) ________________, July 1972, Lower Shell Creek. Watershed Investigation Report.

(19) ________________, October 1969, Middle Popo Agie River Watershed. General Status Report.

(20) ________________, January 1965, Upper and Lower Shell Creek Watersheds. Preliminary Investigation Report.

(21) ________________, (undated), Riverton Watershed. Preliminary Investigation Report.

(22) U. S. Department of Agriculture, Statistical Reporting Service, Crop Reporting Board, Agricultural Prices, various issues. U. S. Government Printing Office, Washington, D. C.

(23) U. S. Department of Commerce, U. S. Bureau of the Census, October 1971, Census of Agriculture 1969, County Data.

(24) U. S. Department of Interior, Bureau of Reclamation, Region 6, Billings, Montana, 1971, Description of Bureau of Reclamation Projects in the Region 6 Portion of Wyoming.

(25) Western Engineers-Architects, Inc., 1969, The Comprehensive Plan for Water and Sewerage in Big Horn County, Wyoming.

(26) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Fremont County, Wyoming.

(27) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Hot Springs County, Wyoming.

(28) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Park County, Wyoming.

(29) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Washakie County, Wyoming.

(30) Wyoming Game and Fish Commission, April 1971, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Big Game and Upland Game for District 6, Game Division. Planning Report No. 6G.

(31) __________________, October 1970, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fur Animals-Predators for State of Wyoming. Planning Report No. 8G.

(32) __________________, December 1970, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Big Game and Upland Game for District 2, Game Division. Planning Report No. 2G.

(33) __________________, March 1972, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fisheries for Management Area 2A, Fish Division. Planning Report No. 2F.

(34) __________________, February 1972, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fisheries for Management Area 2, Fish Division. Planning Report No. 2F.

(35) __________________, Wyoming Recreation Commission, 1970, An Outdoor Recreation Plan for Wyoming.

(36) Wyoming State Board of Equalization, Twenty-Sixth Biennial Report 1969-1970.

(37) Wyoming Water Planning Program, March 1970, Tabulation of Existing Wyoming Reservoirs over 500 Acre-Feet Capacity. Wyoming Water Planning Report No. 4.

(38) Wyoming Water Planning Program, July 1970, Consumptive Use of Irrigation Water in Wyoming. Wyoming Water Planning Report No. 5.

## C H A P T E R V

(1) Berry, Delmar W., and Littleton, Robert T., 1961, Geology and Groundwater Resources of the Owl Creek Area, Hot Springs County, Wyoming. U. S. Geological Survey Water Supply Paper 1519.

(2) Bereman, John S., Consulting Engineer, 1965, Water Resources Inventory for Water Division No. 3. Prepared for the Wyoming State Engineer.

(3) Bilyeu, Jesse A., Hunter, Carlton L., and Trelease, Frank J., January 1971, Irrigated Lands Inventory for Wyoming. Wyoming Water Planning Program Report No. 7.

(4) Bishop and Spurlock, Consulting Engineers, 1962, Report on Water Resources in the Wind River Basin. Submitted to the Wyoming Natural Resources Board.

(5) Blood, Dwight M. and Phillips, Clynn, 1969, Outdoor Recreation in Wyoming, Volume II--Outdoor Recreation Participation by Out-of-State Visitors in Wyoming. Prepared for the Wyoming Recreation Commission by the Division of Business and Economic Research, College of Commerce and Industry, University of Wyoming, Laramie Wyoming.

(6) Blood, Dwight M., Phillips, Clynn, and Moewes, David S., 1969, Outdoor Recreation in Wyoming. Volume III--Recreational Boating in Wyoming's Lakes and Reservoirs. Prepared for the Wyoming Game and Fish Commission and the Wyoming Recreation Commission by the Division of Business and Economic Research, College of Commerce and Industry, University of Wyoming, Laramie, Wyoming.

(7) Cameron Engineers, 1969, Review and Forecast--Wyoming Mineral Industries. A report prepared for the Wyoming Natural Resource Board and the State Water Planning Program.

(8) Documents on the Use and Control of Wyoming's Interstate Streams, 1957, Compacts, Treaties, and Court Decrees. Compiled under the direction of Earl Lloyd, State Engineer and Paul A. Rechard, Interstate Streams Commissioner.

(9) Linsley, R. K., and Franzini, J. B., 1964, Water-Resources Engineering. McGraw-Hill Book Company.

(10) Linsley, R. K., Kohler, M. A., and Paulhus, J. L., 1958, Hydrology for Engineers. McGraw-Hill Book Company.

(11) Lockwood, Andrews, and Newman, Inc., 1967, Cost of Transporting Water by Pipeline. Prepared for the Texas Water Development Board.

(12) Lowry, Marlin E., 1962, Development of Groundwater in the Vicinity of Tensleep, Wyoming. U. S. Geological Survey open file report.

(13) McGraw-Hill, Inc., 1970, Dodge Estimating Guide for Public Works Construction.

(14) Missouri Basin Inter-Agency Committee, June 1969, Comprehensive Framework Study Appendix, Hydrologic Analyses and Projections Final Draft.

(15) Morgan, William E., Pearl, Margaret W., and Barker, Florence F., December 1969, Demographic Study of Wyoming, Population in Transition.

(16) North Central Power Study, Report of Phase I, Volume I, October 1971. Prepared under the direction of Coordinating Committee, North Central Power Study.

(17) Olson, Carl E., Morgan, William E., and Marquardt, Roy A., September 1970, Agricultural Sector Study.

(18) Robinove, Charles J., and Langbord, Russell H., 1963, Geology and Groundwater Resources of the Greybull River - Dry Creek Area, Wyoming 1963. U. S. Geological Survey Water Supply Paper 1596.

(19) State Board of Control, April 1963, Tabulation of Adjudicated Water Rights of the State of Wyoming, Water Division No. 2. Supplement, April 1963 to May 1, 1966. Supplement, May 1, 1966 to November 1, 1968.

(20) ____________________, November 1964, Tabulation of Adjudicated Water Rights of the State of Wyoming, Water Division No. 3. Supplement, November 1, 1964 to May 1, 1966. Supplement, May 1, 1966 to November 1, 1968.

(21) Streeter, Robert L., Consulting Engineer, 1964, Water Resources Inventory for Water Division No. 2. Prepared for the Wyoming State Engineer.

(22) Trelease, Frank J., Bloomenthal, Harold S., Geraud, Joseph R., 1965, Cases and Materials on Natural Resources. American Casebook Series.

(23) Trelease, Frank J., 1972, Federal-State Relations in Water Law, Prepared for the National Water Commission, National Technical Information Service, Springfield, Virginia.

(24) Trelease, Frank J. III, Rechard, Paul A., Swartz, T. J., and Burman, R. D., 1970, Consumptive Use of Irrigation Water in Wyoming. Wyoming Water Planning Program Report No. 5, Water Resources Series No. 19.

(25) U. S. Army Corps of Engineers, January 1969, Water Resource Developments in Wyoming.

(26) U. S. Department of Agriculture, July 1971, Gooseberry Creek. Watershed Investigation Report.

(27) ________________, March 1972, Lower Greybull River. Watershed Investigation Report.

(28) ________________, March 1971, Cyclone Bar. Watershed Investigation Report.

(29) ________________, July 1970, Midvale. Watershed Investigation Report.

(30) ________________, May 1971, Nowood River. Watershed Investigation Report.

(31) ________________, July 1970, Upper Badwater Creek. Watershed Investigation Report.

(32) ________________, February 1970, Upper Beaver Creek. Watershed Investigation Report.

(33) ________________, June 1971, Crooked Creek. Watershed Investigation Report.

(34) ________________, July 1970, Crow Creek. Watershed Investigation Report.

(35) ________________, (undated), Lower Shell Creek. Watershed Investigation Report.

(36) ________________, October 1969, Middle Popo Agie River Watershed. General Status Report.

(37) ________________, January 1965, Upper and Lower Shell Creek Watersheds. Preliminary Investigation Report.

(38) ________________, (undated), Riverton Watershed. Preliminary Investigation Report.

(39) ________________, June 1972, Sage Creek--Pryor Mountain. Watershed Investigation Report.

(40) ________________, February 1972, Wind-Bighorn-Clarks Fork River Basin Summary, Wyoming State Supplement.

(41) ________________, Statistical Reporting Service, Crop Reporting Board, Agricultural Prices, various issues. U. S. Government Printing Office, Washington, D. C.

(42) U. S. Department of Commerce, U. S. Bureau of the Census, October 1971, Census of Agriculture 1969, County Data.

(43) ________________, May 1967, Potential Irrigation Development. Missouri River Basin Reservations, Report No. 185, Appendix No. 1, Wind River Reservation.

(44) U. S. Department of Interior, Bureau of Indian Affairs, Missouri River Basin Investigation Project, Billings, Montana, May 1967, Potential Irrigation Development, Missouri River Basin Reservations, Report No. 185, Appendix No. 2, Crow Reservation.

(45) ________________, 1971, Land and Water Inventory, Wind River Indian Reservation Natural Resources, Wind River Agency, Fort Washakie, Wyoming.

(46) U. S. Department of Interior, Bureau of Reclamation, Region 6, Billings, Montana, 1971, Description of Bureau of Reclamation Projects in the Region 6 Portion of Wyoming.

(47) ________________, March 1964, Boysen Afterbay, Wyoming, Reconnaissance Report, Missouri River Basin Project.

(48) ________________, Rev. July 1967, Polecat Bench Area, Shoshone Extension Unit, Bighorn Basin Division--Wyoming Missouri River Basin Project.

(49) ________________, Rev. September 1968, Plans for Modification of Buffalo Bill Dam, Wyoming Shoshone Project.

(50) ________________, March 1962, Report on Bighorn Basin Division, Wyoming Missouri River Basin Project, and Appendixes I-IV.

(51) ________________, (undated), Report on Clarks Fork Division.

(52) ________________, October 1966, Report on Wind River Division, Wyoming Missouri River Basin Project.

(53) ________________, June 1952, Preliminary Draft, Definite Plan Report Hanover Unit--Wyoming, Volume I-General Plan, Missouri River Basin Project Bighorn Basin Division.

(54) ________________, November 1953, Definite Plan Report Bluff Unit--Wyoming, Volume I-General Plan, Missouri River Basin Project Bighorn Basin Division.

(55) ________________, 1971, Description of Bureau of Reclamation Projects and Plans in the Region 6 Portion of Wyoming.

(56) ________________, 1965, Design of Small Dams, U. S. Government Printing Office.

(57) ________________, 1969, Reclamation Instruction Series 150, Estimating.

(58) Western Engineers-Architects, Inc., 1969, The Comprehensive Plan for Water and Sewerage in Big Horn County, Wyoming.

(59) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Fremont County, Wyoming.

(60) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Hot Springs County, Wyoming.

(61) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Park County, Wyoming.

(62) ________________, 1969, The Comprehensive Plan for Water and Sewerage in Washakie County, Wyoming.

(63) Whitcomb, Harold A., Lowry, Marlin E., Groundwater Resources and Geology of the Wind River Basin Area, Central Wyoming. U. S. Geological Survey Hydrologic Investigations Atlas HA-270.

(64) Wyoming Game and Fish Commission, April 1971, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Big Game and Upland Game for District 6, Game Division. Planning Report No. 6G.

(65) ________________, October 1970, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fur Animals-Predators for State of Wyoming. Planning Report No. 8G.

(66) ________________, December 1970, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Big Game and Upland Game for District 2, Game Division. Planning Report No. 2G.

(67) ________________, March 1972, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fisheries for Management Area 2A, Fish Division. Planning Report No. 2F.

(68) ________________, February 1972, Wyoming Fish and Wildlife Plan--Current Status and Inventory, Fisheries for Management Area 2, Fish Division. Planning Report No. 2F.

(69) Wyoming Recreation Commission, 1970, An Outdoor Recreation Plan for Wyoming.

(70) Wyoming State Board of Equalization, Twenty-Sixth Biennial Report 1969-1970.

(71) Wyoming Water Planning Program, March 1970, Tabulation of Existing Wyoming Reservoirs over 500 Acre-Feet Capacity. Wyoming Water Planning Report No. 4.

(72) ________________, July 1970, Consumptive Use of Irrigation Water in Wyoming. Wyoming Water Planning Report No. 5.

(73) ___________________, September 1970, Water and Related Land Resources of the Green River Basin, Wyoming. Wyoming Water Planning Report No. 3.

(74) ___________________, September 1971, Water and Related Land Resources of the North Platte River Basin, Wyoming. Wyoming Water Planning Report No. 9.

(75) ___________________, April 1972, Water and Related Land Resources of Northeastern Wyoming. Wyoming Water Planning Report No. 10.