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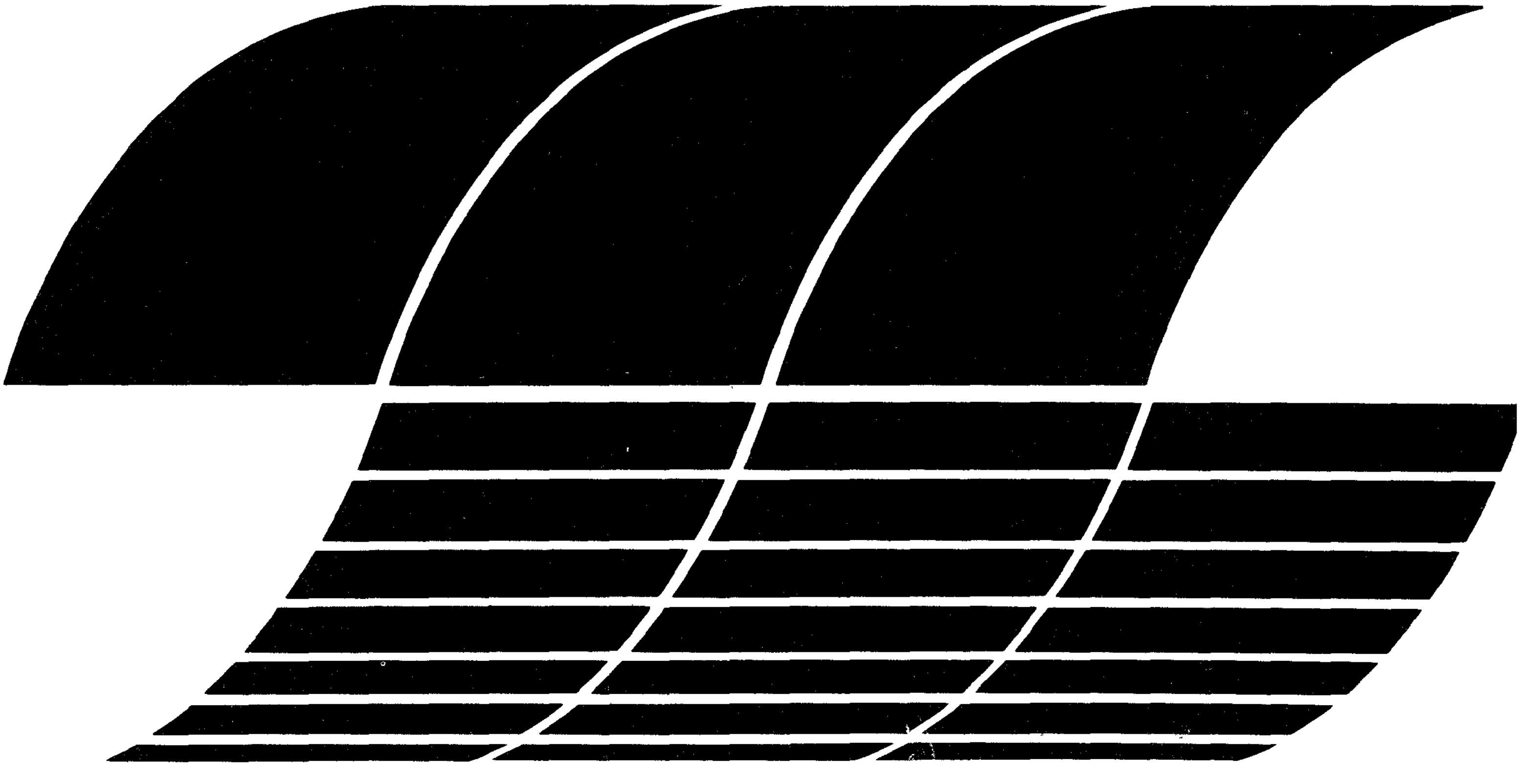
Assessment of Energy Resource Development Impact on Water Quality

The Yampa and White River Basins

Interagency Energy-Environment Research and Development Program Report



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ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY

The Yampa and White River Basins

by

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FOREWORD

Protection of the environment requires effective regulatory actions based on sound technical and scientific data. The data must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of exposure to specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring Systems Laboratory at Las Vegas contributes to the formation and enhancement of a sound monitoring-data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents an evaluation of surface water quality in the Yampa and White River Basins and discusses the impact of energy development upon water quality and water availability. The water quality data collected to date and presented in this report may be considered baseline in nature and used to evaluate future impacts on water quality. This report was written for use by Federal, State, and local government agencies concerned with energy resource development and its impact on western water quality. Private industry and individuals concerned with the quality of western rivers may also find the document useful. This is one of a series of reports funded by the Interagency Energy-Environment Research and Development Program. For further information contact the Advanced Monitoring Systems Division, Environmental Monitoring Systems Laboratory.

Director
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada

SUMMARY

Development of fossil fuel, uranium, and other energy reserves located in the western United States is considered essential. These resources are located primarily in the Northern Great Plains and the Colorado Plateau. Because of our national dependence upon oil and gas, conversion of coal to these liquid and gaseous forms is anticipated.

Development of these resources cannot be accomplished without some environmental impact. The potential for serious degradation of air, land, or water quality exists. Pollution may occur during any or all stages of the extraction, refining, transportation, conversion, or utilization processes. Secondary impacts resulting from increased population pressures, water management, and development of supportive industries are expected. Potential contamination of ground-water supplies from in situ coal and oil shale conversion facilities, and nonpoint pollution from sources such as stack emissions, airborne dust, and localized "spills," are of particular concern in the Yampa and White River Basins. Of special concern in the White River Basin are additional impacts associated with the oil shale industry, including disposal of large volumes of solid wastes and leaching of trace elements or organics from spent shale piles. With careful planning and regulation, such impacts can be minimized and held within tolerable levels.

The primary objective of this report is to evaluate the existing water quality monitoring network in the Yampa and White River Basins and to recommend needed modifications to the present sampling program. As a basis for these recommendations, present and planned developments are discussed and available data examined. The impact of developers on water quality and quantity is defined, particularly related to coal strip mining activities in the vicinity of Craig and oil shale activities in the Piceance Creek Basin.

A monitoring network designed to detect trends in surface water quality is proposed on the basis of our present knowledge. Such a network minimizes the number of observations at the expense of the number of stations in order to provide statistically valid data. This network consists of 13 stations:

USGS Station #	Description
09236000	Bear River near Toponas, Colo.
09244410	Yampa River below diversion, near Hayden, Colo.
09247600	Yampa River below Craig, Colo.
09251000	Yampa River near Maybell, Colo.
09260000	Little Snake River near Lily, Colo.
09260050	Yampa River at Deer Lodge Park, Colo.
09303000	North Fork White River at Buford, Colo.

USGS Station #	Description
09304500	White River near Meeker, Colo.
09304800	White River below Meeker, Colo.
09306222	Piceance Creek at White River, Colo.
401022108241200	White River below Yellow Creek, Colo.
09306500	White River near Watson, Utah
09306900	White River at mouth near Ouray, Utah

A similar network for ground-water monitoring needs to be implemented, particularly in the Piceance Basin; however, presently available data are insufficient to adequately determine specific station locations.

Those biological, physical, and chemical parameters likely to be affected by energy resource development activities were determined. Salinity and suspended sediment concentrations are already a problem in both study basins, and nutrient levels are sufficiently high in the downstream White River that any reservoir construction associated with energy development would likely result in excessive algal growth conditions. Physical and chemical parameters recommended as top priority for monitoring are:

Total alkalinity

Total aluminum

Total ammonia

Total arsenic

Total beryllium

Bicarbonate

Total boron

Total cadmium

Dissolved calcium

Chloride

Total chromium

Specific conductance

Total copper

Total cyanide

Flow

Total mercury

Total molybdenum

Total nickel

Nitrate-nitrite

Dissolved oxygen

Pesticides

Petroleum hydrocarbons

pH

Total phosphorus

Dissolved potassium

Total selenium

Dissolved sodium

Dissolved sulfate

Susended sediments

Temperature

Fluoride

Total iron

Total lead

Dissolved magnesium

Total manganese

Total dissolved solids

Total organic carbon in bottom sediments

Biochemical oxygen demand in bottom sediments

Biological monitoring is considered to be presently the most feasible method of assessing the impact of the introduction of an extensive number of organic chemicals into the environment such as may result from in situ coal conversion activities. These biological analyses recommended as having top priority for monitoring water quality in the Yampa and White River Basins include:

Macroinvertebrates - Counts and identifications, biomass

Periphyton - Biomass, growth rate, identification, and relative abundance determinations

Fish - Identification and enumeration, toxic substances in tissue

Macrophytes - Species identification and community association

Zooplankton (lentic only) - Identification and count

Phytoplankton (lentic only) - Chlorophyll *a*, identification, and enumeration

Microorganisms - Total fecal coliform

To obtain sufficient data for trend analyses, collection of physical/chemical parameters on a weekly basis at the Yampa River station at Maybell and White River station near Watson is recommended. If resources permit, continuous monitoring in the White River downstream from the Colorado oil shale tracts in Yellow and Piceance Creek confluences, and in the Yampa River downstream from the cluster of mining developments below Craig, would be desirable. All other priority stations should collect physical/chemical data on a monthly basis to provide spatial distribution data. Suspended sediment samples should be collected on a monthly basis, and biological samples on a seasonal or semiannual basis (except for monthly bacteriological analyses). Semiannual water samples for organic analyses are recommended. There is an additional need for establishment of intensive source specific monitoring, particularly at the coal mine sites in the Yampa Basin. Such source monitoring would determine which pollution control methods need to be implemented at each mining site, and whether those control procedures already implemented are effective.

In both the Yampa and White River Basins, economic considerations aside, water availability will be the major factor limiting future developments. The oil shale industry in particular will consume a tremendous volume of water. Interbasin transport of water from sources in the Colorado River Basin, expanded use of regional ground-water resources in the Piceance Basin, and reallocation of existing irrigation water rights, are mechanisms expected to assume increasing importance in meeting anticipated industrial water demands in the study area. A large number of additional storage facilities have also been proposed for both study basins to meet anticipated water requirements. If constructed, these impoundments will drastically alter seasonal streamflow patterns, fisheries, and water quality of the basins. Of particular concern is the impact such reservoir construction would have on several threatened and endangered fish species endemic to the area. Establishment of enforceable minimum instream flow requirements in both basins is recommended. It should be noted, however, that in the White River Basin, declaration of an interstate water compact between Utah and Colorado will be necessary before large scale withdrawals or watershed modifications will be feasible.

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SECTION 1

INTRODUCTION

This report is part of a multiagency study involving the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) under various interagency agreements. The primary objective of this study is to evaluate the existing water quality monitoring network in the Yampa and White River Basins of Utah, Wyoming, and Colorado and to recommend needed modifications to the present sampling program design.

As a basis for monitoring strategies recommended in this report, present and planned energy developments are defined, and available baseline data on the Basins are examined. For assessment of these monitoring strategies, the impact of ongoing and anticipated energy development on both water quality and quantity in the western energy basins is considered. Future documents will present more detailed analyses of potential impacts from various energy technologies, sampling methodologies and frequency requirements, and site alternatives in light of updated information regarding water right allocations.

Throughout the 1950's the United States was effectively energy selfsufficient, satisfying its needs with abundant reserves of domestic fuels, such as coal, oil and gas, and hydroelectric power. However, energy consumption has been increasing during the past 10 years at an annual rate of 4 to 5 percent, a per capita rate of consumption eight times that of the rest of the world (Federal Energy Administration 1974). The Federal Energy Administration (1974) in the "Project Independence" report gives the following statistics:

- By 1973, imports of crude oil and petroleum products accounted for 35 percent of total domestic consumption.
- Domestic coal production has not increased since 1943.
- Exploration for coal peaked in 1956, and domestic production of crude oil has been declining since 1970.
- Since 1968, natural gas consumption in the continental United States has been greater than discovery.

The United States now relies on oil for 46 percent of its energy needs, while coal, our most abundant domestic fossil fuel, serves only 18 percent of our total needs (U.S. Bureau of Reclamation 1977). Because we have only a few years remaining of proven oil and gas reserves, and to reduce our vulnerable dependency upon foreign oil, the Federal government is promoting the development of untapped national energy resources in anticipation of up-coming energy requirements. Included among these resources are the abundant western energy reserves. Over half of the Nation's coal reserves are located in the western United States, as well as effectively all the uranium, oil shale, and geothermal reserves. Table 1 shows the projected national annual production levels for some recently expanding energy sources through the year 2000.

TABLE 1. SUMMARY OF TOTAL PROJECTED ANNUAL ENERGY PRODUCTION LEVELS FROM ADVANCED SOURCES (10^{15} joules per year) (modified from Hughes et al. 1974)

Source	1970	1975	1980	1985	1990	1995	2000
Solar	0	0	0	400	2,500	4,000	12,000
Geothermal	1.8	14	72	180	360	720	1,400
Oil shale	0	0	610	2,000	2,700	3,400	4,000
Solid wastes	0	10	55	300	950	3,000	10,000
Total	1.8	24	737	2,880	6,510	11,120	27,400
U.S. demand	70,000	83,000	98,000	120,000	140,000	170,000	200,000
Percent of U.S. demand filled by above sources	$3x10^{-3}$	$3x10^{-2}$	0.8	2	5	6	13

In the Yampa and White River Basins, energy resource development will primarily be oil shale development and increased strip mining of coal with construction of associated coal gasification, coal-fired powerplants and transportation facilities. Development of uranium reserves, oil and gas fields, and other resources will occur, but to a much lesser extent. It is difficult to assess the extent and severity of degradation in environmental quality that can be expected from this development. However, one of the biggest impacts will undoubtedly result from competition for water resources created by growing demands of municipal, industrial, agricultural, and reclamation projects. Energy development, which requires large amounts of water during extraction, transportation, and conversion of resources to a usable form, can potentially have a great impact on water quality in the Basins.

SECTION 2

CONCLUSIONS

1. Water availability in the study area will be the major factor limiting future growth and development patterns, including development of energy resources. Surface discharge in both river systems is highly variable and cannot be relied upon to provide year-round flow for anticipated consumptive use without creation of additional storage facilities. Many reservoirs have been proposed for the study basins to meet projected industrial requirements. Constructions of these impoundments would drastically alter seasonal stream flow patterns, fisheries, and water quality of the basins.

2. Interbasin transport of water from sources in the Colorado River, as well as expended use of regional ground-water resources and reallocation of existing irrigation water rights, are mechanisms expected to assume increasing importance in meeting anticipated industrial demands for water in the Yampa and White River Basins. In particular, there are large reserves of ground water underlying the Piceance Basin, although their high salinity will restrict large-scale usage for many industrial needs.

3. Water quality throughout the Yampa and White River Basins is variable and strongly influenced by episodic high runoff and mineralized ground-water supplies forming the baseflow of intermittent tributaries. Salinity and suspended sediment concentrations are already problems in both basins, and nutrient levels are sufficiently high in the downstream White River that any reservoir construction associated with energy development is likely to result in excessive algal growth conditions. Existing water quality, particularly around the mining activities at Hayden and the oil shale tracts of Piceance Basin, can be expected to deteriorate as availability of water is reduced with increasing regional development. The parameters most likely to be affected by increased activities in the basins are elemental toxic substances, salinity, suspended sediments, and nutrients. Pollutants from surface mines are expected to move primarily in conjunction with local storm events.

4. Irrigation is, and will continue to be, the major consumer of surface water in the Yampa and White River Basins. Regional high salinity already restricts the variety of crops grown in the area, and increasing salinity, particularly in conjunction with reductions in flow, would have a major impact on this important user.

5. There are a number of fish species endemic to the study area which are on the threatened or endangered lists of Colorado. At present, the Yampa and White River Basins, because they are unaltered by high dams, provide habitat

for these species. Additional reservoir construction associated with energy development in the area could have a major detrimental impact on the distribution of these species.

6. Waterborne point source discharges of pollutants from coal mining and coal conversion sites in the basins should be localized and should not pose a problem to overall water quality in the basins if discharge restrictions are strictly enforced. Rather, nonpoint pollution such as stack emissions, airborne dust, and subsurface drainage will be the major contributions. Runoff of effluents released from evaporation ponds to ground water or through overflow during storms poses an additional water quality threat, and regular monitoring for potential violations from energy development operation sites should be monitored.

7. Although point source dishcarges for traditional energy developments are not likely to pose surface water quality problems, the potential for direct contamination of ground-water supplies from in situ coal and oil shale conversion activities is substantial. Organic pollutants from this source are of particular concern due both to the lack of available data regarding their nature and quantity, and to the high costs associated with organic analyses. For many of the organic species likely to be emitted, no water quality regulations presently exist, and the synergistic hazards of their release into the aquatic environment are not well understood.

8. The oil shale industry in the White River Basin will involve processing and disposal of large volumes of waste solids, for which massive amounts of disposal lands must be available. Leaching of trace elements or trace organics from these spent shale piles will be another potential source of ground water contamination in the study area.

9. Pollution impacts of secondary development are likely to become a major contributing problem to water quality in the Yampa and White River Basins. In particular, increases in total dissolved solids (TDS) and sediment levels from urban runoff, hydrologic modifications, and erosion resulting from construction of additional transportation systems are expected.

10. In addition to the long-term trends, increased numbers of pollution "episodes" (spills, etc.) are expected due to the increased transport of energy products in the area and the likelihood of flood runoffs from waste disposal, cooling systems, or mining sites. These brief but massive events could cause both short- and long-term effects that would be disasterous to both the ecology and the economy of the area.

11. Surface water quality monitoring stations presently operated by the U.S. Geological Survey (USGS) are abundant and generally well situated to monitor energy resource development impact. However, they are not sampled frequently enough to permit meaningful data evaluations, nor do they monitor a number of water quality parameters that are considered necessary for monitoring energy activities in the basins. Thirteen USGS sampling stations have been selected as having the highest sampling priority for energy monitoring throughout the basins examined in this report. Priorities have also been established for detecting water quality parameters necessary to monitor impacts from energy development in these watersheds.

SECTION 3

RECOMMENDATIONS

1. Expansion in the number of parameters regularly monitored to assess the impact of energy development on surface water quality in the Yampa and White River Basins is recommended. In particular, most trace elements and nutrients, which are presently collected only irregularly, should be incorporated into a systematically scheduled sampling program. Pesticides, oil and greases, and organics such as phenols are other parameters that should be incorporated into a regular, if occasional, monitoring effort. Increased use of biological monitoring as a tool for measurement of long-term surface water quality trends is recommended.

2. The following U.S. Geological Survey stations are recommended for the highest sampling priority in the Yampa and White River Basins for monitoring energy development impact on surface waters:

Bear River near Toponas, Colorado
Yampa River below diversion, near Hayden, Colorado
Yampa River below Craig, Colorado
Yampa River near Maybell, Colorado
Little Snake River near Lily, Colorado
Yampa River at Deer Lodge Park, Colorado
North Fork White River at Buford
White River near Meeker, Colorado
White River below Meeker, Colorado
Piceance Creek at White River, Colorado
White River below Yellow Creek, Colorado
White River near Watson, Utah
White River at mouth near Ouray, Utah

3. The present surface-water monitoring network should be restructured. The Yampa River station at Maybell and the White River station near Watson should be sampled on a weekly basis in order to permit meaningful trend analyses. The other 11 priority stations should be monitored on at least a monthly basis to provide spatial distribution data. If funds permit, continuous monitoring in the White River downstream from the Colorado oil shale tracts (below Yellow and Piceance Creeks) and in the Yampa River downstream from the cluster of mining developments (below Craig), would be desirable. There is an additional need to establish intensive source specific monitoring, particularly at the coal mine sites in the Yampa Basin. Such source monitoring would determine which pollution control methods need to be implemented at each mining site, and whether the controls already implemented are effective.

4. The following water quality parameters are recommended for at least monthly sampling at the 13 priority stations in order to assess energy development impact in the Yampa and White River Basins:

Total alkalinity
Total aluminum
Total ammonia
Total arsenic
Total beryllium
Bicarbonate
Total boron
Total cadmium
Dissolved calcium
Chloride
Total chromium
Specific conductance
Total copper
Total cyanide
Flow
Fluoride
Total iron
Total lead
Dissolved magnesium
Total manganese
Total mercury
Total molybdenum
Total nickel
Nitrate-nitrite
Dissolved oxygen
Pesticides
Petroleum hydrocarbons
pH
Total phosphorus
Dissolved potassium
Total selenium
Dissolved sodium
Dissolved sulfate
Suspended sediments
Temperature
Total dissolved solids
Total organic carbon in bottom sediments
Biochemical oxygen demand in bottom sediments

5. Development of improved techniques for monitoring of ground-water supplies is recommended. Development of field monitors (automatic or continuous) that would provide detailed analyses of trace elements and trace organics in both surface and ground-water supplies under ambient conditions would be invaluable.

6. Periodic intense field surveys are recommended to determine the nature and extent of pollution discharges, especially from developing in situ oil shale and coal conversion facilities, which will create many potentially harmful organic compounds. The exact nature and degree of escape of these compounds is presently unknown. Development of additional and more inexpensive analytical procedures to identify organics is also needed.

7. Definition of the amounts of water needed to establish enforceable minimum in-stream flow requirements in the Yampa and White River Basins is recommended, particularly in light of the tremendous potential impact to fisheries and recreation areas from proposed reservoir construction in the basins.

8. Declaration of an interstate water agreement between Utah and Colorado regarding water allocations of the White River Basin is recommended. Large scale proposals to develop the oil shale industry in both states make an agreement, more specific to this Basin than the Colorado River Compact, ultimately mandatory, and the sooner it is accomplished the sooner realistic estimates can be made on the availability of surface waters for the industry in both states.

SECTION 4

STUDY AREA

GEOGRAPHY

Location and Size

The White and Yampa River Basins are located along the border region of the State of Colorado, Utah, and Wyoming (Figure 1). The area encompasses approximately 37,943 km^2 in the following counties: Moffat, Rio Blanco, Garfield, Routt (Colo.), Sweetwater, Carbon (Wyo.), and Uinta (Utah). It is bordered by the Roan Plateau and Flat Top Mountains to the south, the Continental Divide and Colorado River to the east, the Red Desert Basin to the north, and the Green River to the west.

Most major tributaries to the Yampa River Basin (24,683 km^2) originate in the Park Range and White River Plateau areas along the east and southeastern edges of the drainage area (U.S. Economic Research Service et al. 1969). The basin is approximately 206 km long from east to west, and averages 121 km wide as the river flows to its confluence with the Green River in Dinosaur National Monument. Elevations in the basin range from 3,808 m on Flat Top Mountain (Table 2) in the southeast to 1,524 m near the confluence point with the Green River. Major tributaries include the Williams Fork, Little Snake, and Elk Rivers.

The North Fork White River (13,260 km^2) has its headwaters near Trappers Lake on the White River Plateau in northwestern Colorado and flows westward through the towns of Meeker and Rangely across the Utah-Colorado border to its confluence with the Green River. The Basin is approximately 172 km long and averages 56 km wide. Elevations vary from 3,657 m on Shingle Peak in the Flat Tops of the White River Plateau to 1,466 m at the White River's confluence with the Green River. The Piceance Creek is the only major perennial tributary in the Basin.

Climate

The climate of the study area is characteristic of its highly variable physiography, being generally semiarid with relatively warm summers and cold winters. Temperature variations are largely related to the wide range of exposures and elevations; temperature extremes of -42°C to 39°C have been reported at Meeker in the White Basin, and -48°C at Steamboat Springs to 38°C at Craig in the Yampa Basin (U.S. Economic Research Service et al. 1966, 1969).

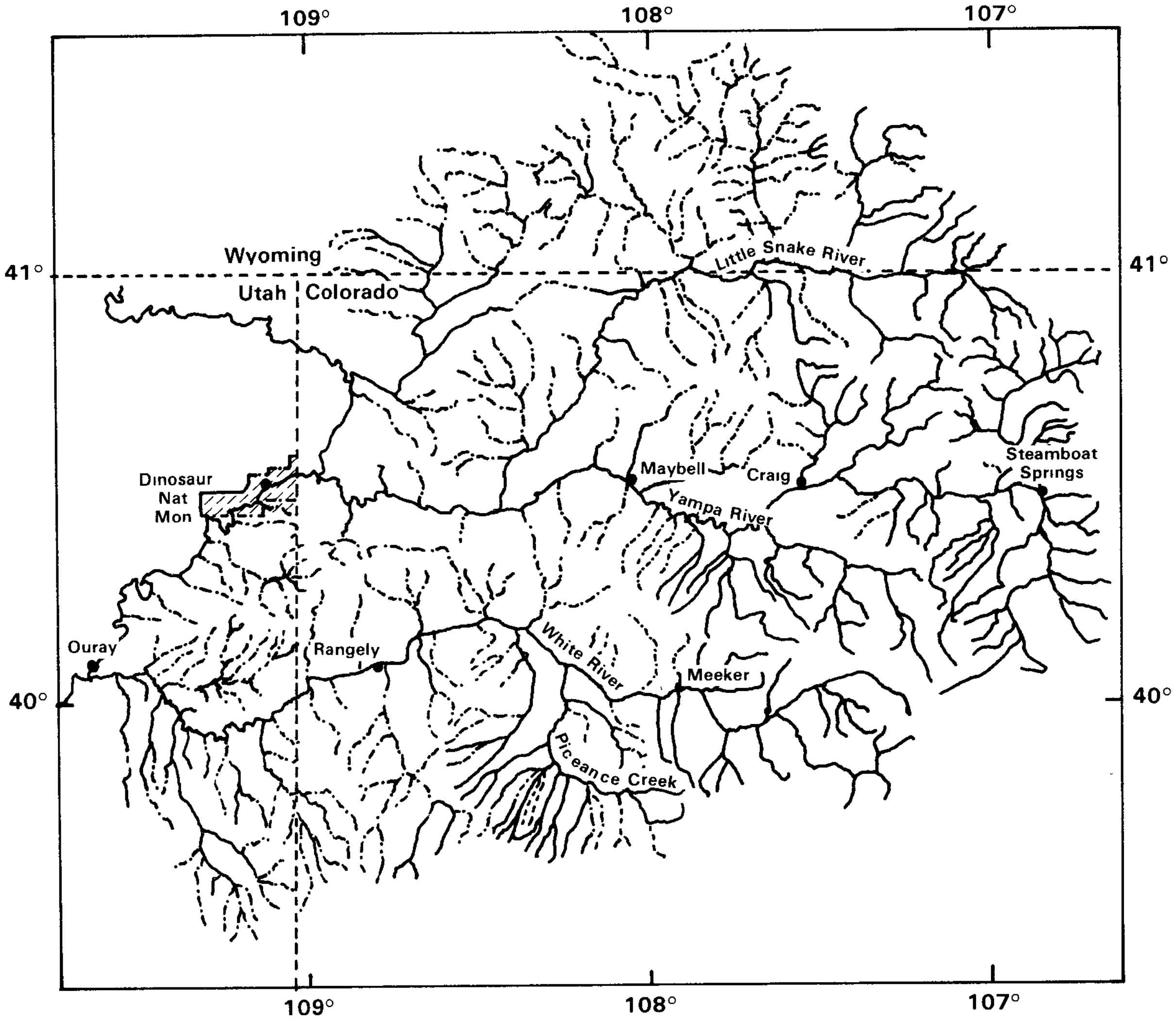

Figure 1. Location of the Yampa and White River Basins.

TABLE 2. ELEVATIONS OF MAJOR MOUNTAINS CONTRIBUTING TO RUNOFF IN THE WHITE AND YAMPA RIVER BASINS

Mountain	Elevation (meters)
Flat Top Mountain	3,808
Sheep Mountain	3,732
Mt. Orno	3,690
Shingle Peak	3,657
Trappers Peak	3,654
Marvine Peak	3,619
Pagoda Peak	3,431
Sleepy Cat Peak	3,306
Hahns Peak	3,299
Gore Mountain	3,257
Bear Ears Mountain	3,249
Welba Peak	3,200
Diamond Peak	3,178
Buffalo Mountain	3,163
Pilot Knob	3,001
Uranium Peak	2,850
McAlpine Mountain	2,798
Pinnacle Mountain	2,514
Colorow Peak	2,438

Precipitation in the study area is fairly evenly distributed throughout the year. In the lowland regions, precipitation averages 23 to 30 cm per year, while in the higher alpine elevations along the Continental Divide, annual rainfall averages 127 cm/year (U.S. Department of Interior 1973). Winter snow accumulation during December to April is the principal source of surface runoff in the basins. Warm moist air masses from the Gulf of Mexico, and Pacific air masses originating on the coasts of Southern California (Iorns et al. 1965), commonly bring summer storms. These summer showers, however, contribute very little to overall water supplies in the basins except during episodic cloudbursts that result in flooding and short-term peak flow. Evaporation rates in the lower elevations often exceed the total annual precipitation (U.S. Bureau of Land Management 1978).

Geology

The structural history of the area is one of repeated coastal and marine deposition in shallow seas followed by emergence and erosion. Shallow epicontinental seas spread eastward and southeastward from the Cordilleran Geosyncline. Deposition of marine sediments probably was continuous through Ordovician and Silurian time (Haun and Kent 1965). In late Silurian, and well into the Devonian, emergence occurred, and much of the sedimentary record was destroyed. In late Devonian, shallow seas again advanced into the area and the Chaffee formation was deposited (Curtis 1962). This general pattern was repeated throughout the Late Paleozoic and Early Mesozoic Eras. During the Jurassic age, seas advanced from the northwest into two embayments formed by the White River Uplift (Curtis 1962). The Morrison formation of latest Jurassic age begins a new tectonic and sedimentary pattern characterized by mudstones, sandstones, conglomerates, and freshwater limestones of continental origin. Geanticlinal mountains arose and migrated eastward providing a sediment source. During Cretaceous time, sediments were deposited into a marine trough that developed east of the mountain belt. Deposition of the interfingered, coarse continental clastics on the west with marine shales and limey shales toward the east (Dakota Sandstone, Mancos Shale, Mesaverde Sandstones, Lewis Shale, Fox Hills Sandstone, and Lance formation) record the various advances of western land at the expense of eastern seas. Late Cretaceous time brought a general elevation of northwestern Colorado (Curtis 1962).

In latest Cretaceous and Cenozoic time, pulses of Laramide orogeny caused differential elevation throughout the region. The Park Range and the Uncompahgre-Douglas Creek uplifts had begun (Curtis 1962). In Eocene time, the area between the Park and Uncompahgre trends sank forming a shallow lake basin. In its waters the kerogen-bearing marlstones and calcareous shales of the Green River formation were deposited, while around its edges the fluvial and deltaic Wasatch formation was formed. Many of the present-day structural features were formed during the period of orogeny from Late Cretaceous to early Tertiary times (Quigley 1965). During the Oligocene, uplift and smoothing to a low order relief apparently occurred. During the Miocene, deposition of the Browns Park formation was followed by volcanism. The area continued to be raised as a unit, but the eastern end of the Uinta Arch remained stable, and in Pliocene time it collapsed relative to its surroundings (Curtis 1962). The structural geology of the area is generalized in Figure 2. Intensified erosion produced a superposition of stream patterns with intrenched meandering rivers crossing prominent structural and topographic high areas. The moist Pleistocene period further strengthened stream erosion and produced vigorous mountain glaciation in the region.

The sediment types have been very important in the accumulation of gas and oil after the Laramide orogeny. Virtually all the oil and gas in the Paleozoic age rocks has been produced from the Weber Sandstone. In the Weber Sandstone, intergranular porosity and permeability alone are insufficient to support commercial production. Folding and fracturing have been all important in establishing commercial reserves. Accumulations of Cretaceous and Tertiary oil and gas are similarly controlled (Quigley 1965). Production of oil has been from the Wasatch, Mancos, Dakota, Morrison, Entrada (Sundance), Shinarump, Moenkopi, and Weber formations. The relative geologic positions of these and other strata are shown in Table 3. In 1962 these formations had produced 64 billion liters (403 million barrels), most of this (49 billion liters) from the Rangely Field (Weber) (Piro 1962). The Green River formation, particularly the Evacuation Creek* and Parachute Creek members, is the host rock for oil shale. Coal reserves exist in the Green River, the Fort Union, and Lance formations, and in the Mesaverde Group. The most important are those of the Williams Fork formation of the Mesaverde Group where beds in excess of 4 meters thick are common. Underlying coal beds in the Iles formation are also important (Hancock 1925). Coal resource development, as expected, closely follows the surface outcrop patterns (Figure 3) of the Green River, Fort Union, William Fork, and Iles formations.

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* In present nomenclature, Evacuation Creek member is included as a part of the Parachute Creek member (Cashion and Donnell 1974). The order nomenclature is used throughout this report.

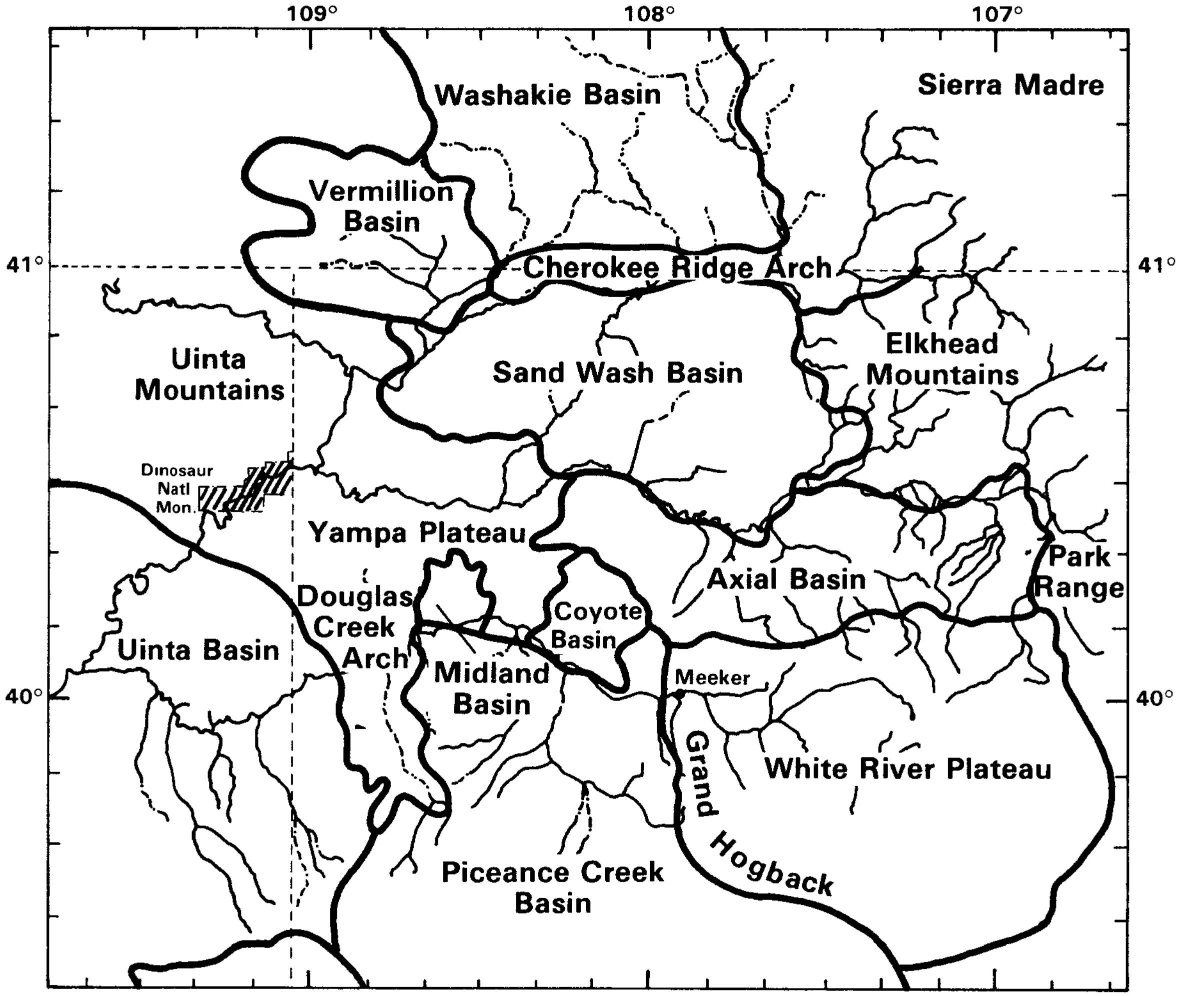

Figure 2. Structural geologic provinces in the Yampa and White River Basins. (modified from Quigley 1965, and Beebe 1962)

TABLE 3. GENERALIZED STRATIGRAPHIC SECTION OF THE YAMPA AND WHITE RIVER BASINS (modified from Greene 1962)

System	Series	Group	Formation	General Description	Thickness
Recent Pleistocene			Recent Alluvium	Undifferentiated Sediment	
Quaternary	MIOCENE		Browns Park	Sandstone and Conglomerates with thin limestone layers	0-1800'
			Bishop Cgl.	Boulders and pebbles of sandstone and quartzite	0-300'
T E R T I A R Y	EOCENE	GREEN RIVER FORMATION	① Evacuation Creek member	Sandstone, interbedded claystone, marlstone black with oil stain	0-700'
			Parachute Creek member	Marlstone, petroliferous, interbedded thin layers of nacholite, claystone	0-1600'
			② Garden Gulch member	Shale, interbedded dolomitic and argillaceous marlstones and limestones	0-500'
			② Douglas Creek member	Interbedded siltstone, shale, and sandy limestone Sandstone Claystone Coaly shale Limestone Shale Interbedded siltstones, shale and sandstones	0-1100'
			Wasatch	Claystone Interbedded claystone, coaly streaks, siltstone, and sandstones Claystone, Clay nodules	0-6500'
	PALEOCENE		Fort Union	Claystones, shales, thin coals Sandstone Coals Sandstones Interbedded carbonaceous shales	0-1300'
C R E T A C E O U S	UPPER CRETACEOUS		Lance	Carbonaceous shale Sandstone, siltstone and coal Shale and siltstone	
			Fox Hills Sandstone	Sandstone trace coals Shale and siltstone	
		MESAVERDE GROUP	Lewis	Interbedded shale and sandstone Siltstone Shale Bentonite Shale	0-2200'±
			Williams Fork	Sandstone with interbedded shale Thin coal layers Sandstone, interbedded Shale and coal Shale and coal Coal	5000'±

(continued)

TABLE 3. (Continued)

System	Series	Group	Formation	General Description	Thickness
Recent Pleistocene			Recent Alluvium	Undifferentiated Sediment	
CRETACEOUS		MANCOS SHALE	Trout Creek SS. member	Sandstone	1600'±
			Iles	Shale Shale, siltstone Coal layers Sandstone and siltstone with coal partings Shale, interbedded siltstone	
			Mancos	Shale	5000'±
			Morapos SS. member	Sandstone	
			Meeker SS. member	Sandstone	
				Shale	
			Niobrara	Shale	5000'±
			Frontier	Shale Sandstone, interbedded shales Shale	
	Lower Cretaceous		Mowry	Shale	100-200'
			Dakota ③	Sandstone Claystone Sandstone - small conglomerate	70-150' 0-120' 0-90'
JURASSIC	LATE	San Rafael Group Morrison Formation	Brushy Basin member	Claystone and thin limestone Thin sandstone Limestone Claystone	200-800'
			Salt Wash member	Sandstone Interbedded claystone and shale	
			Curtis Fm.	Siltstone Shale Sandstone	0-200'
			Entrada SS.	Sandstone	0-300'
			Carmel	Sandstone and shale	0-50'
	EARLY	Gleen Canyon Group	Navajo SS. (Nugget)	Sandstone	0-800'

(continued)

TABLE 3. (Continued)

System	Series	Group	Formation	General Description	Thickness
Recent Pleistocene			Recent Alluvium	Undifferentiated Sediment	
TRIASSIC	LATE		Chinle	Siltstone Shale Claystone	0-450'
			Shinarump	Sandstone and conglomerate	
	EARLY		Moenkopi	Siltstone Interbedded shale Sandstone	0-850'
PERMIAN			Park City	Limestone Siltstone	0-300'
			Weber Maroon Maroon Maroon	Sandstone	0-1200'
PENNSYLVANIAN	DE MOINES		Weber Weber Maroon Weber	Sandstone	0-2000'
	Morrow and Atoka		Upper Morgan	Interbedded limestone and sandstone Limestone and dolomite Sandstone Shale	500-1400'
			Middle Morgan	Limestone Sandstone Shale	
			Lower Morgan	Sandstone Shale, siltstone, sandstone Limestone Chert	
			Molas	Shale	
MISSISSIPPIAN			"D" Zone	Limestone Chert	0-700'
			"C" Zone	Limestone	
			"B" Zone	Dolomite Chert	
			"A" Zone	Limestone	
DEVONIAN	Upper Devonian	Chaffee Formation	Dyer member (Ouray)	Dolomite, with shale and chert partings Limestone	200-270'
			Parting member (Elbert)	Shale, quartzite, sandy dolomite	
ORDOVICIAN	Lower Ordovician	Manitou 4 Formation	Tie Gulch Dolomite	Dolomite, sandy Limestone	80-155'
			Dead Horse Conglomerate	Limestone conglomerate Interbedded shale	

(continued)

TABLE 3. (Continued)

System	Series	Group	Formation	General Description	Thickness
Recent Pleistocene			Recent Alluvium	Undifferentiated Sediment	
CAMBRIAN	Upper Cambrian	Dotsero ④	Clinetop Algal LS.	Limestone, white algal	100'
			Glenwood Canyon	Limestone conglomerate Dolomite	
			Sawatch	Sandstone Dolomite Quartzite, sandstone Quartzite	0-520'
PRECAMBRIAN		Unita Mt. Group		In northern part of area quartzitic and conglomeratic sandstones	
				In White River uplift, Upper Cambrian strata lie on metamorphic and igneous Precambrian	

In no one area would this entire composite section be present.

- Oil and Gas shows

① Bridger Formation overlies Green River in portions of Sand Wash and Piceance Basins

② Anvil Points member in Piceance Basin

③ Dakota is subdivided regionally into the Dakota, Fuson, and Dakota near Wyoming. In Utah the unit is called Dakota, Cedar Mountain, Buckhorn. In the southern portion the Cedar Mountain, and Bullhorn is referred to as Burro Canyon.

④ In the absence of the Clinetop Algal limestone bed the Manitou and the Dotsero cannot be separated and is called the Dotsero.

Population and Economy

The population of the Yampa and White River Basins is primarly distributed throughout a number of small rural communities. In the Yampa drainage area, year-round population in 1976 was estimated at 18,000 persons, with the communities of Craig and Steamboat Springs together accounting for over half the total basin population (Steele et al. 1976). This region receives large seasonal influxes during the summer and winter recreation month of persons who are not included in the population estimate. Approximately 7,000 individuals reside in the White River Basin; more than 90 percent of those are in Rio Blanco County (U.S. Economic Research Service et al. 1966). Populations in some parts of the study area are expected to more than double by the 1990's (Table 4).

The economic base for the White and Yampa River Basins is traditionally agricultural, dominated by cattle and sheep ranching and by production of crops including corn, wheat, oats, barley, rye, hay, and potatoes. The retail trade industry employs approximately 20 percent of the regional workforce, and

QT = *Undifferentiated Quaternary and Tertiary*
Tbp = Browns Park Formation
Tbr = Bridger Formation
Tui = Uintah Formation
Tgr = Green River Formation
Tw = Wasatch Formation
Tfu = Fort Union Formation
Kl = Lance Formation
Kls = Lewis Shale
Kmv = Mesa Verde Group
Kwf = Williams Fork Formation
Ki = Iles Formation
Kmc = Mancos Shale
Kd = *Dakota Shale*
JTr = Jurassic Triassic Undivided
P₽u = Permian and Pennsylvanian Undivided
₽mo = Morgan Formation
Mu = Mississippian Undivided
Єu = Cambrian and Precambrian

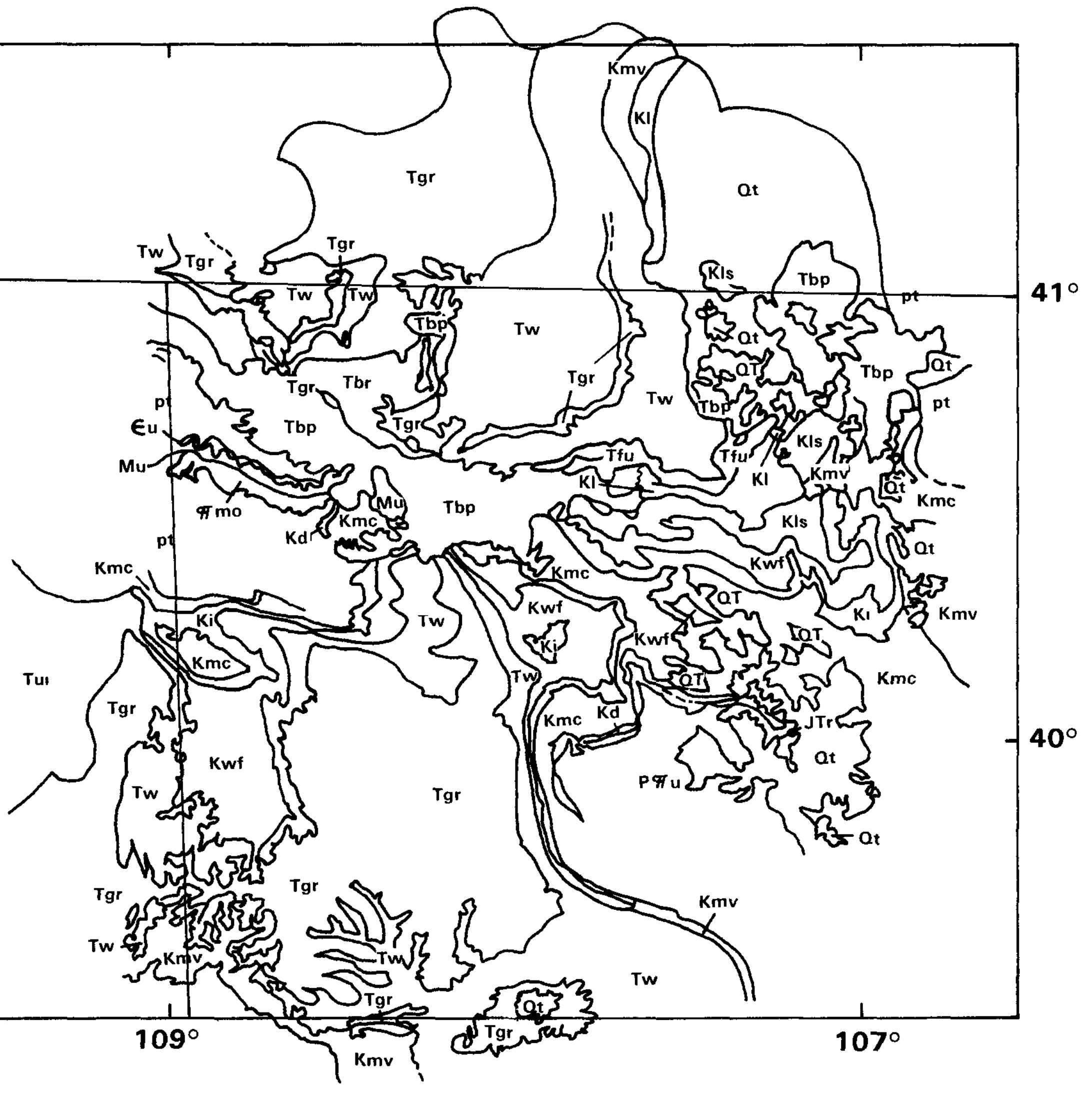

Figure 3. Generalized surface outcrops of the geologic formations in the Yampa and White River Basins.

TABLE 4. CURRENT AND PROJECTED POPULATION FOR THE WHITE AND YAMPA RIVER BASINS*

Communities	1975	1980	1985	1990
Moffat County	8,336	10,154	11,234	13,547
Craig	5,426	8,945	9,320	11,373
Dinosaur	311	408	947	975
Other areas	2,599	801	967	1,199
Rio Blanco County	5,349	11,171	16,978	18,541
Meeker	1,986	5,672	6,629	7,353
Rangley	1,792	3,356	7,838	8,094
Other areas	1,571	2,143	2,511	3,094
Routt County	9,858	14,492	17,005	17,704
Hayden	1,338	2,212	2,520	2,533
Oak Creek	780	1,868	2,224	2,287
Steamboat Springs	3,013	8,089	9,631	9,885
Yampa	370	408	498	600
Other areas	4,357	1,915	2,132	2,399
Carbon County	16,745	---	---	---
Baggs	250	---	---	---
Dixon	47	---	---	---

*Modified from U.S. Bureau of Land Management (1976a) and U.S. Department of Commerce (1977a, 1977b).

timber production is important in some regions of the Yampa Basin (Table 5). Increasingly, however, mineral production (particularly of petroleum and coal) and associated conversion facilities, are gaining in significance to the local economy. The U.S. Economic Research Service et al. (1969) reported "mining is by far the most important economic activity in northwestern Colorado." In the Yampa Basin, the population is expected to more than double in the next 15 years (Steele 1976) in response to the growing coal industry. The communities of Craig and Hayden have already experienced rapid population increases since 1973 as a result of construction of a new coal-fired power generating plant near Craig, and addition of a second unit to the existing Hayden facility. The community of Meeker is undergoing population expansion due to increasing focus on development of oil shale reserves in the Piceance Creek Basin. Renewed interest in oil and gas exploration in Rangely could also affect population growth in the White River Basin.

TABLE 5. EMPLOYMENT DISTRIBUTION IN THE WHITE AND YAMPA RIVER BASINS, 1970
(modified from U.S. Bureau of Land Management 1976a)

	Moffat County	Rio Blanco County	Routt County	Region Total	Percent of Total*	State Percent*	National Percent*
Labor force	2,622	1,981	2,607	7,210			
Unemployed	119	35	80	234	3.25	3.3	4.9
Total employed	2,503	1,946	2,527	6,976			
Agriculture	351	294	362	1,007	14.44	4.63	4.67
Mining	124	280	175	579	8.30	1.72	0.84
Construction	294	152	232	678	9.72	6.41	4.57
Manufacturing	42	42	95	179	2.57	14.83	26.13
Transportation, communications and utilities	185	94	228	507	7.27	7.33	6.07
Wholesale, and retail trade	628	272	541	1,441	20.66	22.27	20.14
Finance, insurance, and real estate	54	56	73	183	2.62	5.63	4.98
All other private services	689	603	711	2,003	28.71	30.45	15.68
Public administration	136	153	110	399	5.72	6.73	16.93

*Percent unemployed is percent of labor force. Percents by sectors are percents of total employed.

Land Ownership and Usage

The White and Yampa Rivers drain nearly 38,000 km^2 and include portions of Utah, Colorado, and Wyoming. Over 60 percent of the land is Federally owned, most of it Bureau of Land Management or Forest Service lands (Table 6). The Yampa Basin drains portions of Medicine Bow and Routt National Forests. Most of the Basin downstream from the Little Snake River lies within Dinosaur National Monument (Figure 4). The headwaters of the White River drain portions of the Routt and White River National Forests. The interior stretches of both basins are dominated by Bureau of Land Management property in the west, and by state lands, such as the Rio Blanco Lake and Lake Avery State Recreation Areas, in the east.

Approximately 30 percent of the total land area in the White and Yampa River Basins is privately owned (U.S. Economic Research Service et al. 1966 and 1969). The confluence of the White and Green Rivers is located on Uinta and Ouray Indian Reservation land, the only tribally owned acreage in the study area.

The primary usage of land in the White and Yampa River Basins is agriculture (Figure 5), with an estimated 74 percent being used for grazing, and 4 percent for cropland. Cropland production in the basins is comprised of corn and alfalfa, as well as winter wheat, oats, barley, and other small grains.

Industrial utilization of land, such as mining and urban development, is relatively slight at present, particularly in light of the regional economic benefits to be derived from the exploitation of its mineral resources. However, mining of valuable fuel reserves, along with development of power supply facilities, is expected to increase in future years and to use increasing amounts of land. The oil shale industry in particular may have a large land impact since solid wastes and spent shale will probably be handled on the land surface (Jones et al. 1977). Recreation, including fishing, hunting, boating, camping, and general vacation activities, is also an important usage of basin lands. Care must be taken to ensure that these recreational uses are not needlessly sacrificed as a result of the explosive development of energy resources in the basins.

WATER RESOURCES

Lotic Waters

Surface water supplies in the White and Yampa Rivers, both of which arise on the north edge of the White River Plateau in Garfield County, are derived primarily from the melting of winter snowpacks accumulated in the higher basin elevations. Peak flows in the rivers occur during April, May, and June (Figure 6); about 50 percent of the White River surface runoff and 80 percent of the annual Yampa River discharge occur during these months (McCall-Ellingson and Morrill, Inc. 1974). River flows rapidly diminish after snowmelt. This, compounded by irrigation diversions throughout the growing season, produce annual low flows in August and September, particularly in the lower portions of the basins.

TABLE 6. TOTAL LAND USE (km^2) IN THE YAMPA (Colorado and Wyoming) AND WHITE (Colorado only) RIVER BASINS, 1964 (modified from U.S. Economic Research Service et al. 1966 and 1969)

Ownership	Cropland		Grazing	Timber and Grazing	Timber	Wilderness	Recreation	Other
	Irrigation	Dryfarm						
Private land	538.2	870.5	8,131.5	543.9	113.7	0	27.5	382.8
State land								
State and local government	0.8	31.2	1,311.6	55.4	18.6	0	0	98.3
Game, fish, and parks department	8.9	0	88.6	10.5	0	0	7.3	60.3
Federal land								
BLM	0	0	15,616.8	257.4	103.2	0	48.2	428.2
Forest Service	0	0	573.0	2,312.0	1,629.3	450.4	2.8	234.3
National Park Service	0	0	0	0	0	0	592.9	0
Percent of total (Total = 34,548.1)	1.6	2.6	74.4	9.2	5.4	1.3	1.9	3.5

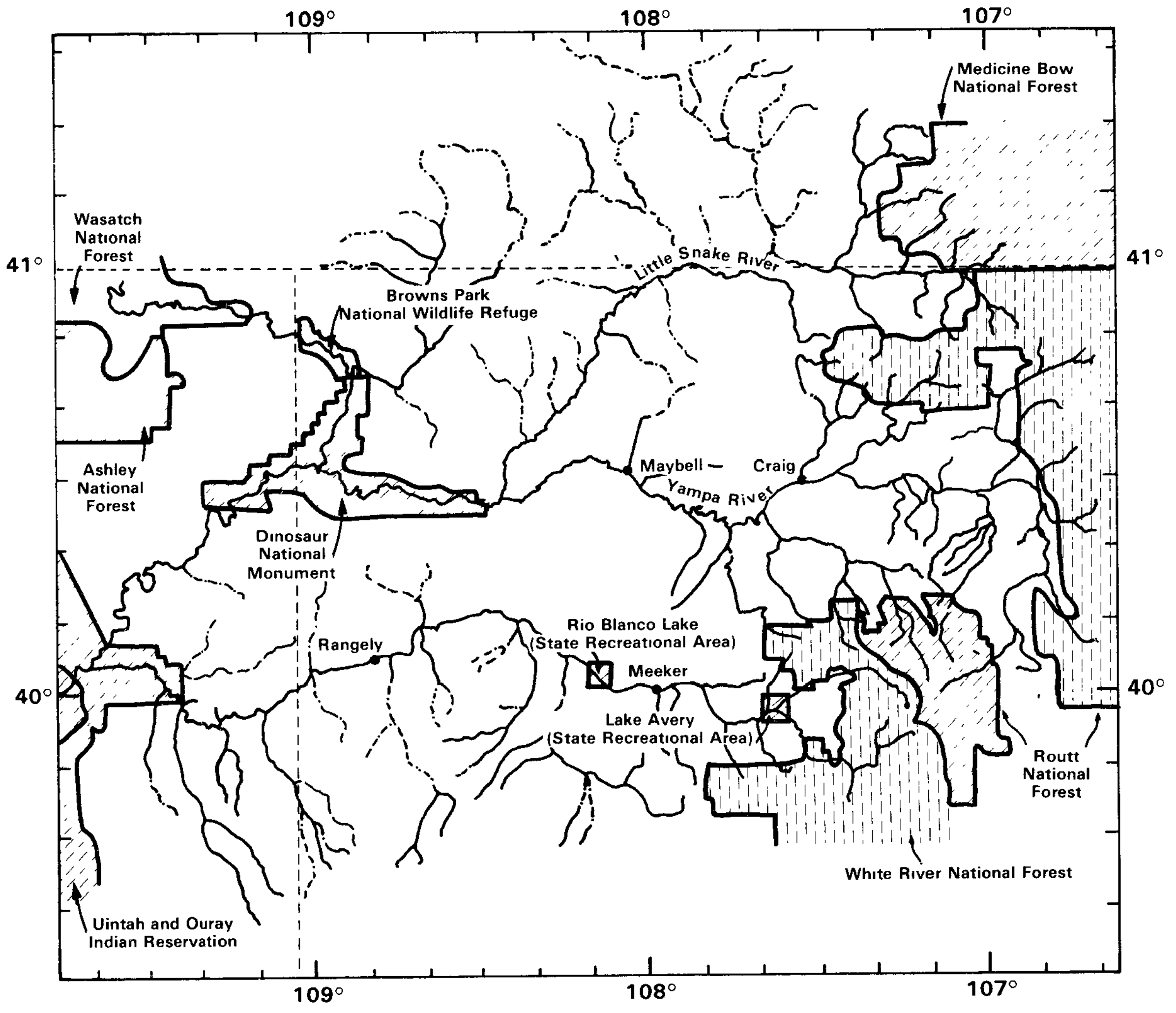

Figure 4. Major land use areas of the Yampa and White River Basins.

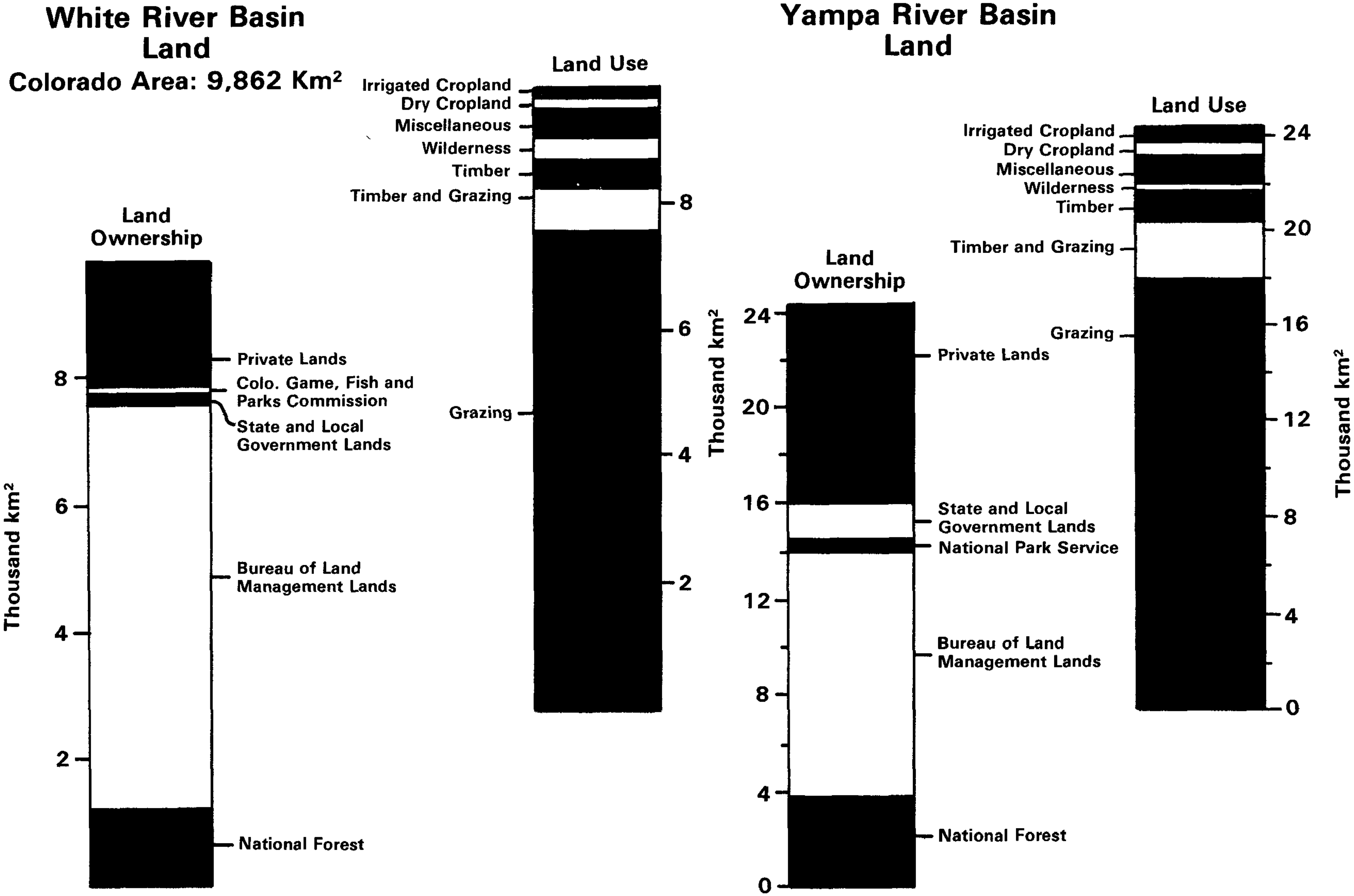

Figure 5. Use and ownership of land resources in the White River Basin (Colorado) and the Yampa River Basin (Colorado and Wyoming). (modified from U.S. Economic Research Service et al. 1966, 1969)

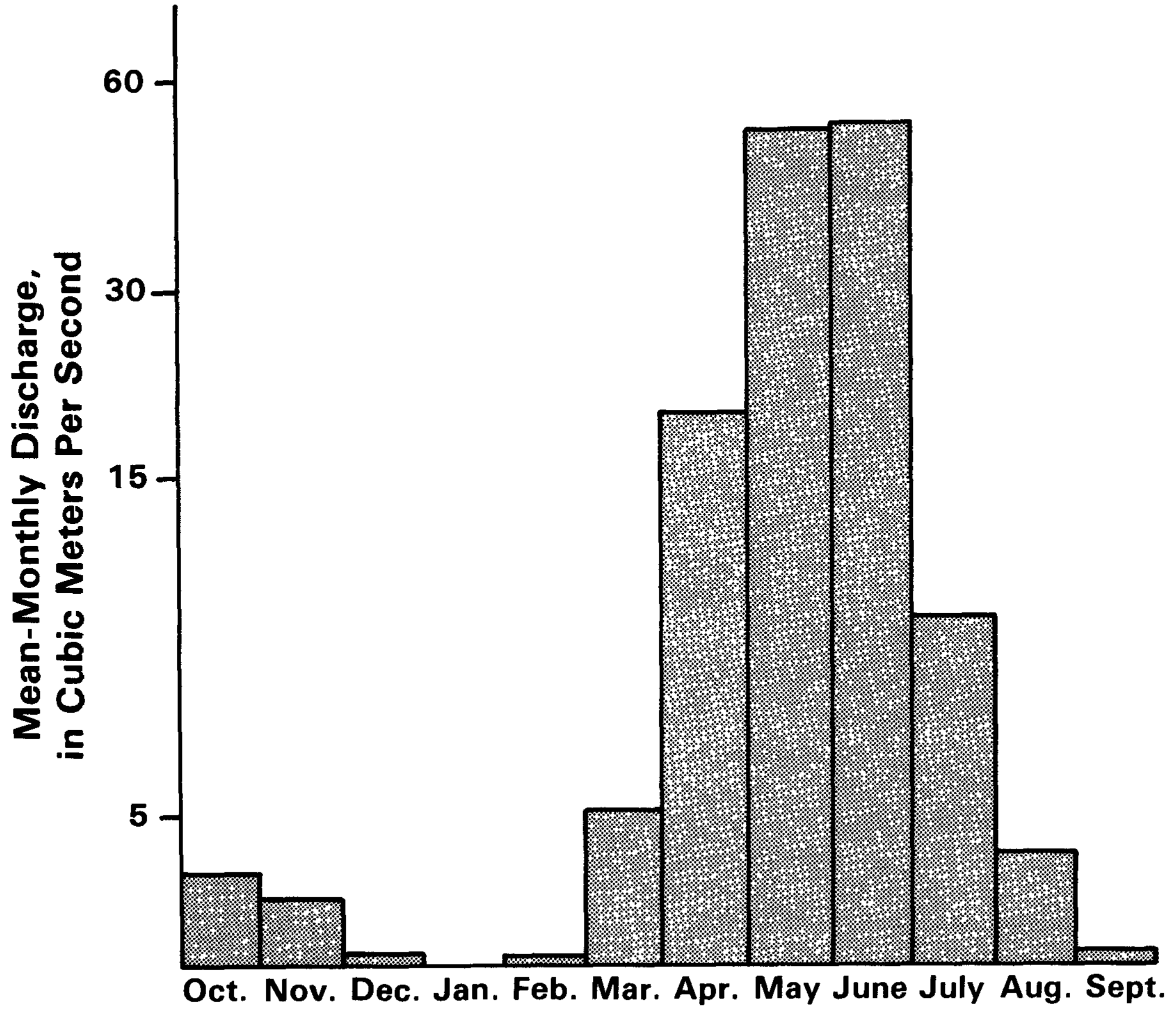

Figure 6. Mean monthly discharges, Yampa River at Steamboat Springs. (modified from Bauer et al. 1978)

Approximately 94 percent of the White River flow comes from only 27 percent of the total basin area, i.e., that portion of the basin upstream from Meeker (U.S. Economic Research Service et al. 1966). What additional runoff does occur in the lower basin is primarily a result of intense localized summer thunderstorms and a sustained ground-water baseflow in the watershed. It is estimated that 20 percent of the Yampa River headwaters area produces 58 percent of the total surface discharge (McCall-Ellingson and Morrill, Inc. 1974).

Lentic Waters

There are only five major (>6.2 million m^3 storage capacity) reservoirs in the study area. These include Steamboat Lake (Upper Willow Creek Reservoir), Pearl Lake, Lester Creek Reservoir, and Stillwater Reservoir in the Yampa Basin, and Lake Avery in the White River Basin near Buford. The largest of these is Steamboat Lake with a storage capacity of 22.9 million m^3 (Wentz and Steele 1976). Hundreds of other impoundments, including stock watering ponds and erosion control structures, exist in the basins to satisfy irrigation, industrial, recreational, and livestock demands, but these are substantially smaller in size. There are also a large number of small natural lakes in the basins. The largest of these are Trapper, Rio Blanco, McAndrews, and Hog Lakes.

Although both the White and Yampa River Basins are essentially unaltered by major reservoirs, they are substantially affected by irrigation diversions during the summer months. If energy development activities in this region are to progress as anticipated, additional storage facilities will be necessary to sustain year-round industrial operations, particularly in the summer months. Development of a number of large reservoirs has, in fact, been proposed for the Yampa and White River Basins. Total storage capacities of these impoundments would total 2.9 billion m^3 in the Yampa Basin alone; approximately 1.5 times the long-term mean annual streamflow discharged from the Basin (Wentz and Steele 1976). The potential impact of these developments on seasonal streamflow patterns, fisheries, and downstream water quality should be carefully examined before implementation is allowed to take place.

Ground Water

Ground-water supplies exist throughout the White and Yampa study basins. However, value of these supplies is restricted by the low yields of wells and often poor water quality, which is typical of the low permeability rocks of the region (Table 7). In general, ground-water resources of the area fall into four categories: those areas underlaid by crystalline rocks, areas underlaid by thick marine shales, areas underlaid by other sedimentary rocks (including all the coal-producing formations), and alluvium along the streams (U.S. Bureau of Land Management 1976a).

Those fractures in crystalline rocks yield good quality water (total dissolved solids <500 mg/liter) at an average rate of 0.01 to 0.04 m^3/min (U.S. Bureau of Land Management 1976a). The thick marine shales yield only poor quality waters at a rate of <0.01 to 0.02 m^3/min, although if sandstone members of these formations are encountered within 61 m of the surface, water will be of acceptable quality for livestock. Water derived from other sedimentary rocks, including saturated sandstones within 305 m of the surface, is generally of fair to good quality. Yields from this region depend on the thickness of the saturated rock penetrated (U.S. Bureau of Land Management 1976a); a shallow well might produce at a rate of only 0.01 to 0.04 m^3/min, whereas a very deep well could pump at a rate several hundred times faster. Finally, the alluvium along steams typically yields small quantities of highly mineralized water. There are some isolated sites that produce water up to 5.68 m^3/min, but these are rare and cannot sustain the high yield for long.

WATER USES

Ground water in the study area is used for mainly livestock and rural domestic supplies (Steele et al. 1976b), and if industrial activities in

TABLE 7. WATER BEARING CHARACTERISTICS OF GEOLOGIC FORMATIONS IN THE WHITE AND YAMPA RIVER BASINS (modified from U.S. Bureau of Land Management 1976a, 1976c)

Formation	Yield (m^3 x 10^{-3}/min)			Dissolved Solids (mg/liter)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Alluvium, young gravels and young glacial drift	18.9	189.2	5,677.5	20	100	2,000
Eolian deposits, old gravels and old glacial drift	3.8	7.6	37.8	20	300	2,000
Basalt of bimodal volcanic suite, volcanic rocks and upper tertiary intrusive rocks	7.6	18.9	189.2	20	50	200
Fort Union formation, Moen Kopi formation	7.6	18.9	189.2	20	50	200
Sedimentaries, Bridger formation, Unita formation, Green River formation, Wasatch formation, Browns Park formation	7.6	37.8	75.7	30	1,500	20,000
Lance formation	7.6	75.7	378.5	200	800	3,000
Lewis shale	3.8	7.6	75.7	600	4,000	10,000
Mesa Verde group, Iles formation, Williams Fork formation	3.8	37.8	1,135.5	200	1,000	8,000
Mancos shale	3.8	7.6	75.7	600	4,000	10,000
Dakota sandstone	7.6	37.8	378.5	100	1,000	10,000
Morrison formation, Curtis formation, Entrada and Carmel formations, Sundance and Glen Canyon Formations	3.8	37.8	757.0	300	1,000	10,000
Chinle formation, Chugwater formation	3.8	18.9	378.5	500	1,500	10,000
Park City formation	3.8	18.9	378.5	500	2,000	20,000
Mississippian, Devonian, and Cambrian rocks	18.9	378.5	7,570.0	1,000	5,000	20,000
Devonian	3.8	37.8	189.2	200	500	2,000
Granitic rocks and quartzite	3.8	18.9	189.2	20	50	200

the region increase, ground-water reserves could become significantly more valuable. Its development is mostly limited to small capacity wells and springs. According to the Bureau of Land Management (1976a), of the estimated 370 million m^3 annual recharge to ground water in the region drained by the Yampa River above Maybell, only about 370 thousand m^3 is currently developed. The Bureau also reports, "There are no known ground-water sources that are capable of the sustained high yields that would be required for municipal supplies, power plant cooling, coal gasification, or slurry pipelines.

However, possible high yield source is the aquifer under the oil shale area of Piceance Creek Basin, which overlies the most significant quantities of ground water in the region (Kinney et al. 1979). The University of Wisconsin (1976) estimates that between 3,000 and 31,000 million m^3 of water is in reserve under the Piceance and Yellow Creek drainages. Kinney et al. (1979) report total dissolved solids concentrations in this water ranges from 2,000 to 63,000 mg/liter. The EPA (1977) has suggested that groundwater aquifers may supply future oil shale developments with 12 billion m^3 of water, enough to satisfy a 159-million-liter-per-day industry for 50 years.

The surface water resources of the Yampa and White River Basins serve a variety of needs. Streams in the basins provide water for such uses as municipal water supplies, irrigation, recreational activities (including fishing and other sports), industrial needs, livestock watering, governmental uses, and limited generation of electricity.

FISH AND WILDLIFE RESOURCES

The White and Yampa River Basins support an abundance of fish and wildlife. A number of areas of the basins, including all of the Elk River, the Yampa River upstream of Craig, and the north and south forks of the White River from their sources to Buford, are unaltered by any project construction and are considered high quality trout streams (Upper Colorado Region State-Federal Inter-Agency Group 1971c). The Little Snake River and Williams Fork, as well as some of the smaller Yampa Basin tributaries such as Bear, Trout, Fish, Morapos, Slater, and Savery Creeks, provide excellent small-stream fishing. Numerous fishing impoundments have been constructed throughout the study basins (Table 8). Stream fishing pressure averages 57,000 fisherman days annually in the White River Basin and 111,250 fisherman days annually in the Yampa Basin (U.S. Economic Research Service et al. 1966 and 1969).

Fisheries in the study basins change from cold-water distribution near the headwaters to warm-water distribution farther downstream. Blue-ribbon trout fisheries dominate the upstream stretches of the basins; in the western, downstream segments catfish, carp, sunfish, bass, crappie, and pike are the major species. Lentic fisheries in the basins are generally two-story combinations of warm- and cold-water species. In Ralph White Reservoir, for example, major species are the green sunfish, bullhead catfish, channel catfish, rainbow trout, and northern pike (U.S. Bureau of Land Management 1976a).

There are several fish species on the threatened and endangered species list of Colorado that occur in the White and Yampa Basins study area (Table 9). These endangered native fishes are slowly being eliminated from the Colorado Basin both due to the large numbers of reservoirs that have been constructed, and from competition with exotic fish species which have been introduced into the watershed. The Bureau of Land Management (1976a) reports "The Yampa River . . . remains free flowing and unaltered by construction of high dams. It is thus a significant habitat for these four endangered species [endangered and threatened species indicated in Table 9], and any development

TABLE 8. FISH INSTALLATIONS AND BIG GAME MANAGEMENT AREAS IN THE YAMPA AND WHITE RIVER BASINS[*]

Hatcheries and Rearing Units

- Buford (Bel Aire) Rearing Unit[†]
- Finger Rock Rearing Unit

Fishing Impoundments

- Bailey Lake
- Divide Creek Reservoir
- Freeman Reservoir
- Hahns Peak Reservoir
- Lake of the Woods
- Lester Creek (Pearl) Reservoir
- Little Causeway Lake
- McGinnis Lake
- Meadows Creek Reservoir
- Pearl Lake
- Peterson Draw Reservoir
- Ralph White (Fortification) Reservoir
- Rio Blanco Lake
- Skinny Fish Lake
- Steamboat Lake
- Swede Lake
- Upper Stillwater (Yampa) Reservoir
- Vaugn (Poose) Lake

Big Game Management Areas

- Big Beaver Management Area
- Cathedral Bluffs Management Area
- Indian Run Management Area
- Little Hills Management Area
- Meeker Pasturage Management Area
- Missouri Creek Management Area

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[*] Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971c), and U.S. Economic Research Service et al. (1969).

[†] Closed in the early 1970's.

on the Yampa River drainage that alters the present environment might eliminate one of the last refuge areas of these species."

The wildlife of the Yampa and White River Basins varies with habitat type. The mountain regions provide a home to elk, deer, bear, mountain sheep, mountain lion, beaver, snowshoe rabbits, coyote, chipmunks, squirrels, and various waterfowl. Wildlife is still plentiful in the lower elevation foothills, canyons and deserts, which supply homes for sage and sharptailed grouse, jack and cottontail rabbits, coyotes, bobcats, pheasants, ground squirrels, waterfowl, and others (U.S. Economic Research Service et al. 1966 and 1969). These communities could be substantially affected by industrial development during the next 15 years, particularly by strip mining and reclamation activities, and reservoir construction.

TABLE 9. CRITICAL HABITAT AND SPAWNING PERIOD CRITERIA FOR SOME FISH SPECIES FOUND IN THE WHITE AND YAMPA RIVER BASINS*

Common Name	Scientific Name	Habit Preferences	Spawning Period	Status of Species in Analysis Area†
Rainbow trout	<u>Salmo gairdneri</u>	Water temperature of 10-16°C; can adapt to almost any coldwater environment; exhibits best growth in warmer, richer lakes and streams at lower elevations	Spring, April to June	Most abundant game fish in analysis area, frequently stocked in both lakes and streams by Colorado Division by wildlife on an annual basis
Brook trout	<u>Salvelinus fontinalis</u>	Water temperature of 13-16°C; mountain streams and lakes above 2,743 meters	Fall, generally October	Common; mainly in lakes and small, clear streams at high elevation
Cutthroat trout	<u>Salmo clarki</u>	Prefer colder water than their near relative, the rainbow; typically found in headwaters of high mountain streams and in mountain lakes	Spring, April to June	Only trout native to Colorado; abundance has been greatly reduced; usually present at higher elevations
Brown trout	<u>Salmo trutta</u>	Most versatile of trouts; can adjust to almost any cold water habitat	Fall, normally October	Present, generally in larger streams and lakes at lower elevations
Mountain whitefish	<u>Prosopium williamsoni</u>	Larger rivers with good pools, three or four feet deep with riffle areas and gravel bottoms	Fall	Present in larger drainages such as the Yampa and Elk Rivers
Flannelmouth sucker	<u>Catostomus latipinnis</u>			
Longnose sucker	<u>Catostomus catostomus</u>	High lakes, reservoirs and streams	Late spring	Present in major drainages
White sucker	<u>Catostomus commersoni</u>	Lakes and reservoirs; pools in streams where there is much cover from bank vegetation	Spring and early summer	Abundant in reservoirs, lakes, and tributary streams
Bluehead sucker	<u>Catostomus discobolus</u>			
Colorado squawfish‡	<u>Ptychocheilus lucius</u>	Historically, larger streams in Colorado River Basin	Early spring	Present in Yampa and White Rivers
Channel catfish	<u>Ictalurus punctatus</u>	Warm water rivers and reservoirs	Late spring or early summer	Present in lower, warm reaches of larger streams and in warm water lakes
Carp	<u>Cyprinus carpio</u>	Warm shallow water with plenty of aquatic vegetation	Late May to early June	Present in Little Snake, Yampa, and White Rivers and Rio Blanco Lake
Bonytail‡	<u>Gila elegans</u>	Historically, larger streams in the Colorado River Basin	Late June to early July	Present in Yampa and White Rivers

(continued)

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*Modified from U.S. Department of Agriculture (1974) and U.S. Bureau of Land Management (1976d), common and scientific names of fishes are from Bailey, et al. (1970).

TABLE 9. (Continued)

Common Name	Scientific Name	Habit Preferences	Spawning Period	Status of Species in Analysis Area[†]
Red Side Shiner	*Richardsonius baltaetus*			
Humpback chub[‡]	*Gila cypha*	Historically, canyon areas of large streams in the Colorado River Basin	Not known	Present in Yampa and White Rivers
Humpback sucker[§]	*Xyrauchen texanus*	Historically, in slack waters of large rivers or impoundments of the Colorado River system	March to June	Present in Yampa and White Rivers
Mottled sculpin	*Cottus bairdi*	Small mountain trout streams	Spring	Common in trout streams
Green sunfish	*Lepomis cyanellus*	Warm water fisheries habitats	June to mid-August	Present in Axial Basin, Ralph White, and Rio Blanco Reservoirs
Black bullhead	*Ictalurus melas*	Warm water fisheries habitats	Late spring or early summer	Present in Axial Basin, Ralph White, and Rio Blanco Reservoirs
Northern pike	*Esox lucius*	Warm water lakes and reservoirs	Early spring	Present in Ralph White and Rio Blanco Reservoirs
Yellow perch	*Perca flavescens*	Warm water fluctuating reservoirs	Spring	Present in Axial Basin Reservoir
Black crappie	*Pomoxis nigromalulatus*	Clear, weedy lakes	Spring	Present in Axial Basin Reservoir
Largemouth bass	*Micropterus salmoides*	Warm water, fluctuating, heavily vegetated reservoirs	Late May through June	Present in Axial Basin Reservoir
Kokanee salmon	*Oncorhynchus nerka*	Large, fluctuating mountain reservoirs	Mid-October to late December	Present in Crosho Lake
Speckled dace	*Rhinichthys osculus*	Small to moderate-sized swift streams	Spring	Common in trout streams

[†] Abundant = species is plentiful in analysis area; common = species is found regularly in analysis area; present = species is found occasionally in analysis area.

[‡] Colorado list of endangered species.

[§] Colorado list of threatened species.

MINERAL RESOURCES

Fossil fuel resources are located throuhgout the Yampa and White River Basins. The area contains reserves of petroleum, natural gas, coal, and oil shale along with the nonfossil resources of gold, copper, uranium, zinc, iron, vanadium, lead, molybdenum, fluorite, silver, and sand and gravel (U.S. Economic Research Service et al. 1966 and 1969). Dawsonite and nahcolite, two sodium minerals, are also present in commercial quantities. These are found in, or associated with, the oil shales of the Piceance Basin. Dawsonite contains aluminum and is a potential source for that ore. Nahcolite can readily be recovered during the crushing step necessary for surface retorting of oil shale and recovered as soda ash (U.S. Department of Interior 1973). Gilsonite, a tar-like substance, is also mined in the area. Although it is a potential oil source, it presently finds wide application for other purposes.

Since 1950, Rio Blanco County (which includes most of the White River Basin) has been the largest producer of natural gas and oil in the state of Colorado (U.S. Economic Research Service et al. 1966). Of greatest potential significance to the basin, however, are the oil shale deposits occurring in the Green River Formation that underlies the Piceance Creek drainage area and are the largest known deposits of shale in the world. Development of a mature industry in the White River Basin could produce 159 million liters (1 million barrels) of shale oil per day (Kinney et al. 1979), and would substantially augment existing domestic petroleum supplies. In the Yampa River Basin, petroleum, natural gas, coal, and sand and gravel are the most important minerals produced (U.S. Economic Research Service et. al. 1969).

SECTION 5

ENERGY RESOURCE DEVELOPMENT

ACTIVE DEVELOPMENT

Oil and Gas

Production of domestic oil and gas is a major industry in the White and Yampa River Basins (Figure 7). In 1973, there were a large number of producing oil and gas fields in Moffat, Rio Blanco, and Routt Counties (Table 10), with an annual production of 3.5 billion liters (22 million barrels) crude oil and 1,551 m^3 natural gas (Table 11). These three counties accounted for 60 percent of the Colorado state total petroleum yield, and 30 percent of the natural gas production: value of this oil and gas amounted to 120 million dollars in 1973, compared to only 20 million dollars from 1973 coal production in the study area (U.S. Bureau of Land Management 1976a).

Oil and gas production in the Yampa Basin is primarily from the western Powder Wash and Hiawatha fields; the Rangely and Wilson fields are the largest producers in the White Basin (U.S. Economic Research Service et al. 1966 and 1969). Exploration activity in the study area is heavy, and it is expected that oil and gas operations in northwestern Colorado should continue for another 40 years (U.S. Bureau of Land Management 1976a). Such predictions, however, are based upon discovery of new and improved recovery methods as well as additional sources. In particular, extraction of gas using various gas stimulation techniques such as advanced hydrofracturing and nuclear fracturing has been considered. Project Rio Blanco in the Piceance Creek was conducted by the U.S. Energy Research and Development Administration to test the feasibility of nuclear fracturing for the release of gas from low permeability reservoirs that could not be recovered economically by conventional means (U.S. Atomic Energy Commission 1972). Such methodology, however, is still in the investigative stages. Previous fracturing experiments in the San Juan Basin in 1967 and in Garfield County in 1969 were unsuccessful at yielding desired amounts of gas, and resulted in numerous irreversible environmental impacts to the surrounding area. These impacts include: architectural damage resultant from surrounding ground motion, the release of low levels of radioactivity during periods of testing to air and water supplies, and deposition of radioactive materials onto bedrock (U.S. Atomic Energy Commission 1972).

It should be noted that extensive oil and gas development can at times conflict with potential uranium exploration and coal mining operations (U.S. Bureau of Land Management 1976a). For example, in many locations, oil or gas occurs below coal beds, and simultaneous operation of a coal mine and producing oil or gas field is difficult. Careful planning is necessary if

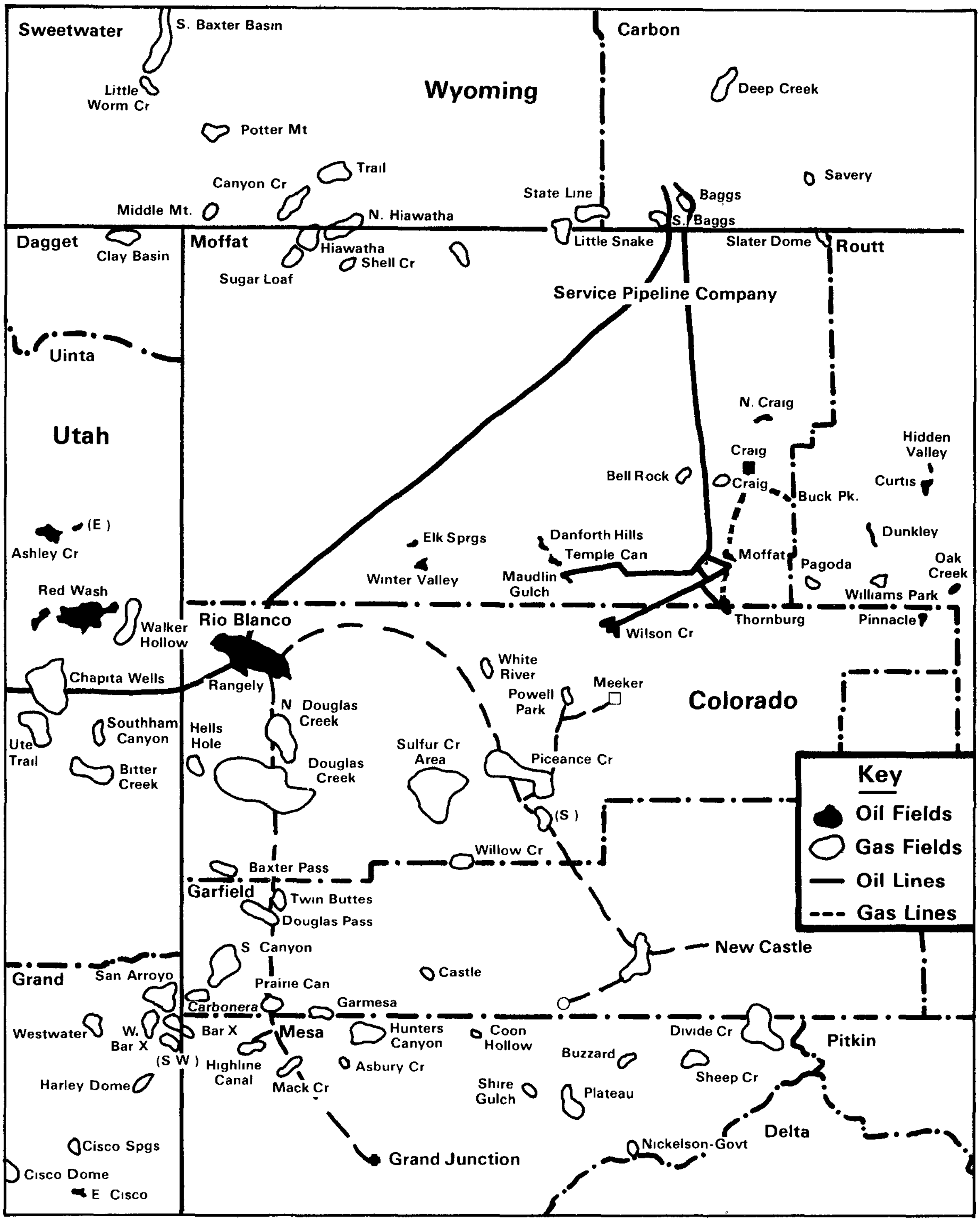

Figure 7. Oil and gas fields and pipelines in the Yampa and White River Basins. (modified from Beebe 1962).

TABLE 10. OIL AND GAS FIELDS IN THE WHITE AND YAMPA RIVER BASINS, COLORADO (modified from Brainerd and Carpen 1962, and Turner 1962)

Field Name	Year of Discovery	Producing Formation	Oil*	Gas*
Ace		Fort Union, Wasatch	m	M
Baggs, South		Wasatch, Fort Union, Lewis		M
Battlement		Mesaverde		M
Baxter Pass	1958	Dakota, Morrison		M
Baxter Pass, South	1959	Burro Canyon or Buckhorn, Morrison		M
Bell Rock	1930	Mesaverde	M	
Big Gulch	1960	Mesaverde, Frontier		M
Buck Peak, Mesaverde-Mancos		Mesaverde, Mancos		M
Niobrara	1957	Niobrara	M	
Shinarump		Shinarump	M	m
Weber	1957	Weber	M	
Castle	1957	Wasatch		M
Cathedral Creek		Mancos		M
Colorow		Niobrara	M	
Craig	1932	Mesaverde (Mancos, Frontier, Entrada, Shinarump)†		M
Craig, North	1956	Lewis		M
Crosho Lake		Shinarump	M	
Currier		Mesaverde		M
Curtis	1958	Niobrara	M	m
Danforth Hills and North	1954/58	Morrison, Entrada, Moenkopi, Weber	M	m
Debeque		Mesaverde	M	m
Douglas Creek	1943	Mancos, Dakota, Burro Canyon or Buckhorn	m	M
Douglas Creek, North and West	1956	Mesaverde-Mancos, Weber‡	m	M
Dragon Trail	1959	Mesaverde (Emery)		M
Elk Springs	1947	Dakota, Weber	M	
Elkhorn		Niobrara	M	
Fawn Creek	1960	Green River, Mesaverde	m	M
Four Mile Creek	1959	Lance, Lewis		M
Grand Mesa	1958	Mesaverde		M
Grassy Creek	1959	Niobrara	M	m
Hells Hole	1952	Mesaverde		M
Hiawatha and West	1927/56	Fort Union, Wasatch, Lance, Mesaverde	m	M
Hidden Valley	1957	Niobrara	M	
Horse Draw, Lower	1961	Mesaverde		M
Horse Gulch		Niobrara	M	
Iles	1927	Mowry, Morrison, Entrada, (Weber)	M	m
Indian Run	1956	Dakota		M
Lay Creek		Wasatch, Fort Union, Lance		M
Little Snake		Wasatch, (Fort Union)		M
Mauldin Gulch	1947	Morrison, Entrada, Weber	M	
Missouri Creek		Morrison		M
Moffat, Niobrara	1924	Niobrara	M	
Dakota		Dakota	M	
Morrison		Morrison	M	
Entrada		Entrada	M	
Shinarump	1954	Shinarump	M	
Weber	1959	Weber	M	

(continued)

TABLE 10. (Continued)

Field Name	Year of Discovery	Producing Formation	Oil*	Gas*
Oak Creek	1949/62	Shinarump	M	
Overland Reservoir		Mesaverde		M
Pagoda	1948	Shinarump		M
Piceance Creek	1930	Wasatch, Green River, Mesaverde		M
Piceance Creek, South	1955	Wasatch	M	m
Pinnacle	1957	Dakota, Shinarump	M	
Powder Wash	1931	Fort Union, Wasatch	M	m
Powell Park	1957	Lance, Lewis		M
Rangely, Shale	1902	Niobrara, Mancos	M	
Dakota		Dakota		M
Shinarump		Shinarump, (Entrada, Morrison)	M	
Weber	1933	Weber	M	
Rangely, Southeast		Dakota	M	
Sage Creek	1959	Niobrara	M	
Sage Creek, North	1960	Niobrara	M	
Scandard Draw	1958	Mesaverde		M
Seely Dome		Niobrara		M
Shell Creek	1955	Fort Union, Wasatch		M
Slater	1954	Mesaverde-Mancos		M
State Line	1958	Dakota, Morrison		M
Sugar Loaf	1953	Lewis, Mesaverde		M
Sulfer Creek	1959	Fort Union, Green River, Mesaverde		M
Sulfer Creek, South	1959	Green River, Wasatch, Mesaverde		M
Taylor Creek		Dakota		M
Temple Canyon, Niobrara	1953	Niobrara	M	
Morrison		Morrison (Dakota)	M	m
Thornburg	1925/55	Dakota, Entrada, Weber	M	M
Tow Creek	1924	Niobrara	M	
Twin Buttes	1951	Morrison		M
Webster Hill		Mesaverde		M
White River	1960	Wasatch, Mesaverde		M
Williams Park		Frontier, Niobrara, Dakota	m	M
Willow Creek	1956	Wasatch, Mesaverde		M
Wilson Creek	1938	Morrison, Entrada, Weber	M	
Winter Valley	1956	Dakota, Weber		M
Wolf Creek	1961	Mesaverde		M

*m = minor product, M = major product.

†(formation) - indicates formation, contains minor shows or is currently sub-commercial.

‡Mesaverde - Mancos indicates transition zone, either Mesaverde or Mancos.

all mineral resources are to be extracted from a common field with a minimum of permanent environmental impact.

Coal

Substantial amounts of fossil fuels must be extracted in the near future in order for the United States to both satisfy increasing energy demands and achieve energy self-sufficiency. Coal, 1000 kg of which is equivalent to

TABLE 11. OIL AND GAS PRODUCTION IN THE YAMPA AND WHITE RIVER BASINS (modified from U.S. Bureau of Land Management 1976a)

	Moffat County	Rio Blanco County	Routt County	Total
Number of producers wells	183	572	12	767
1973 Production:				
Oil (million liters)	164.7	3,303.2	10.0	3,477.9
Gas (thousand cubic meters)	752.5	793.4	35.4	1,581.3
Cumulative Production to 1-1-74:				
Oil (million liters)	8,046.1	90,304.4	650.2	99,000.7
Gas (thousand cubic meters)	11,194.1	27,215.5	14,411.1	52,820.7

the heating value of 788 liters of oil, is the most likely candidate to be used to offset shortages in domestic gas and liquid fuel production. This is particularly true since coal is the nation's most abundant and widely distributed fuel resource, with total existing reserves estimated at over 1,415 trillion kg (Grim and Hill 1974). Already coal is gaining in importance in the generation of western electrical power, and the decline of natural fuel supplies has also promoted research into conversion of coal to gas and liquid fuels through gasification and hydrogenation. It is estimated that the national projected need for coal will rise from a 1974 level of 547 billion kg to 1.2 trillion kg in 1980 and 1.9 trillion kg in 1985 (Atwood 1975).

Most of the coal resources in the United States (72 percent) are found in the Rocky Mountain and Northern Great Plains States (Atwood 1975). This coal is particularly attractive because 43 percent is located in thick seams (2-40 m), and is close enough to the surface to strip mine (Atwood 1975). The size of western coal fields is also well suited to the establishment of large adjacent gasification and liquefaction plants.

In the Yampa and White River Basins, coal development is primarily centered in the state of Colorado (Figure 8), which ranked eighth in the nation in bituminous coal reserves (Speltz 1976). Coal production in Moffat County in 1977 was almost double that of 1976 due to increasing surface and underground mine development, and in 1977 Routt County was the largest coal producing county in the state (Colorado Division of Mines 1977). It is estimated that over 900 billion kg of strippable coal exist in the study area (Speltz 1976). Those coal beds of greatest economic interest occur in the Iles and Williams Fork formations of the Mesaverde Group, and the Lance, Fort Union, and Wasatch formations (Figure 9). Heat content for coal in this area

Company	Mine	Location
Colowyo Coal Company	Colowyo Strip	1
Empire Energy Corporation	Williams Fork Strip	2
	Eagle #5	3
	Eagle #9	4
Utah International, Inc.	Trappers Strip	5
Sewanee Mining Company, Inc.	Rienau #2	6
Energy Fuels Corporation	Energy Strip #1	7
	Energy Strip #2	8
	Energy Strip #3	9
Pittsburg & Midway Coal Mining Company	Edna Strip	10
Seneca Coals Ltd.	Seneca Strip #1	11
Sun Coal Company, Inc.	Meadows Strip # 1	12
Sunland Mining Corporation	Apex #2	13
Jim Tatum	Blazer.	14
Yampa Mining Company	Hayden Gulch Strip	15
Rock Castle Coal Company	Mine #1 Strip	16

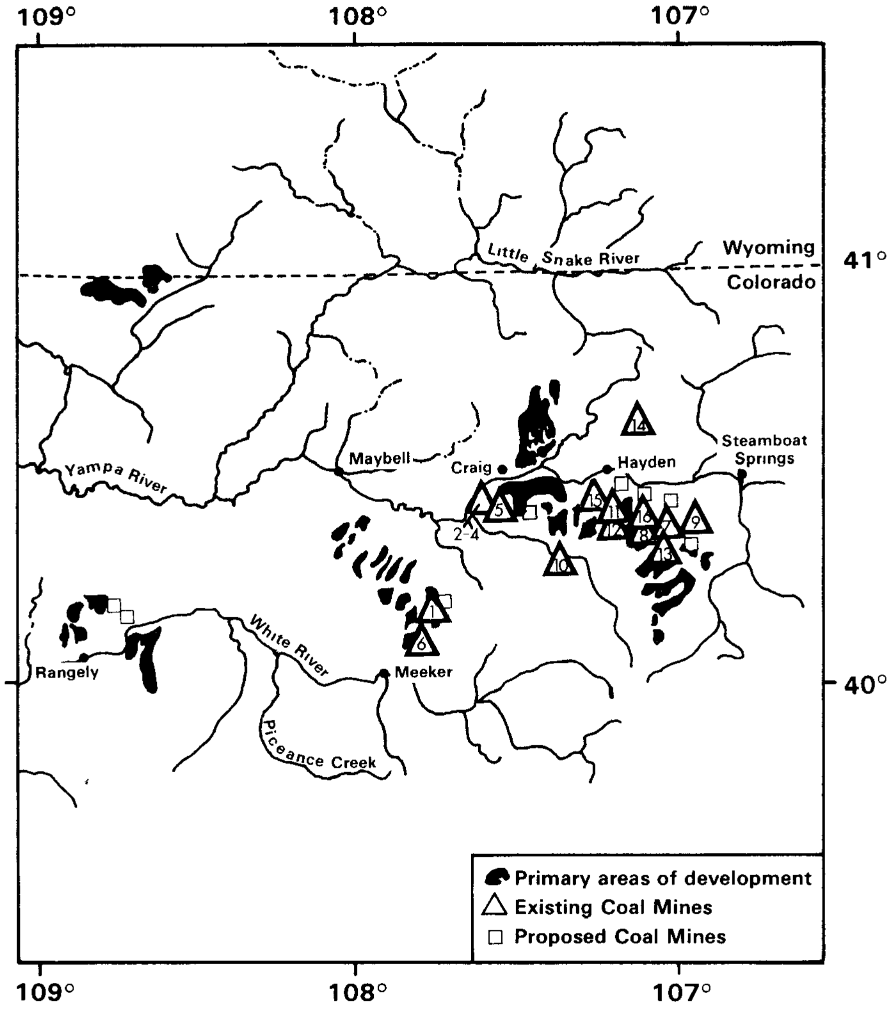

Figure 8. Location of coal mines in the Yampa and White River Basins.

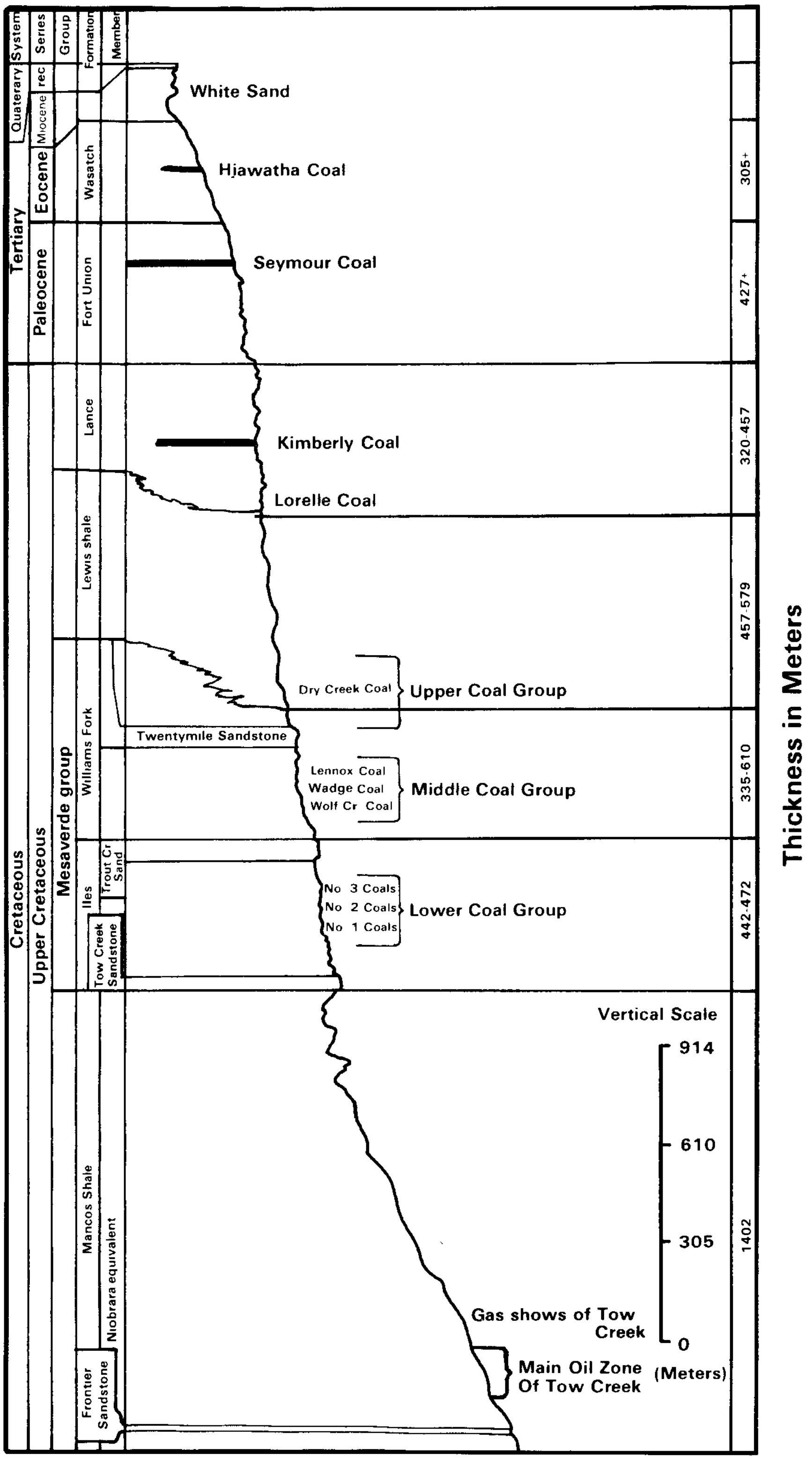

Figure 9. Stratigraphic section of coal bearing formations of northwestern Colorado. (U.S. Bureau of Land Management 1976a)

ranges from 26,116 joules/gm to 31,721 joules/gm (Speltz 1976). Sulfur content is low, ranging from 0.2 to 2.8 percent, with most samples containing less than 1 percent.

Annual coal production in northwestern Colorado is expected to reach more than 18 billion kg by 1990, a five-fold increase over 1974 production levels (Steele et al. 1976a). At present, most of this coal (85 percent) is transported out of the study basins by unit train, with the remainder used in local conversion to electric power (14 percent) and marketing for heating (Steele 1976). There are 16 coal mines currently operating in the study area (Table 12), but a number of additional mines and expansions to existing facilities are planned (Table 13) to meet projected production levels. A brief discussion of the existing mining operations follows below.

W. R. Grace and Company--

The W. R. Grace Coal Company began operations at Colowyo Mine in 1976 but was not the first company to mine the area. The area was first mined in 1914 by the Collum Coal Company which changed names several times in the course of its history. The current operation is located in the Danforth Hills coal field approximately 40 km southwest of Craig. The company has estimated its recoverable reserves to be near 149 billion kg; in 1978 the mine produced over 775 million kg (Table 12). During the thirty year life of the mine, approximately 77 billion kg are expected to be removed and 6.1 km^2 disturbed (U.S. Bureau of Land Management 1976b).

At present, the coal mined at the W. R. Grace site is distributed to various consumers throughout the state, including the city of Colorado Springs for use in the Martin Drake Power Plant. W. R. Grace has plans also for construction of an additional railroad spur to transport coal from the mine to a loading facility to be constructed 40 km away south of the Yampa Project generating station (U.S. Bureau of Land Management 1976b).

The potential environmental impacts of the Colowyo Mine and associated developments are well defined by the U.S. Bureau of Land Management (1976b). However, runoff from potential impact areas, particularly in the Good Spring Creek drainage, should be closely monitored to assure that both surface and ground-water resources are not adversely affected.

Empire Energy Corporation--

Three mines in the study area, the Williams Fork strip mine, and the Eagle #5 and the Eagle #9 (both underground) mines are owned and operated by the Empire Energy Corporation. The three mines are located in Moffat County within 3 km of each other. The Corporation began mining in 1969 and currently total operations for all three mines cover 37 km^2 of land (Personal communication, 1979, S. Langley, Empire Energy Corporation, Denver, Colorado). Coal from all three facilities is shipped to the Union Electric Power Company in Rushtower, Missouri, and to the Iowa Electric Power Company in Crandic, Iowa.

The Eagle #5 (Wise Hill #5) mine was opened in 1969; in 1978 the mine produced approximately 417.6 million kg of coal from its underground facilities during the first 10 months (Table 12). The mine, located near the

TABLE 12. COAL MINES CURRENTLY OPERATING IN THE YAMPA AND WHITE RIVER BASINS*

County	Company	Mine	Jan-Oct 1978 Production (million kg)
Moffat	W. R. Grace and Company	Colowyo Strip	775.6
	Empire Energy Corporation	Williams Fork Strip	189.4
		Eagle #5 (=Wise Hill #5)	417.6
		Eagle #9 (=Wise Hill #9)	66.7
	Utah International, Inc.	Trappers Strip	1,800.0†
Rio Blanco	Sewanee Mining Company, Inc.	Rienau #2	17.7
Routt	Energy Fuels Corporation	Energy Strip #1	2,250.0
		Energy Strip #2	189.8
		Energy Strip #3	191.1
	Pittsburgh & Midway Coal Mining Co.	Edna Strip	703.4
	Peabody Coal Company	Seneca Strip #1	1,046.1
	Sun Coal Company, Inc.	Meadows #1	153.2
	Sunland Mining Corporation	Apex #2	13.1
	Jim Tatum	Blazer	--
	H-G Coal Company	Hayden Gulch Strip	3.2‡
	Rock Castle Coal Company	Mine #1 Strip	5.0

*Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver, Colorado, and D. Eubanks, H-G Coal Company, Hayden, Colorado.

†Production to date.

‡Total 1978 production.

TABLE 13. PROPOSED COAL MINES FOR THE WHITE AND YAMPA RIVER BASINS (modified from Corsentino 1976)

Mine Name and Location	Operator	Mine Type	Planned Annual Production (million kg in year)	Planned Markets	Remarks
Unnamed, 32 km west of Steamboat Springs, Routt County	Coal Fuels, Rollinsville, Colo.	Underground	1,814-1980		Start-up in 1977. Plans and markets unknown.
Unnamed, 5 km north of Pagoda, Routt County	American Electric Power (AEP) System	Strip	907-1980, 1,270-1985	AEP powerplants, eastern United States	Start-up in 1981. Operation and plans are unknown.
Unnamed, SW of Steamboat Springs, Routt County	Morgan Coal Company	Strip	unknown		Proposed mine. Plans are unknown.
Unnamed, 14 km north of Meeker, Rio Blanco County	Consolidation Coal Company Denver, Colo.	Underground and Strip	See remarks		Exploratory drilling began in 1974. Plans are unknown. Employment and productions estimates included in Merchant Petroleum production below. Start-up planned for 1981.
Unnamed, 16 km west of Steamboat Springs, Routt County	Merchants Petroleum Company	Strip	3,991-1980 (includes Consolidation Coal Company, and T. C. Woodward)		Employment and production estimate includes Consolidation Coal Company mine above and Woodward mine below. Company leased 21.4 km^2 in Routt County with 91-249 billion kg of reserves. Start-up in 1980.
Unnamed, 19 km west of Steamboat Springs, Routt County	Thomas C. Woodward, Casper, Wyo.	Strip	See remarks		Operator of mine unknown. Employment and production estimates included in Merchants Petroleum estimate above. Start-up in 1980.
Unnamed, 13 km northwest of Rangely, Rio Blanco County	Midland Coal Company	Strip	181-1980, 272-1985		Start-up in 1981. Markets and plans are unknown.
Unnamed, Savery area, Moffat County	Kemmerer Coal Co., Kemmerer, Wyo.	Underground	unknown		Proposed mine. In planning stage. Dependent upon BLM lease approval. Plans unknown.
Unnamed, 6 km west of Rangely, Moffat County	Blue Mountain Coal Company	Strip and underground	unknown	Export	Proposed mine. Completed exploration in late 1974. Old mining operation closed. Plans unknown.
Wilson Creek Mine, 40 km south of Craig, Moffat County	Utah International, Inc., San Francisco, Calif.	Strip	unknown	Export and Craig powerplant	Prospecting completed. Have existing leases. Plans unknown.
Unnamed, (2 mines) 32 km south of Craig, Moffat County and 22 km east of Steamboat Springs, Routt County	Paul S. Coupey	Strip	907-1980	unknown	Mine operators unknown. Proposed mines. Plans unknown.
Gordon Mine, 16 km east of Rangely, Rio Blanco County	Moon Lake Electric Company, Roosevelt, Utah	Underground	1,360-1980 2,086-1985 3,356-1990	Mine-mouth powerplant for oil shale development	Adjacent to old Staley Mine. Market for potential 1,000 MW power complex in late 1980's.

Williams Fork River, pumps 115 liters per minute of ground water for domestic consumption, cooling, and dust control (Personal communication 1979, S. Langley, Empire Energy Corporation, Denver, Colorado). Coal from the mine is also shipped by rail from Craig to Colorado Springs for use in the Martin Drake Power Plant.

The Eagle #9 (Wise Hill #9) underground mine was opened in 1977, and is now producing 68 million kg/year (Personal communication 1979, S. Langley, Empire Energy Corporation, Denver, Colorado). The mine is situated 2 km from the Eagle #5 mine just south of Craig. Water use at the mine site is restricted, with only 57 liters/min ground water pumped for limited usage in fire prevention, domestic consumption by mine personnel, and dust control (Personal communication 1979, S. Langley, Empire Energy Corporation, Denver, Colorado).

The Williams Fork Mine opened in July 1974 and is scheduled to close as soon as an additional 45-54 million kg of coal have been mined (approximately three months). The mine is located south of Craig approximately 91 m off the Yampa River on state and private coal leases but does not divert surface waters for mine use. The Williams Fork Mine has disturbed approximately 121 km^2 land since its opening, and in 1978 mined over 189 million kg coal (Table 12).

Utah International, Inc.--

The Trapper Mine, operated by Utah International, Inc., opened in May 1977, approximately 8 km south of Craig, Colorado. Since 1977, mining activities at the strip mine have disturbed approximately 4.7 km^2 of land and produced over 1.8 billion kg of coal. Annual production is estimated at 2.3 billion kg/year, and impacts approximately 0.81 km^2/year (Personal communication 1979, F. Natter, Trapper Mine, Craig, Colorado).

The Trapper Mine receives its water supply from a pipeline diversion of 1.7 m^3/min from the Yampa River above the Craig Power Plant. This water is used for both potable and dust control purposes. Any drainage is channeled into storage impoundments, where sediment may settle and treatment for the removal of the many effluent salts can be completed (Personal communication 1979, F. Natter, Trapper Mine, Craig, Colorado).

Of the 2.3 billion kg of coal produced annually at the Trapper Mine, 15 percent is shipped to power generation facilities in the midwest such as St. Louis, Missouri. The remaining 85 percent is transported to the Craig Power Plant for power generation.

Sewanee Mining Company, Inc.--

The Rienau #2 Mine is a small underground operation located on federal lease land approximately 2.4 km north of Meeker, Colorado (U.S. Bureau of Land Management 1978a). The Sewanee Coal Company has owned and operated the site since 1977 when it assumed ownership from American Fuels Corporation. In 1978, the mine produced over 17 million kg of coal (Table 12). Sewanee Coal is currently expanding its facilities to modernize the underground mine and begin surface extraction of coal (Colorado Division of Mines 1977a).

Energy Fuels Corporation--

The Energy Fuels Corporation operates three coal surface mines in the Yampa River Basin, and is currently the largest producer of coal in the State of Colorado (Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver, Colorado). The three sites are located in the east-central part of the Yampa Basin near Fish, Foidel, and Middle Creeks. In 1978, yearly production for the three sites exceeded 3.1 billion kg, and the company predicts that production may ultimately surpass 4.5 billion kg/year. If this goal is achieved, as much as 1.4 km^2 of land will be stripped and reclaimed annually by the corporation.

Energy #1 began operations in 1962 and today is the largest of the three mines, with a 1978 production of 2.6 billion kg of coal (Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver, Colorado). The mine, situated on Federal and private lease lands, is located near two other coal operations, the Apex Mine (Sunland Mining Corporation) and the Edna Strip Mine (Pittsburg and Midway Coal Mining Company). The Energy #1 facility is a potential source of pollution to nearby Foidel Creek; already, sediment concentrations in the vicinity of the mine are increasing to the point where annual water temperatures are borderline for many of the cold water species that exist there (U.S. Bureau of Land Management 1976b).

Energy #2 began operations in 1972, and during 1978 produced 0.23 billion kg of coal (Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver, Colorado). The mine parallels Fish Creek in the Yampa Basin. The Energy #3 Mine opened in 1974, and in 1978 produced 0.3 billion kg of coal. In each of the three Energy Fuels mines the majority of the coal production is distributed to nearby coal-fired generating plants at Hayden and Craig.

Each of the three Energy Fuels coal mines are planning expansions for the future, provided they receive the necessary mineral rights and federal leases. The proposed mining activity for the mines may disturb as much as 21 km^2 of land in the Trout Creek watershed during the next 15 years and could cause considerable degradation to the Fish and Foidel Creek watersheds as well. Data at a USGS water quality station (STORET #09244100) in Fish Creek near Milner have already reported cadmium, lead, mercury and iron concentrations in excess of recommended criteria (see Section 8, Table 28), and elevated sediment and total dissolved solids concentrations as well (U.S. Bureau of Land Management 1976b). Excessive concentrations of these parameters are common in areas of coal development (Wachter and Blackwood 1978) and may partially be a result of runoff from the Energy Fuels facilities. However, further investigation is needed to determine the extent to which mining activities are contributing to these pollutant levels in the Yampa Basin.

Pittsburg and Midway Coal Mining Company--

The Pittsburg and Midway Coal Mining Company is a subsidiary of Gulf Oil Corporation and currently operates the Edna surface coal mine. The mine site is located just north of Oak Creek in Routt County on federal, state and private leases, and extracts coal from the Wadge seam in the Williams Fork formation. The mine has operated since 1946, although Pittsburg and Midway have owned the mine only since 1961 (U.S. Bureau of Land Management 1976a).

Annual production at the mine was 1.1 billion kg/year in 1976, but production is expected to drop to 0.9 billion kg/year during 1979, and will continue to decline until the close of the mine in 1991 (U.S. Bureau of Land Management 1976a). Total production on Federal coal leases alone is expected to amount to 1.3 billion kg and will disturb some 6.0 km^2 of land (McWhorter et al. 1975). Over 90 percent of the coal produced at the Edna mine is being consumed by Colorado users, with the majority of that applied to industrial activities (63 percent) and utilities (35 percent) (U.S. Bureau of Land Management 1976a).

Peabody Coal Company--
The Peabody Coal Company opened the Seneca strip mine in 1964 and has since (1974) made application to expand their operations (U.S. Bureau of Land Management 1976a). Current production is approximately 1.3 billion kg/year, and disturbs approximately 0.4 km^2 of land annually with mine operations. The mine is located on the northeast slopes of the Williams Fork Mountains near Hayden and currently supplies coal to the Hayden Power Plant Unit #1. Additional private and state leases are expected to increase coal production by 816 million kg per year in 1980, and will supply coal to the Hayden #2 facility.

Development of the proposed Seneca 2-W Mine site would destroy as much as 0.9 additional km^2 per year and construction of haul roads and surface facilities may require the rerouting of Hubberson Gulch. The Wadge, Wolf and Sage Creek watersheds are also expected to be impacted through the expansion. Although removal of vegetation in the mined area will increase the potential for runoff, increasing absorption by mine spoils and surface drainage into mine pits could actually result in a net decrease in surface flows (U.S. Bureau of Land Management 1976b).

Sun Coal Company, Inc.--
Sun Coal Company, Inc. opened the Meadows #1 strip mine in August, 1977. The Company plans to operate this site until some time in 1980 at which time it will begin to mine other coal reserves in the area. Current production from the mine is approximately 327 million kg/year (Personal communication 1979, D. Ellison, Sun Coal Company, Milner, Colorado), and mining operations disturb 0.11 km^2 of land annually. However, Sun Coal is investigating the feasibility of converting its new operations into an underground facility, which would impact substantially less land in the future. Coal from the existing mine is shipped via train to Denver, and ultimately to Illinois.

At the mine site, two wells supply 0.13 million m^3 of water annually which is used for dust control, treatment of coal, and domestic purposes (Personal communication 1979, D. Ellison, Sun Coal Company, Milner, Colorado). Ground water runoff from the facilities is channeled into large sedimentation holding ponds for evaporation. Any additional runoff from the mine generated by precipitation crosses the Seneca strip mine and ultimately flows into Grassy Creek.

Sunland Mining Corporation--
The Apex #2 Mine, owned and operated by the Sunland Mining Corporation, is an underground facility located near Oak Creek in the upper Yampa River Basin.

The 1978 coal production at the site was approximately 13 million kg, most of which was used for domestic heating (Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver Colorado). Presently, however, the mine has ceased production.

Jim Tatum--
The Blazer Mine, which is located near Deep Creek, to the north of Hayden, was purchased by Jim Tatum in 1976, but has been closed down since that time (Personal communication 1979, A. Deborski, Colorado Division of Mines, Denver, Colorado). The mine is not expected to begin operation in the near future, and presently poses little threat to water quality in the Yampa Basin. However, should mining activities resume, monitoring activities to assess environmental impacts associated with the facility should be reactivated.

H-G Coal Company--
The Hayden Gulch Strip Mine was opened in July of 1978 by the H-G Coal Company. Total 1978 production was 3.2 million kg, all of which was transported out of state to the Celanese Textile Company in Texas (Personal communication 1979, D. Eubanks, H-G Coal Company, Hayden, Colorado). H-G Coal has submitted plans for disruption of 5.7 km^2 of land during the projected nine year life of the mine. To date, approximately 0.5 km^2 have been disturbed as a result of development of both the mine and associated transportation facilities.

The Hayden Gulch Mine is located 23.3 km south of Hayden, in the Williams Fork Mountains. Loading facilities for mining operations are situated approximately 15 to 18 km north of the mine; during maximum production, coal is shipped from the site every four days via a 73 car unit train (Personal communication 1979, D. Eubanks, H-G Coal Company, Hayden, Colorado). Currently, however, the mine is not transporting any coal, although shipments to the Celanese Textile Company are expected will resume in July of 1979.

Wastewaters from the mine operations are discharged into settling ponds. Water needed at the mine is provided from two ground-water wells, and is released at a rate of 0.04 to 0.06 m^3/min for treatment and cleaning of coal, dust control, and domestic use. At the loading facilities north of the mine as much as 0.57 m^3/min is pumped to satisfy water requirements (Personal communication 1979, D. Eubanks, H-G Coal Company, Hayden, Colorado).

Rock Castle Coal Company--
The Rock Castle Company owns and operates Mine #1 (Grassy Creek Mine), one of the newest coal mines in the study area. The company began operations in 1978 and during that year produced over 5 million kg of coal (Table 12). Plans are underway to enlarge mining operations in the near future.

Reclamation--
Successful rehabilitation of the existing and proposed mining areas in the Yampa and White River Basins rests not only on the physical potential of the land but also upon an effective administrative policy. In past years, reclamation of surface mines in the study area ranged from nothing to very little, with any rehabilitation attempts carried out subsequent to cessation

of mining activities (U.S. Bureau of Land Management 1976a). Modern day coal leases, however, generally require concurrent reclamation of mine sites, which is a more cost-efficient means of restoring the mine sites to original condition (Grim and Hill 1974). Reclamation activities include making the reclaimed site safe and acceptable in appearance (including regrading soils to approximate original terrain, and replacing topsoil and vegetation), and returning the site to a productive status (that would benefit livestock/ wildlife or recreational users).

Mine sites throughout the area are required to evaluate their proposals in an environmental impact statement that should include determination of the various plant species established in the environment, and which method of rehabilitation is appropriate for the region. One of the major factors determining the quality of an area for rehabilitation is the amount of precipitation and the subsequent potential for erosion runoff. Reclamation of stripped areas is difficult in regions of low precipitation where sufficiently large quantities of water are not available to allow for plant cover necessary for long-term stability of the surface. In the downstream stretches of the Yampa and White River Basins, where precipitation is below 25 cm per year, the likelihood of having land that is difficult to restore is much greater than in the higher elevations upstream where precipitation may be greater than 50 cm per year.

Administrative planning for rehabilitation activities is not only the responsibility of the mining developer but also that of the state and federal government. In Colorado, the Mined Land Reclamation Act of 1976 outlined the state regulations that developers must meet before being granted a lease to mine (Personal communication 1979, B. Campbell, Colorado Departmment of Natural Resources, Denver, Colorado). It contains a clause that insures money will continue to be available to implement reclamation, even if the operating company should have no capital at the end of the life of the mine (Personal communication 1979, B. Campbell, Colorado Department of Natural Resources, Denver, Colorado). The Utah Mined Land Reclamation Act of 1975 outlines similar rules that will affect the developers in Utah (Personal communication 1979, R. Daniels, Utah Department of Natural Resources, Salt Lake City, Utah). In August of 1977, Congress passed the Surface Mining Control and Reclamation Act in response to accumulated concern over the extensive environmental impact caused by strip coal mining. This Act outlines the proper procedures for restoration of Federal, State or private lands, and provides information to be used as a basis for predictions regarding the suitability of impacted lands for rehabilitation activities (U.S. Bureau of Land Management 1978).

Oil Shale

Oil shale is defined as "a fine grained rock that contains varying amounts of organic material called kerogen which upon pyrolysis, or retorting, yields a synthetic oil and gas" (U.S. Energy Research and Development Administration 1977). Oil shale deposits are found throughout the United States but the richest reserves exist in the Green River Formation in Colorado, Utah and Wyoming (Figure 10). Of the high grade shale in the formation (i.e., that which yields greater than 0.1 liter/kg of rock), approximately 80 percent is located in the Piceance Basin (Gold and Goldstein 1978). It is estimated that

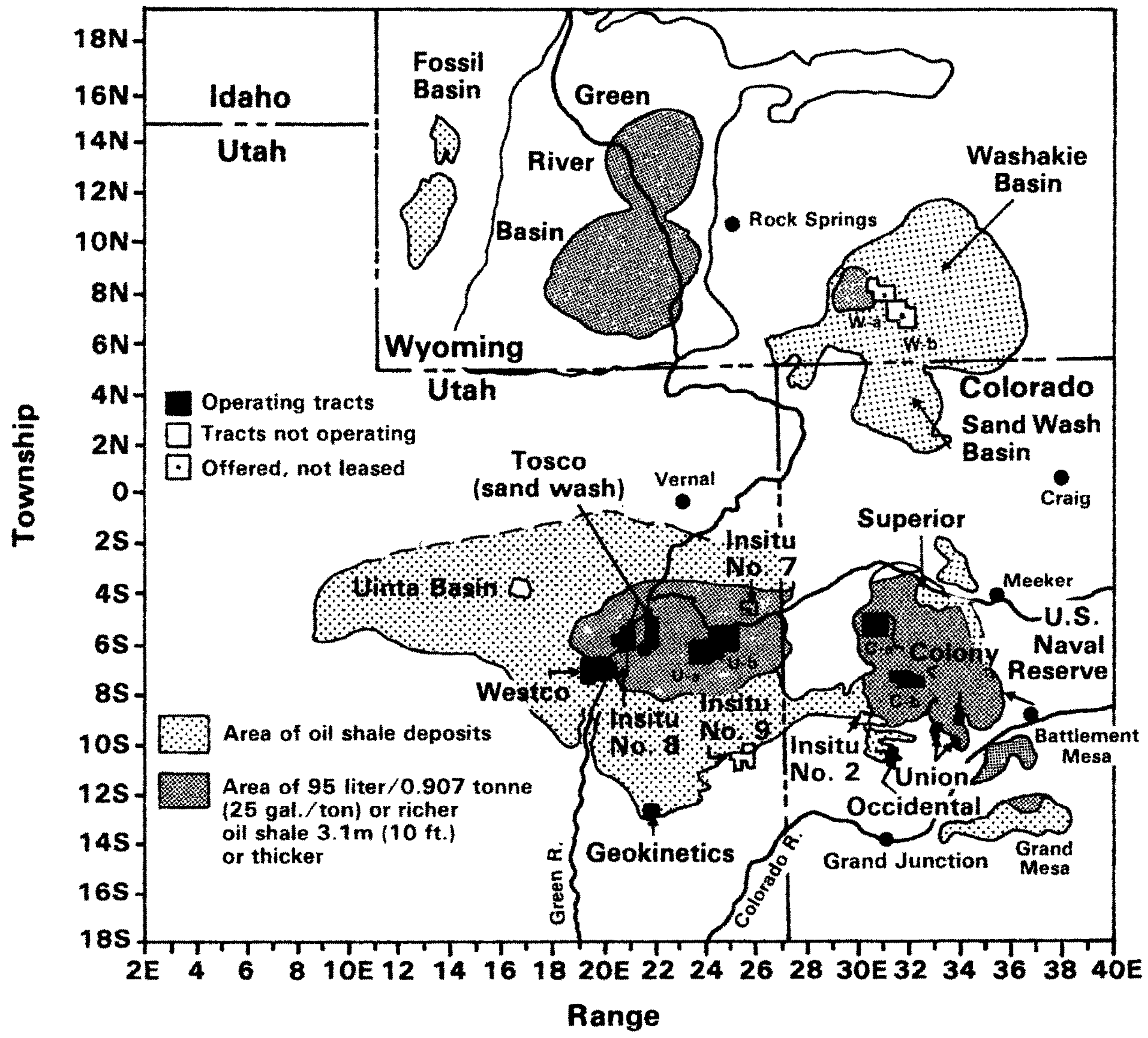

Figure 10. Oil shale development activities in the Green River formation. (modified from Slawson and Yen 1979)

approximately 95 trillion liters (600 billion barrels) of oil equivalent are available in the shale deposits of the Green River Formation (Slawson and Yen 1979). This value is equal to 100 years petroleum supply at 1977 consumption rates (Harbert and Berg 1978).

In the early 1970's a federal prototype oil shale leasing program was created which would assess the anticipated environmental impact of development and operation of a small-scale industry using various mining and processing technologies (Kinney et al. 1979). To this end, four tracts of public land, two in the Piceance Basin in Colorado (C-a, C-b), and two in the White Basin in Utah (U-a, U-b) were leased by industry from the Federal government in 1974. Attempts to lease two additional tracts in the less oil-rich Wyoming shale area were unsuccessful (University of Wisconsin 1976). Each of the four lease tracts are 6.1 km^2 in size; if small scale development activities ongoing here (Table 14) prove environmentally acceptable, it is hoped that a mature commercial industry may evolve. Full discussion of the lease provisions, which include mandatory self-monitoring by industry prior to, during, and subsequent to developmental activities, is available from the U.S. Department of Interior (1973).

A mature oil shale industry in the study basins would produce 159 million liters (1 million barrels) per day of oil. Detailed explanation of the various retorting processes in developmental stages can be found in Jones et al. (1977), Shih et al. (1976), and in the environmental impact statement for the prototype oil shale leasing program (U.S. Department of Interior 1973). However, in general, there are three retorting processes being investigated to produce the shale oil: surface or above ground, in situ, and modified in situ. Each of these potentially could severely impact the environment during the mining, crushing, conveying, retorting and ugrading stages of operation (Table 15). In particular, considerable potential exists for contamination of ground water by oil shale activities, a serious problem in light of the existing high salinity of regional ground-water resources, especially in the Piceance Basin (University of Wisconsin 1976). Development of the oil shale industry would involve massive solids handling problems: approximately 66.7 million kg/day of raw oil shale containing 114 liters of oil per ton of shale must be extracted to support a small 7.9 million liters (50,000 barrels)/day industry (Jones et al. 1977). Disposal of these massive volumes of spent shale, which occupy a larger volume than the raw ore before oil extraction, is one of the biggest environmental problems associated with the industry; up to 2.0-4.0 km^2 of mesa land or canyon fill could be required annually for disposal of spent shale in a mature industry (Harbert and Berg 1978). Stabilization and revegetation of these shale disposal sites also produce environmental difficulties of their own (Table 16).

If extraction of the regional shale oil should prove to be environmentally and economically acceptable on a prototype scale, the single factor that will eventually limit commercial industry size will be water availability (Kinney et al. 1979). Virtually all phases of the industry consume water, with disposal of the processed shale and oil upgrading having the greatest consumptive use requirements. Water use requirements for a mature industry would range from 149 to 233 million m^3/year (Kinney et al. 1979). In 1978 the Bureau of Reclamation stated, "Unless there are breakthroughs in technology, shale oil is not expected to be competitive with oil and gas until their prices rise considerably above current levels. Even then, shale development might not be competitive because historically increases in prices have tended to lag behind increases in cost." Slawson and Yen (1979) estimate that by 1985, shale oil probably will still account for only about 1 percent of total

TABLE 14. PROJECTED OIL SHALE ACTIVITIES IN THE GREEN RIVER FORMATION, July 1978-85 (personal communication 1978, T. Thoem. EPA. Denver, Colo.)

Projects	1978	1979	1980	1981	1982	1983	1984	1985
Occidental, Logan Wash and Tract C-b	Burn retort #6	Mine rubblize retorts #7, #8	Burn retorts #7, #8 Mine, rubblize #9, #10	Burn retorts #9, #10	Construct initial retorts on C-b		Test burn initial retorts	
	Sink shafts, construct facilities on Tract C-b					Construct retort cluster A-2	Construct commercial mine	Test, burn cluster A-2
Project Rio Blanco (Tract C-a)	Shaft sinking Mining experimental retort	Rubblize, burn small retorts #1	#2 #3	#4 #5	Rubblize, burn commercial prototype reports #6, #7, etc. Begin commercial mine development, ancillaries			
Union Oil (Commercial module)	Design and engineering Construct experimental mine and plant			Break-in operation	Experimental plant operation			
Paraho (Commercial module)	Complete 100,000 barrels (15.9 million liters) for Navy	Module design and engineering	Construct module plant		Break-in operation	Operate module plant	Design full-scale plant	
Colony-Tosco (Davis Gulch)	Construct and pre-test one or more commercial modules			Operate commercial modules		Construct full-scale plant	Operate full-scale plant	
Development of Naval Oil Shale Reserves (NOSR)	Management plans; engineering analyses; baseline environmental studies		Economic, legal studies baseline environmental studies	Analyze techniques; EIS; environmental studies	Complete EIS, technical studies; costs	Initiate actual development of NOSR (schedule unknown)		
USBM Experimental Deep Mine	Four levels: Level #1 (274 m deep)-mining experiments, including rubblization, Level #2 (512 m deep)-saline zone flow studies, Level #3 (558 m deep)-further hydro studies (nahcolite), Level #4 (610 m deep)-rock mechanics, etc. (dawsonite)							
Geokinetics, Inc. (Uinta Basin)	Small retorts	Drill, blast, retort 6-8 retorts (24 x 9 x 24 m)	Drill, blast, retort 2-5 retorts (37 x 15 x 76 m)-evaluate design	Design commercial operation (schedule unknown) ————(?)				
Equity Oil (Piceance Basin)	Site preparation	Operation of superheated steam injection project in leached zone						
LERC-DOE (other field projects)	White Mountain, etc. ———— (?) - - - - - Schedule in new DOE 50-year plan							
White River Shale Project (Tracts Ua-Ub)	Schedule unknown pending litigation - - - - (?) - - - -							

TABLE 15. POTENTIAL ENVIRONMENTAL CONCERNS ASSOCIATED WITH THE OIL SHALE INDUSTRY (modified from U.S. Energy Research and Development Administration 1977)

Phase	Oil Shale Processes	Physical Disturbances	Pollutant Discharges	Affected Resources	
				Physical	Socioeconomic
Extraction through retorting	Surface retorting	Aquifer local interruption Land disconfiguration (stripmining) Roof collapse Noise (drilling, retorting) Retorted shale waste piles Land subsidence Waste water holding ponds	Runoff or leachate (metals organics, salts) from retorted shale pile Dust from mining, crushing and grinding Fugitive emissions and off-gases from retort (venting to air) Contaminated retort water (metals, organics, salts) in settling ponds Mineralized water from dewatering operations	Water for dust control process cooling and vegetation and community use Secondary recovery of minerals	Financing Labor force
	True in situ	Work site disturbance Subsidence or uplift Noise (drilling, fracturing) Aquifer local interruption Heat	Leachate (metals, organics, salts) from retorted shale into aquifer Fugitive emissions and off-gases from retorting (venting to air) Contaminated retort water (metals, organics, salts) in containment ponds	Water for community use and process cooling	Community services Power
	Modified in situ	Aquifer local interruption Subsidence or uplift Noise (drilling, fracturing) Raw shale waste piles Heat	Leachate (metals, organic, salts) from retorted shale into aquifer Runoff or leachate (mainly salts) from raw shale piles Dust from mining/fracturing Fugitive emissions and off-gases from retorting (venting) Contaminated retort water (metals, organics, salts) in settling ponds	Water for community use, processing, and vegetation of raw shale	Equipment
Upgrade through end-use	All processes	Land disturbances for facilities, roads/other transportation Physical plants	Evaporation and emissions of crude oil volatiles, during storage, upgrading and refining Accidental spillage	Water for upgrade/and use stages and community use	

TABLE 16. SUMMARY OF POTENTIAL WATER POLLUTION PROBLEMS CAUSED BY SPENT OIL SHALE RESIDUES (modified from Slawson 1979)

Source Area	Source Priority Ranking	Potential Pollution Source	Potential Pollutant Ranking		
			Highest	Intermediate	Lowest
Spent shale disposal area	Highest	Spent shale	TDS, Na, SO_4, As, Se, F, organics (PAH, carcinogens)	Ca, Mg, Zn, Cd, Hg, B, organics (phenols, etc.)	Pb, Cu, Fe
		High TDS waste water	TDS	---	---
		Sour water	Ammonia, phenols	Organics	---
		Retort water	As, Cl, S, organics (POM, carboxylic acids, phenols)	TDS, organics (amines etc.)	Carbonates, PO_4, NO_3
		Spent catalysts	As, Mo	Zn, Ni	Fe, Cu, Co
	Intermediate	Stormwater runoff	TDS, organics, As, Se	Na, Ca, SO_4, HCO_3, organics	Zn, Cd, Hg
		Water treatment plant sludges	TDS	Major macroinorganics	Trace metals
		Miscellaneous landfill materials	Sulfides, organics	Sulfides	---
		Sulfur byproducts	Sulfides, sulfates	---	---
		Oily waste waters	Organics	Trace metals	---
		Spent filters	Organics, As	Trace metals	---
	Lowest	Sewage sludge	Organics	Nutrients	---
		Mine water	TDS, oil and grease	Trace metals, organics	Macroinorganics
		Sanitary waste water	Organics	Nutrients	Macroinorganics
		Surface disturbance	Calcium salts, TDS	Macroinorganics	---

oil consumption in the United States. However, in 1979 the President's energy program set a goal of producing 63.6 million liters of oil per day from oil shale by 1990, and the Government is expected to provide substantial funding to achieve that goal (Personal communication, L. McMillion, U.S. Environmental Protection Agency, Las Vegas, Nevada).

Power Plants

The number of existing coal-fired power plants in the Yampa and White River Basins is small; presently, only 14 percent of the coal produced in the Yampa Basin is converted to electric power within the basins (Steele 1976). However, the potential for such development is high. Currently, the only two power plants in the study area are in the Yampa Basin: the Hayden Plant has two units with a total generating capacity of 450 MW, and the Craig Power Plant will have a total capacity of 760 MW from two units upon completion of construction in 1979 (U.S. Bureau of Land Management 1976a). Both plants are operated by the Colorado-Ute Electric Association. The company also has plans to construct two supplementary units at the Craig Station, that will add an additional 760 MW to that facility when full commercial operation is achieved. The only other power facility for the area has been proposed by the Moon Lake Electric Association which is considering the installation of a mine-mouth generating plant (total capacity 1,000 MW) at Hatch Flats, northeast of Rangely (U.S. Bureau of Land Management 1976a). This facility will depend upon development of the oil shale industry in the Piceance Creek area. Suggestions have been made to the BLM (1976a) for the construction of a plant on the Williams Fork River (Yampa Basin), and for four coal conversion plants in Utah near Bonanza (Personal communication 1979, J. S. Merrill, Deserett Generation and Transmission Cooperative, Sanby, Utah).

All of the above power facilities (with the exception of the Hayden #1 Unit, which began operation in 1965) are a result of the Yampa Project. The Yampa Project was created in 1969 when the Colorado-Ute Electric Association, the Public Service Company of Colorado, and the Salt River Project Agricultural Improvement and Power District began cooperative planning for construction of power generating facilities to meet the area's existing and anticipated electrical demands. Colorado-Ute is based in Montrose, Colorado, and supplies power to various consumers, including agricultural, recreational, residential, industrial and mining facilities. The company currently operates the Hayden facilities, as well as three 13 MW coal-fired generating stations outside the study area at Nucla Station (U.S. Bureau of Land Management 1976a). The second of the large distributors, the Salt River Project (based in Phoenix, Arizona), had also contracted for power from Hayden Plant. Other large companies involved with the Yampa Project are the Tri State Generation and Transmission Association, Inc. based in Denver, and the Platte River Municipal Power Association, based in Fort Collins. The Yampa Project was responsible for construction of Elkhead Reservoir, that provides water storage for the operation of the Hayden and Craig Plants during low flow periods. The Trappers strip coal mine provides coal for the existing power generation facilities.

The operation of the existing and proposed power plants should be maintained under the careful scrutiny of state-of-the-art energy conservation requirements. It is estimated that 1.8 billion kg/year of coal would be neccessary to suport 7,200 MW of electrical power generation in the area. If the coal were utilized in mine-mouth power generation, substantial quantities of water could be conserved in transportation and processing. The anticipated maximum annual water consumptive requirements for the Craig station plant will be 23 million m^3, although average consumptive needs will be substantially less (Stearns Rogers, Inc. and Utah International, Inc. 1974). At present, the Hayden power plants divert and consume an estimated 8.6 million m^3/year: the Hayden #1 plant consumes 2.4 million m^3/year, and the Hayden #2 plant consumes 6.2 million m^3/year (Personal communication 1978, S. Mernitz, Colorado Department of Natural Resources, Denver, Colorado). The majority of these consumptive use demands result from evaporative cooling of the condensers; both facilities use surface water from the Yampa River to satisfy water requirements (Steele et al. 1976b).

Uranium

Although uranium mineralization is widespread throughout the study area, the major reserves in the Yampa and White River Basins lie in the Brown Park formation near Lay and Maybell, west of Craig (U.S. Economic Research Service et al. 1969), and north of Rangely near the Colorado-Utah state line. Minor deposits occur in the Precambrian rocks of the Park Range near Steamboat Springs, and in the Dakota sandstone east of Meeker (U.S. Bureau of Land Management 1976a).

Low grade uranium ore is presently extracted by the Union Carbide Corporation through a leaching process using materials mined near Maybell during past operations. The Midnight Mine, east of Meeker near Uranium Peak, has also been producing some uranium ore during the summer and fall months. In 1977, Moffat County uranium production was approximately 26 thousand kg of U_3O_8, and production from Rio Blanco County was 2,900 kg (Colorado Division of Mines 1977b).

Although there are presently no formal proposals for new uranium mines in the study area, substantial exploration activities are ongoing in the western portion of the region. Particularly if the price of uranium increases in the near future, potential for accelerated mining will increase dramatically (U.S. Bureau of Land Management 1976a). Most of the uranium in the basins overlies principle coal-bearing beds which must be extracted with underground techniques. Differences in depth of the two minerals is sufficient that extraction of one should not interfere with later mining activities of the other (U.S. Bureau of Land Management 1976a).

FUTURE DEVELOPMENT

Coal Gasification and Liquefaction Plants

Coal conversion by gasification or liquefaction processes could become a significant future industry in the Yampa and White River Basins. There are currently no gasification facilities in the study area, and none proposed for development. However, Steele (1976) states that in the Yampa Basin "natural gas reserves in the region are declining and coal gasification may be proposed . . . to supply the existing gas-pipeline network."

Present coal reserve data indicate that sufficient strippable coal exists in the Yampa coalfield in Routt and Moffat Counties to support gasification and liquefaction facilities (Lindquist 1977). One limiting factor to this development is the widespread distribution of coal reserves in the study area. As a result, two or more mines will be required to supply the necessary feed for a basic coal conversion plant. Other disadvantages to development in the basins include remoteness from existing gas markets, opposition to the development, on environmental and economic grounds and restrictions on water availability (Lindquist 1977). Total water circulation requirements for a standard-sized coal gasification complex are approximately 750 million m^3/year, which is equivalent to nearly 40 percent of the mean annual flow from the Yampa River (Steele 1976). Although water consumption from such a plant would be more than an order of magnitude less, these circulation requirements are a major consideration to development in the semiarid study region.

Hydroelectric Power

At present there are no hydroelectric power plants in the Yampa and White River Basins. Currently, most hydro-generated electricity in the study area is imported from the upper Colorado River region, but future power demands and economic restrictions on development of alternative energy resoures may dictate that hydroelectric power be implemented locally.

There are presently three hydroelectric sites proposed in the basins. The White River hydroelectric plant is planned by the Uinta County Water District in Utah and will have a capacity of 3 MW (Corsentino 1976). The Juniper Project, designed primarily to provide power for irrigation of lands in the Maybell and Sunbeam areas, will be located on the Yampa River downstream from Craig and will have a generation capacity of 30 MW (U.S. Economic Research Service et al. 1969). The third and largest of the three proposed facilities is the Flattops Project, that will be located on the South Fork of the White River and may generate up to 51 MW electrical power (Upper Colorado Region State-Federal Inter-Agency Group 1971d).

TRANSPORTATION OF ENERGY RESOURCES

Transportation of energy resources from the Yampa and White River Basins is an important part of the total environmental impact of energy development. Colorado and Utah are major exporters of coal, natural gas, and oil. In the Yampa drainage area, 85 percent of the coal is transported from the basin by unit train (Steele 1976). Development of oil shale in the White Basin will necessitate expansion of transportation facilities. These western transportation developments present some unique problems, however, since materials must frequently be moved large distances, and power generation lines and railroad routes may require hundreds of square kilometers of right-of-way.

Transportation facilities in the Yampa and White Basins will have to be enlarged to handle increases in coal and oil shale mining operations (Steele et al. 1976b). At present, the Yampa Valley is serviced by a line of the Denver & Rio Grande Western Railroad, which has its western terminus at Craig. This line is the major link between the Yampa mining region and Denver, which is the primary market for coal in the area (U.S. Economic Research Service et al. 1969). There are numerous highways and roads used by local mining operations which cross the study area, with the greatest intensity of truck routes centered in the vicinity of Craig, Meeker, Hayden and Rangely. A great number of gas and electrical power transmission lines are also located throughout the study region.

Increasing transportation developments in the study area involve expansion of old systems (pipeline, rail and power transmission), and creation of new systems. Any proposal for development must consider mode of transport, water requirements, environmental impacts such as increased soil erosion and hydrological modifications to local watersheds, and total cost. In the Yampa and White River Basins, a number of transportation developments for regional coal activities have been proposed (Table 17). The anticipated environmental impacts associated with these developments have been defined in other sources (U.S. Bureau of Land Management 1976a, 1976b).

TABLE 17. TOTAL PROJECTED COAL-RELATED TRANSPORTATION DEVELOPMENT IN THE YAMPA AND WHITE RIVER BASINS (modified from U.S. Bureau of Land Management 1976a)

Development Activities	Year 1976-80	 1976-85	 1976-90
Cumulative kg coal produced (billions)	36.4	109.7	205.0
Kilometers of new railroads	37	42	137
Kilometers of new road	24*	80*	145*
Kilometers of new powerline	121	322	563

* Includes coal exploration trails, access roads, and haul roads.

The primary mode of coal transportation to power generation facilities will be by 100 car unit trains, each train capable of carrying 91 thousand kg of coal (U.S. Bureau of Land Management 1976b). Several plans for railroad construction have been proposed, among them a plan submitted by W. R. Grace Corporation for construction of a railroad between Craig and Axial, Colorado. The use of slurry pipelines for coal transport has been discussed because, under optimum conditions, slurry lines can provide service at lower costs than rail or waterways. However, large volumes of water are needed for operation of a slurry line (1 liter water per 1 kg coal). Because of the inadequate surface and ground-water supplies in the Yampa and White River Basins, and the distance of existing coal slurry lines from the White-Yampa coal fields, railway transportation is generally favored over coal slurry development in this region. There is, however, a small slurry line that serves to transport gilsonite from the lower White River Basin to Grand Junction, where it is processed into gasoline and asphalic products (Iorns et al. 1965).

SECTION 6

OTHER SOURCES OF POLLUTION

EROSION

Much of the White and Yampa River Basins study area is subject to moderate erosion damage, with the greatest impact occuring in the lower, arid elevations where vegetation cover is sparse and over grazing is common. Insufficient vegetative ground cover results in poor soils that contain little organic matter and are susceptible to wind erosion. Sediment comes largely from crop and range lands in the basins; the Bureau of Land Management (1976a) reports that a third of the dry crop land in the study area is maintained with adequate erosion control. Severe range and watershed abuse by early settlers produced loss of the limited and fragile original top soil in the area, and heavy grazing has restricted recovery of this damage (U.S. Bureau of Land Management 1978).

Summer storms and flash floods generally cause severe erosion and subject receiving waters to elevated suspended sediment loads. Local soils that are derived from the Mancos and Lewis shales and shaley portions of other formations are subject to gullying, particularly around streambanks (U.S. Bureau of Land Management 1976a). These soils are rich in silt and clays and go into suspension easily during episodic runoff. Erosion in the study area has been reported to be more than 1.1 million kg/km^2 year, although the bulk of the sediment is deposited along the way and never reaches the main streams (U.S. Bureau of Land Management 1976a). The oil shale region of the White River Basin has a particularly high sediment yield (Table 18).

TABLE 18. EROSION RATES IN THE PICEANCE AND YELLOW CREEK WATERSHEDS (modified from University of Wisconsin 1976)

Area	Yield	
	(m^3/km^2)	(thousand kg/km^2)
All of C-b tract	0-190.5	0-291.4
Ryan Gulch and Yellow Creek	142.9-381.0	215.1-582.7
Northwest part of C-a	190.5-381.0	291.4-582.7
East of C-b on upper Piceance	238.1-476.2	358.6-717.2
Eastern half of C-a	238.1-714.4	358.6-1,075.8
Mouth of Yellow Creek	619.1-952.5	941.3-1,434.4

Future energy development in the study basins may contribute substantially to existing erosion problems. Construction of power lines, strip coal mines, open pit mines, roads, and refineries or retort facilities will disturb the established soil surface and the watershed through erosion (Table 19). It is estimated that oil shale development will increase erosion three-fold in the White River watershed, and six-fold in the Colorado River Basin (University of Wisconsin 1976). Disturbance of land in the oil shale area will cause immediate problems that will continue as long as construction activities go on. Nevertheless, industrial erosion in the study basins will probably continue to be small compared to erosion associated with agriculture.

TABLE 19. PREDICTED IMPACT ON THE WHITE AND YAMPA RIVER BASINS AS A RESULT OF ACCELERATED EROSION ASSOCIATED WITH ENERGY DEVELOPMENT
(modified from University of Wisconsin 1976)

Gullying: destruction of agricultural lands
increased costs of leveling land for construction

Loss of fertile topsoil: increase in surface runoff
decrease vegetation and crop yields
extensive drought damage
increased flood damage

Reduced capacity of downstream channels and reservoirs

Increased costs for a suitable water supply

Degradation of fish and wildlife habitats and recreational areas

Decreased potential for water power

Reduced carrying capacity and increased costs of maintenance of irrigation systems

Increased costs of road and highway maintenance

Increased damage to flooded cities and homes

Increased costs to industry of maintaining cooling and power facilities

MINE DRAINAGE

The impact of mine effluents on water quality will be of growing concern in the White and Yampa River Basins as the number of energy development facilities increase. Potential sources of water quality contamination associated with mining activities include loading, crushing and screening facilities, access and hauling roads, equipment maintenance and building areas, leakage of fuels from mine machinery, overburden removal and deposition, retortion of oil shale, construction of water control facilities, stream diversions, and population influx due to increased availability of jobs. Each of these sources pose a specific environmental threat to the water quality of the basins.

The acid mine drainage from coal extraction, common in the eastern United States, is not a problem in the Yampa and White River Basins, where the sulfur content of coal is generally less than 1 percent and soils are akaline. In this area, total dissolved solids and suspended solids from erosion of the disturbed areas are the most obvious potential pollutants. Pollution from ground-water aquifers may result when they are intercepted during mining operations, producing a net inflow and accumulation of water in the active pit. Surface runoff, or shallow ground water such as that from irrigation return flows, may percolate through mine spoil areas resulting in increased salts, especially sulfates or heavy metals. Mining operations may also directly discharge toxic substances into surrounding surface water supplies. To date, there have not been any major pollution impacts associated with mining effluents to the White and Yampa River Basins. However, as the number and size of these energy developments increase, the potential for major spills and contamination will also increase. Careful on-site monitoring should be established to reduce the prospect of serious pollution from future mine drainage.

URBAN RUNOFF

There may be rapid population growth associated with increased industrial development in the Yampa and White River Basins. An influx of people would increase the likelihood of urban runoff and augment the consumptive water demands and burden on existing sewage facilities in the basins. The area surrounding Craig, Hayden, Steamboat Springs, Rangely, Meeker, Yampa, and the Piceance Creek drainage are expected to experience the greatest growth from the expanding mining industry within the study area.

Nonpoint urban runoff is produced by precipitation that washes a population center, flushing a variety of city wastes into the nearest water system. This runoff is greatest during episodic heavy rainfall and is high in nutrients and suspended sediments. Storm and domestic sewer overflow is a common urban source of organic pollution to the aquatic ecosystem. Animal wastes, fertilizers, pesticides, and litter are other urban pollutants.

SECTION 7

WATER REQUIREMENTS

WATER RIGHTS

The appropriation of water rights in the Western States, including Colorado, has traditionally been governed by the doctrine of "first in time, first in right," which specifies that the first individual to divert water to a beneficial use establishes a dated and quantified right to first use of the water (Knudsen and Danielson 1977). All stream users thus establish dated rights, and as water supplies decrease, those bearing latter priority dates are shut off until senior rights are met. In light of population growth and water demands in the Colorado River Basin, however, Federal and State regulations to control use have been established; it is probable that legal rights to use water will become a major factor in regional decisions regarding future energy development.

The Colorado River Compact of 1922 and the Upper Colorado River Basin Compact of 1948 are the primary federal laws governing distribution of surface waters in the study area. The former law specifies that the Upper Colorado Basin (upstream from Lee Ferry) is allowed beneficial consumptive use of 9.2 billion m^3/year of Colorado River water, but the Upper Basin States must insure that the flow of the river at Lee Ferry is not depleted below a aggregate of 92.5 billion m^3 for any period of 10 consecutive years (University of Wisconsin 1976). The Upper Colorado River Basin Compact allocates water to the Upper Basin States on a percentage basis: Colorado is entitled to 51.75 percent of the Upper Basin (Utah is authorized 23 percent; Wyoming, 14 percent; and New Mexico, 11.25 percent). The 1948 Compact also states that the Upper Basin States must curtail water consumption and meet a demand for water by Lower Basin waters in the event of a "compact call" (University of Wisconsin 1976).

There are two stipulations in the 1948 Compact regarding the Yampa River Basin. One specifies that Colorado must not cause the flow of the Yampa River at Maybell to be depleted below an aggregate of 6.2 billion m^3 for any consecutive 10-year period (Knudsen and Danielson 1977). This is equivalent to a minimum average flow of 0.62 billion m^3/year, which has been met in all years except one during the entire 1917-76 water year period of record for that site (James and Steele 1977). A second stipulation requires water administration in the Little Snake River Sub-basin, and differentiates between water allocations assigned prior to signing of the Compact and those rights initiated after the Compact. For rights approved prior to the Compact, water which is above the confluence of the Little Snake River and Savery Creek shall be administered without regard to diversions below the confluence. Those waters diverted below the confluence must comply with interstate regulations prepared by the Upper Colorado Commission (Knudsen and Danielson 1977). Any necessary curtailment of diversions associated with rights approved after the 1948 Compact will be made on an equitable basis for each square kilometer irrigated.

The White River Basin is presently unregulated by any interstate agreement (University of Wisconsin 1976). The 1948 Compact included no statement specifying what amount of water the State of Colorado must deliver from the White River to the State of Utah (University of Wisconsin 1976). Furthermore, Ute Indians in Utah claim usage of 2.3 m^3/seconds from the White River for irrigation of reservation lands based on the reserved rights doctrine. Final decisions regarding both the Indian claims and allocation rights of the State of Utah from the White River must yet be decided in the courts. As reported by Gold and Goldstein (1978), "the absence of any agreement on the disposition of White River water almost guarantees an eventual clash between the states of Colorado and Utah when an attempt is made in either state to put a large amount of water to use." Other federal acts which affect water allocations in the Upper Colorado Basin, and thus, in the White and Yampa River Basins, include federal treaties with Mexico, and the Upper Colorado River Storage Project Act. This Act contains provisions that authorized construction of the major reservoirs in the Upper Basin and associated reclamation projects (including the Savery-Pot Hook project on the Little Snake River, which was never completed). Establishment of wild and scenic rivers by Federal water policy is another consideration affecting water availability, since such a designation greatly restricts development along such a river in order to maintain its natural qualities. Parts of the Yampa River Basin, including the Little Snake River, are under consideration for such a designation (Gold and Goldstein 1978).

WATER AVAILABILITY

It is estimated that the State of Colorado has been authorized consumption of 3,926.2 million m^3/year from the Upper Colorado River Basin, including allowable depletions from the Yampa and White River drainages (Slawson and Yen 1979). However, the University of Wisconsin (1976) states it is "apparent that anyone seeking firm estimates of water availability must be doomed to disappointment." The problem is partially a factor of provisions of the Colorado River Compact, which left many questions of interpretation unresolved, particularly regarding to what extent the Upper and Lower Basins are responsible for meeting the Mexican obligation. The problem is complicated both by the variability of the Colorado River flow, and the fact that, although the Basin is already overappropriated by conditional decrees, many of these proposed developments will never be realized due to economic and political restrictions (University of Wisconsin 1976). For example, increasing emphasis on minimum instream flow requirements may complicate the transfer of water rights. For these reasons, estimates of water availability in the White and Yampa Rivers must be recognized as tentative and subject to change with future interpretation of water rights legislation in the controversial area.

The average annual discharge from the White River near Watson is 628.3 billion m^3; the maximum recorded runoff during 52 years of record was 1,550.4 million m^3 in 1934 (Colorado State University and Colorado Division of Water Resources 1977). Flows have been reported as high as 231.1 m^3/seconds (in 1929) and as low as 0.3 m^3/second (reported in 1972 as a result of river freeze-up). The average annual discharge of the Yampa River at the mouth is 1,850.2 million m^3; the maximum recorded runoff during 54 years of record was 3,577.1 million m^3, and the minimum recorded annual discharge was 561.2 million m^3 (James and Steele 1977).

The mean annual consumptive use of surface waters in the Yampa River Basin during 1975-76 was 75.2 million m^3, and in the White River Basin was 123.3 million m^3 (Table 20). The predominant consumptive use of water in both basins is from irrigation of croplands and stock watering.

TABLE 20. ESTIMATED ANNUAL CONSUMPTIVE USE OF SURFACE WATERS, BY STATE, IN THE YAMPA AND WHITE RIVER BASINS, 1975-76 (modified from Colorado Department of Natural Resources 1979)

	Consumptive Use (million m^3)					
State/ Basin	Thermal	Agriculture	Fish and Wildlife (Recreation)	Mineral Development	Municipal and Industrial	Export
Colorado*						
White	8.6	98.7	7.4	1.2	2.5	0
Yampa	-	45.6	2.5	3.7	1.2	0
Wyoming*						
Yampa	-	13.6	0	0	0	8.6
Utah†						
White	-	4.9	0	0	0	0
Totals:	8.6	162.8	9.9	4.9	3.7	8.6

Total Yampa Basin consumption - 75.2
Total White Basin consumption - 123.3

* Average annual depletion
† 1975 depletion

The average annual consumptive use of surface waters for both basins is well under their respective minimum recorded annual discharges. However, there is such great variability in streamflow from year to year (Figure 11) and from month to month that future developers cannot be assured of the stable, dependable quantity of water required for most proposed activities. Certainly there will be times when adequate water supplies will exist to satisfy all consumptive demands. However, the University of Wisconsin (1976) reports "One obvious implication is that there can be little water resource development without storage." There are few reservoirs at present in the study area, but as many as 30 have been proposed for the Yampa Basin alone (Steele 1978).

YAMPA AND WHITE RIVER WITHDRAWALS

Energy Resource Development

Increased energy development in the Yampa and White River Basins will have a significant environmental impact, particularly on water resources of the region. Surface mining of the enormous coal reserves requires approximately 0.07 to 0.08 liters of water per kg of coal mined (Adams 1975). Conversion of coal into electricity or into natural gas and crude oil requires large quantities of water, particularly if gasification and liquefaction processes are implemented. It has been estimated that as much as 4.3 million m^3/year of water may be ultimately demanded for coal processing operations in the Yampa Basin alone (James and Steele 1977). At maximum anticipated levels of coal production, as much as 136 million m^3/year of Yampa River water could be consumed as cooling water for mine-mouth power generation facilities (James and Steele 1977). A single 1,200 mw power plant, using once-through cooling without some sort of impoundment-recycling system, could annually divert as much as 60 percent of the mean annual flow of the entire Yampa Basin (Steele 1976).

Transport of coal to power plants, if done by coal slurry line can require an additional 2.5-3.7 million m^3/year of water to provide slurry to a 1,000 mw electric generating plant (Adam 1975). Natural gas production is responsible for consumption of large quantities of water. In the Rangely field, 12,241 m^3 of White River water is injected and consumed daily in the gas extraction process (Radian Corporation 1977). The oil shale industry will be another large consumer of water. Although projected water requirement estimates vary depending on the rate of shale oil production and the mining techniques utilized, the most likely water use requirements for a mature shale industry range between 149.9-233.2 million m^3/year (Table 21). All of these water demands are immense since many streams in the Yampa-White resource area are dry much of the year, and high quality ground-water supplies must be carefully pumped to avoid depletion of usable aquifers at a rate in excess of recharge capacity.

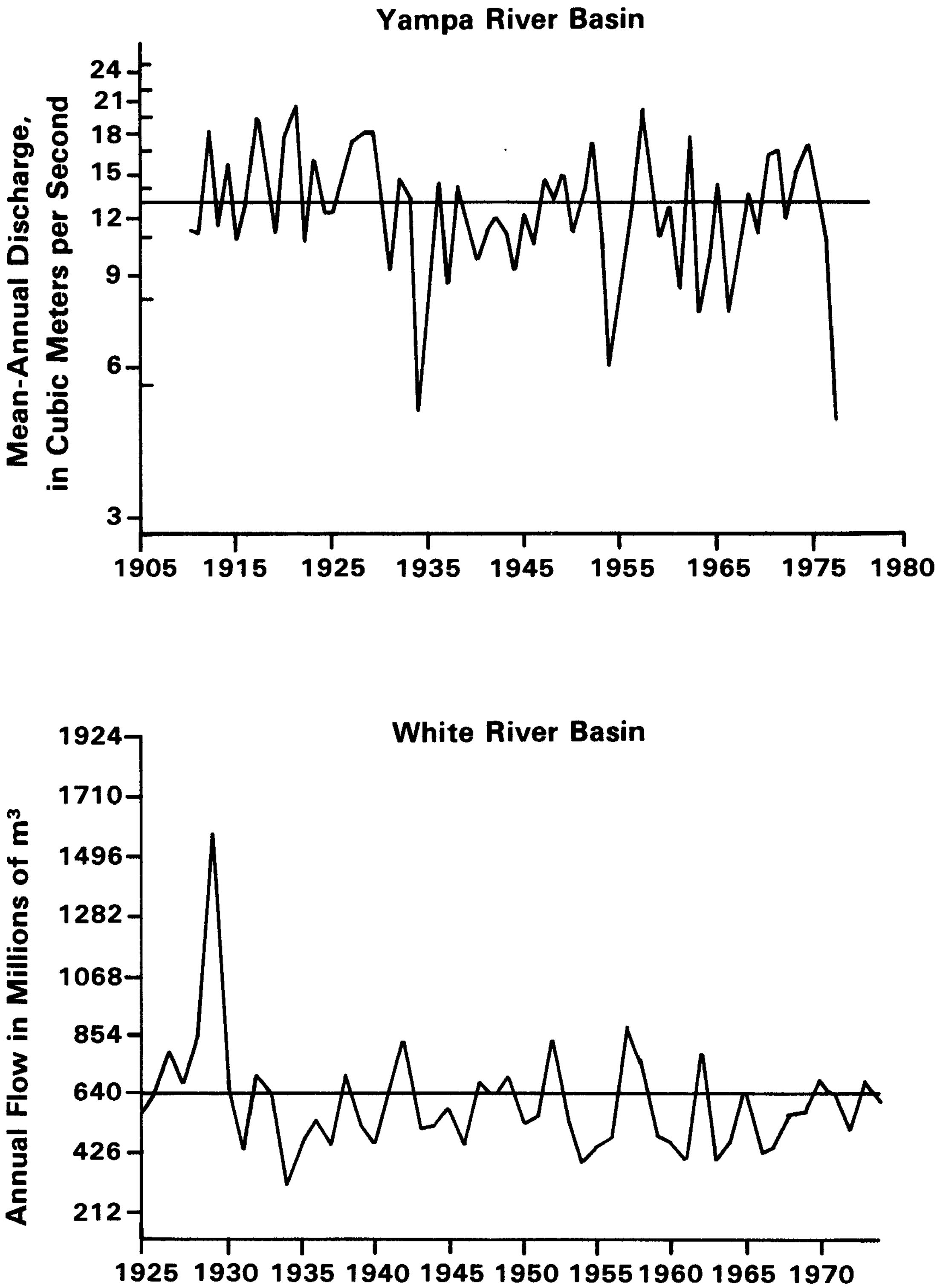

Figure 11. Variability in flow discharge, Yampa and White River Basins. (modified from Colorado State University and Colorado Division of Water Resources 1977, and Bauer et al. 1978)

TABLE 21. CONTINGENT WATER CONSUMPTION FORECASTS FOR A MATURE (1 million barrels/day) SHALE OIL INDUSTRY (modified from Kinney et al. 1979)

Requirements	Range of Consumption (million m^3/year)		
	Lower Range	Most Likely	Upper Range
Processing:			
Mining and crushing	7.4	7.4-9.9	9.9
Retorting	11.1	11.1-14.8	14.8
Shale oil upgrading	21.0-25.9	35.8-54.3	54.3
Processed shale disposal	29.6	58.0-86.3	103.6
Power	12.3	18.5-28.4	45.6-55.5
Revegation	0	0-14.8	22.2
Sanitary use	1.2	1.2-1.2	1.2
Subtotals	82.6-87.5	132.0-209.7	251.6-261.5
Associated urban:			
Domestic use	11.1-13.6	16.0-21.0	21.0
Domestic power	0	1.2-2.5	2.5
Subtotals	11.1-13.6	17.4-23.5	23.5
Ancillary development:			
Nahcolite/dawsonite	---	---	39.5-78.9
Grand Totals	93.7-101.1	149.4-233.2	314.6-363.9

Irrigation

Over 70 percent of the total water consumption in the White and Yampa River Basins is due to depletions for irrigation (U.S. Bureau of Land Management 1976a). Less than 1 percent of this irrigation water consumed is from ground-water supplies (U.S. Economic Research Series et al. 1969).

In the study basins during 1975-76, approximately 162.8 million m^3 of water was consumed for agricultural purposes, including irrigation and consumption by livestock (Colorado Department of Natural Resources 1979). This value, derived from 112.2 million m^3/year depletion in the Yampa Basin and 50.6 million m^3/year depletion in the white, is an increase over consumptive levels reported in the study area during 1943-60. In that time period, approximately 142.4 km^2 of land in the White Basin was irrigated, and 36.1 million m^3 of water annually was consumed for irrigation requirements (U.S. Economic Research Service et al. 1966). In the Yampa Basin, including the Vermillion Creek drainage, 323.8 km^2 of land was irrigated between 1943-60, and 88.1 million m^3/year of water was consumed (U.S. Economic Research Service et al. 1969). More than 95 percent of the total regional irrigation water requirements are used for production of hay and irrigated pasture.

One of the greatest problems in the Yampa and White River Basins is the need for a reliable irrigation water supply throughout the growing season. To meet this need, there exist numerous private irrigation diversions throughout the study area built on small storage facilities. There are a number of additional large irrigation projects which have been proposed for the area including the Yellow Jacket Project (develop waters of the White and Yampa Basins), the Juniper (Lower Yampa) and Yampa Valley Projects, and the Savery-Pot Hook Project on the Snake River (Knudsen and Danielson 1977). The Savery-Pot Hook is the only one of these projects which has been federally authorized; however, it is not likely that it, or any of these strictly agricultural-purpose projects, will be funded unless national priorities change (University of Wisconsin 1976).

Some proposals exist to shift irrigation water rights over to satisfy energy development needs in the study area, particularly in the arid downstream stretches of the basins (Colorado Department of Natural Resources 1979). However, it is not likely that sufficient water could be obtained from reallocation of irrigation rights to satisfy anticipated industrial requirements, especially of the oil shale industry. The University of Wisconsin (1976) reports, "On the White River, irrigation rights will probably play an insignificant role in present company water strategies. Only 30,000 AF (37.0 million m^3) is presently consumed by irrigation in the White River Basin. Purchase of these rights would seem to serve little purpose at a time when the river is still relatively underveloped."

Municipal and Industrial

There are additional requirements for water in the Yampa and White River Basins. These include domestic, manufacturing, governmental, and commercial needs. Although there are many municipal and industrial users in the study area (Table 22), surface water consumption related to these systems is relatively minor. The Upper Colorado State-Federal Inter-Agency Group (1971b) reports that in 1965, water withdrawals related to municipal and industrial demands in the Colorado portion of the study basins were only 6.4 million m^3, and total consumption was 1.8 million m^3. This depletion represented approximately 1 percent of the total consumptive use of the study areas. In 1972, diversions for the Yampa and White region for municipal purposes amounted to approximately 14.2 million m^3/year (McCall-Ellingson and Morrill, Inc. 1974).

The major municipalities in the study area are population centers having less than 10,000 persons. Most of the smaller communities satisfy domestic and municipal needs with ground water, since this source is generally cheaper, readily available in the small quantities needed, and requires less treatment prior to use than the surface water supplies (U.S. Economic Research Service et al. 1969). The larger communities, including Craig, Yampa, Steamboat Springs, Hayden, Meeker, Rangely, Oak Creek and Dinosaur, require a greater volume of water and must use surface supplies to meet municipal and industrial needs. Present annual municipal and industrial water demands from the study basins are not known, although the Upper Colorado State-Federal Inter-Agency Group (1971b) projected in the Colorado portion of the basins, municipal and industrial users would withdraw up to 20.6 million m^3/year and consume 8.3 million m^3 annually by the year 2020.

In addition to the consumptive impact on usable water, a large proportion of municipal and industrial diversions are returned to nearby streams and pollutants from these return flows can substantially impact downstream users. The Bureau of Land Management (1976a) reports that "adequacy of water treatment facilities varies widely in the study region," and that the communities of Craig and Yampa have the only treatment facilities with sufficient capacity to meet anticipated use demands associated with expanding populations. Most of the other municipal users, in fact, already have difficulty meeting peak flow demands. Bauer et al. (1978) report effluent discharges from mine waste water treatment plants are the major source of organic pollution in the Yampa River. Plans exist to install a regional water quality treatment plant in the Steamboat Springs area that would combine advanced treatment with either land disposal or extended aeration (Bauer et al. 1978). Industrial dischargers within the basin areas are predominantly associated with the mining industries and they must also treat effluents to prevent contamination of surface and ground-water supplies with salts and toxic elements.

Although surface water withdrawal requirements are presently low in the study basins, future water requirements may increase due to population growth, especially in those areas with rapidly expanding energy development activities such as around Meeker, Craig, and Hayden. Traditionally, reallocation of existing irrigation water rights, in combination with addition of storage, have been the methods most commonly used to meet increasing urban needs. However, the simple act of cities condemning or buying irrigation water for urban use has come under serious criticism (Anderson and Wengert 1977), and

TABLE 22. MAJOR POINT SOURCES AND ASSOCIATED SEWAGE TREATMENT FACILITIES IN THE WHITE AND YAMPA RIVER BASINS (modified from McCall-Ellings and Morrill, Inc. 1974)

Point Source	Treatment
White River	
Meeker Well	--
Meeker sewage treatment plant	extended aeration
Rangely sewage treatment plant	aerated lagoon
California Oil Camp	lagoon
Texas Oil Camp	lagoon
Dinosaur National Monument sewage treatment plant*	lagoon
Dinosaur sewage treatment plant*	stabilization pond
Yampa River	
Morrison Creek District sewage treatment plant	extended aeration
Timber sewage treatment plant	aerated lagoon
Oak Creek sewage treatment plant	activated sludge
Abandoned Coal Mine	--
Siegrist Construction Gravel	settling pond
Mt. Werner District sewage treatment plant	aerated lagoon
Fish Creek Park sewage treatment plant	extended aeration
Bear Pole Ranch sewage treatment plant	extended aeration
Mineral Springs at Steamboat Springs	--
Whiteman School sewage treatment plant	extended aeration
Steamboat Springs sewage treatment plant	aerated lagoon
KOA Campground sewage treatment plant	extended aeration
Sleepy Bear Park sewage treatment plant	extended aeration
Steamboat Springs II sewage treatment plant	extended aeration
Yampa Valley Industries Gravel Pit	settling pond
Steamboat Lake District sewage treatment plant	extended aeration
Bear River Gravel Pit*	settling pond
Colorado Ute Electric-Hayden Station	settling pond
Hayden Water Treatment Plant	clarifer sludge
Hayden sewage treatment plant	aerated lagoon
Craig, Sand and Gravel*	settling pond
Craig waste treatment plant	clarifer sludge
Big Country Meats sewage treatment plant	aerated lagoon
Craig sewage treatment plant	aerated lagoon
Silengo Coal Mine	none
Juniper Hot Springs	--
Dixon, Wyo., sewage treatment plant	stabilization pond
Baggs, Wyo., sewage treatment plant	stabilization pond

*No discharge

environmental considerations may limit the addition of future impoundments in both the Yampa and White River Basins.

Fish and Wildlife

Water requirements for fish and wildlife activities in the Yampa and White River Basins include management of refuge wetlands, fish hatcheries, various impoundments and the maintenance of instream flows. The areas of greatest water use in the study area include the Browns Park National Refuge, the Finger Rock rearing fishery, Buford fishery (now closed but still diverting water) and the National Forest areas to the east and south of the basins.

Water consumption related to fish, wildlife, and recreation requirements in the basins (including reservoir evaporation losses) is approximately 9.9 million m^3/year (Colorado Department of Natural Resources 1979). The Finger Rock rearing facility diverts water at a rate of 0.17 m^3/second, and the Buford facility diverts 0.05 m^3/second (Personal communication 1978, C. Sealing, Colorado Department of Wildlife, Grand Junction, Colorado). These are the only water diversion allocations for fish and wildlife in the region; however, if areas are considered which have specified minimum stream flow requirements, or which have been dedicated to the preservation of cutthroat trout, such as the upper reaches of the Little Snake River, millions of cubic meters of surface waters in the basins have been allocated to fish and wildlife resources. These waters, however, are largely unconsumed and may be available for downstream diversions and consumptive uses.

Livestock

Livestock requirements are a substantial portion of the agricultural water diversions in the Yampa and White River Basins. There are presently more than 1,000 stock watering ponds in the study area (U.S. Bureau of Land Management 1976a). Agricultural-related water consumption in the basins is approximately 162.8 million m^3/year (Colorado Department of Natural Resources 1979); what portion of this can be attributed to consumptive and evaporative losses associated with livestock facilities is not known. However, data presented for the entire Green River Subregion in 1965 indicated that less than 2 percent of the total agricultural-related water consumption in the area could be attributed to stockpond evaporation and livestock use (Upper Colorado Region State-Federal Inter-Agency Group 1971a).

EXPORTATION OF WATER

There are two diversions through which water is exported out of the Yampa and White River Basins. The Egeria Creek diversion, in 1974, exported approximately 716.6 thousand m^3 from the Bear River (Upper Yampa Basin) to Egeria Creek in the Colorado River Basin via the Stillwater ditch (U.S. Bureau of Land Management 1976a). The Hog Park Diversion has been exporting approximately 9.6 million m^3/year from the Little Snake River to the North Platte River Basin at Cheyenne, Wyoming, since 1967. Other potential interbasin exports proposed for the study area include: the High Mountain

Water Line Company export, expected to ultimately divert 49.3 million m^3/year from the Yampa River for use in Boulder, Adams, Weld, and Larimer Counties in Colorado; the South Fork Williams Fork Division, which will divert 4.1 million m^3/year to the White River Basin (to the proposed Lost Park Reservoir); and the Rawlins Diversion, which will export 986.8 thousand m^3/year from the Yampa Basin for use near Rawlins, Wyoming (U.S. Economic Research Service et al. 1969).

WATER AVAILABILITY VERSUS DEMAND

As part of the 1948 Upper Colorado River Basin Compact, the State of Colorado must not cause the flow of the Yampa River at Maybell to be depleted below an aggregate of 6.2 billion m^3 for any consecutive 10-year period. The White River Basin is currently unregulated by an interstate agreemment. At present, both basins have adequate surface and ground-water supplies to satisfy existing demands. However, the expansion of industry, particularly in the oil shale area of Piceance Creek and the coal mining regions around Craig, will put increasing stress on the existing water resources of both basins. Average annual water consumption in the White River Basin could rise to 264.1 million m^3/year by the year 2020, a figure over 5.5 times the amount of water consumed in the basin between 1943-60 (U.S. Economic Research Service et al. 1966). Total annual depletions in the Yampa Basin could reach 485.4 million m^3/year by 2020 (U.S. Economic Research Service et al. 1969).

It can be expected that additional storage to regulate the highly variable flows of both the Yampa and White Rivers will be necessary to provide a level of reliable water sources required by the growing energy industry, as well as to insure the maintenance of a minimum baseflow to meet regional fish and wildlife demands. There are over 30 potential surface-water impoundments which have been proposed in the Yampa River Basin in Colorado (Knudsen and Danielson 1977). It should be noted, however, that specification of minimum instream flows as a water right is an issue that will become controversial as industrial claims to the surface resources increases. Although all of the states in the Upper Colorado Basin recognize the right of a private individual to divert water for fish and wildlife requirements (such as to a fish pond or to flood a marsh), none of these states recognize private rights to flows left in a stream (Colorado Department of Natural Resources 1979). Colorado passed legislation in 1973 which authorized the state to purchase water rights for establishment of minimum flows in areas where the natural environment is threatened by ongoing development. However, appropriations obtained through this recent law are very junior water rights which could be sacrificed in case of a compact call or during a low water year. More senior rights can only be obtained through purchase of existing rights from willing sellers (Colorado Department of Natural Resources 1979), most of whom are irrigation and industrial developers.

SECTION 8

WATER QUALITY

SOURCES OF DATA

Available water quality information was used to assess the impact of existing energy developments and irrigation projects in the Yampa and White River Basins and to provide baseline data for determining the impact of proposed developments. Most of the water quality data contained in this report were obtained through the U.S. Environmental Protection Agency's computer-oriented system for STOrage and RETrievel of water quality data (STORET). Other sources of information include government documents, environmental impact statements, and private consulting firms. Physical and chemical data evaluated were primarily from U.S. Geological Survey stations (Tables 23 and 24, Figure 12), although data generated from in-house sampling efforts and some miscellaneous sources available in STORET were also considered.

SUMMARY OF PHYSICAL AND CHEMICAL DATA

Summarized data for selected parameters are included in Appendix B. Data are organized by parameters, station, number, and year for the period 1971-1978. Station number assignments in the appendix tables, as well as on figures in this report, are generally based upon the middle four numerals of the station STORET code unless otherwise indicated (Tables 23 and 24).

In Appendix B, data from 24 USGS stations in the Yampa River, and from 24 USGS stations in the White River Basin, are presented. In general, for any given parameter, the annual arithmetic mean for that parameter at each station is presented, along with the annual minimum and maximum values and number of samples collected. It should be noted that no attempt was made to verify data retrievals from STORET; all parameter measurements were accepted at face value with the exception of those data that were obviously impossible (e.g., pH = 42) and were thus deleted. No summary tables were prepared from the limited miscellaneous data sources available in STORET for this area.

IMPACT OF DEVELOPMENT ON SURFACE WATER

Salinity

The Salinity Problem--

Salinity, the total concentration of ionic constituents, is a major water

TABLE 23. U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	Station Name	Latitude/Longitude
09236000	Bear River near Toponas, Colo.	40°03'00"/107°04'00"
09239500	Yampa River at Steamboat Springs, Colo.	40°29'01"/106°49'54"
09241000	Elk River at Clark, Colo.	40°43'03"/106°54'55"
09243700	Middle Creek near Oak Creek, Colo.	40°23'08"/106°59'33"
90243900	Foidel Creek at mouth, near Oak Creek, Colo.	40°23'25"/106°59'39"
09244100	Fish Creek near Milner, Colo.	40°20'10"/107°08'20"
402330107082000	Grassy Creek at Grassy Gap, Colo.	40°23'30"/107°08'20"
09244300	Grassy Creek near Mt. Harris, Colo.	40°26'45"/107°08'38"
09244410	Yampa River below diversion, near Hayden, Colo.	40°29'18"/107°09'33"
402522107134100	Sage Creek near Mt. Harris, Colo.	40°25'22"/107°13'41"
402918107094400	Sage Creek near Hayden, Colo.	40°29'18"/107°09'44"
09245000	Elkhead Creek near Elkhead, Colo.	40°40'15"/107°17'10"
09246550	Yampa River below Elkhead Creek, Colo.	40°29'50"/107°30'34"
09247600	Yampa River below Craig, Colo.	40°29'04"/107°36'23"
09249000	East Fork Williams Fork near Pagoda, Colo.	40°18'45"/107°19'10"
09249200	South Fork Williams Fork near Pagoda, Colo.	40°12'44"/107°26'31"
401857107243500	South Fork Williams Fork near Pagoda, Colo.	40°18'57"/107°24'35"
09249750	Williams Fork at mouth near Hamilton, Colo.	40°26'14"/107°38'50"
09251000	Yampa River near Maybell, Colo.	40°30'10"/108°01'45"
09257000	Little Snake River near Dixon, Wyo.	41°01'42"/107°32'55"
405937107462500	Little Snake River above Thornburgh near Baggs, Wyo.	40°59'37"/107°46'25"
09259700	Little Snake River near Baggs, Wyo.	41°00'00"/107°55'10"
09260000	Little Snake River near Lily, Colo.	40°32'50"/108°25'25"
09260050	Yampa River at Deer Lodge Park, Colo.	40°27'02"/108°31'20"

quality parameter of concern in the Yampa and White River Basins. Two processes contribute to increases in salinity: salt loading and salt concentration. Salt loading, the addition of salts to the water system, occurs through irrigation return flows, natural sources, abandoned wells, and municipal and industrial wastes. Salt concentrating, reduction of the amount of water available for dilution of the salts already present in the river system, results from consumptive uses of water and from evaporation and transpiration losses.

TABLE 24. U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	Station Name	Latitude/Longitude
09303000	North Fork White River at Buford, Colo.	39°59'15"/107°36'50"
09304000	South Fork White River at Buford, Colo.	39°58'28"/107°37'29"
09304200	White River above Coal Creek, Colo.	40°00'18"/107°49'29"
09304500	White River near Meeker, Colo.	40°02'01"/107°51'42"
09304800	White River below Meeker, Colo.	40°00'48"/108°05'33"
09306007	Piceance Creek below Rio Blanco, Colo.	34°49'34"/108°10'47"
09306061	Piceance Creek above Hunter Creek, Colo.	39°51'02"/108°15'30"
09306175	Black Sulfur Creek near Rio Blanco, Colo.	39°52'17"/108°17'13"
09306200	Piceance Creek below Ryan Gulch near Rio Blanco, Colo.	39°55'16"/108°17'49"
09306210	Piceance Creek near White River, Colo.	39°56'20"/108°17'20"
09306222	Piceance Creek at White River, Colo.	40°04'29"/108°14'08"
09306230	Stake Springs Draw near Rangely, Colo.	34°55'37"/108°25'14"
09306244	Corral Gulch at 84 Ranch, Colo.	39°56'02"/108°25'35"
09306248	Duck Creek at Upper Station, Colo.	39°58'55"/108°27'10"
09306250	Duck Creek near 84 Ranch, Colo.	39°58'49"/108°24'27"
09306255	Yellow Creek near White River, Colo.	40°10'07"/108°24'02"
401022108241200	White River below Yellow Creek, Colo.	40°10'22"/108°24'12"
09306300	White River above Rangely, Colo.	40°06'26"/108°42'44"
09306380	Douglas Creek at Rangely, Colo.	40°05'15"/108°46'32"
09306400	White River above Hells Hole Canyon, Utah	39°58'26"/109°07'49"
09306500	White River near Watson, Utah	39°58'46"/109°10'41"
09306600	White River above Southam Canyon near Watson, Utah	39°57'15"/109°15'28"
09306700	White River below Asphalt Wash near Watson, Utah	39°55'32"/109°17'30"
09306900	White River at mouth near Ouray, Utah	40°03'54"/109°38'06"

Ambient Levels--

Total dissolved soilds (TDS) concentrations and conductivity levels provide an indication of the dissolved constituents present in water. Values for these two parameters (Appendix B), as well as concentrations of each of the major cations (calcium, sodium, magnesium, potassium) and anions (bicarbonate sulfate, chloride) generally increased from upstream to downstream in both the Yampa and White River Basins. In the former, conductivity levels during 1977 increased from 239 µmho/cm to 488 µmho/cm between the Yampa sites at Steamboat Springs and near Maybell. In the White River, surface water samples in the South Fork White at Buford, Colorado, and

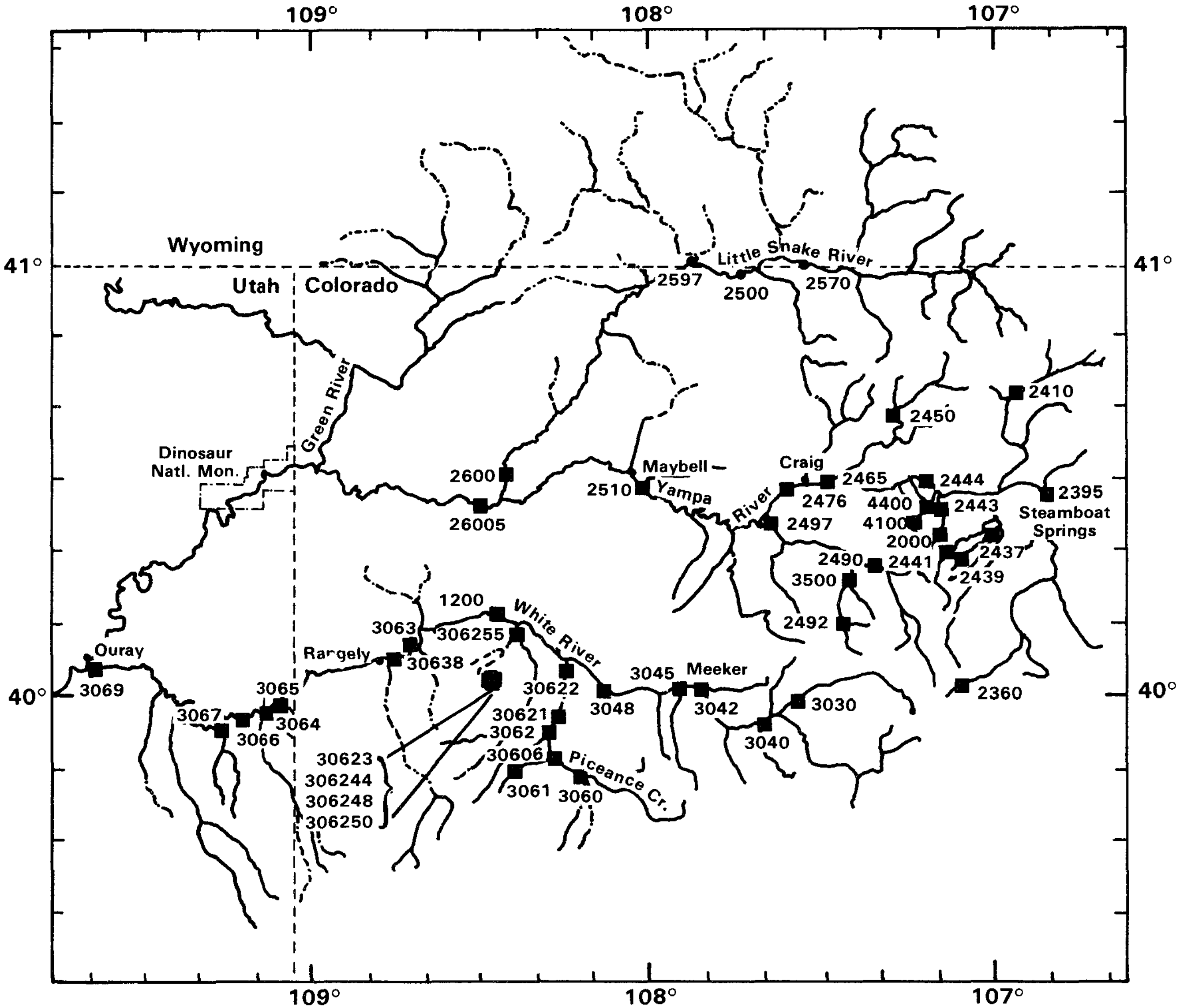

Figure 12. Location of selected U.S. Geological Survey water quality sampling stations in the Yampa and White River Basins.

at the mouth of the White near Ouray, Utah, showed an increase in average TDS concentrations from 172 mg/liter to 653 mg/liter and an average conductivity increase from 276 µmho/cm to 976 µmho/cm during 1977 (Table 25).

In the upstream stretches of the White River, calcium is the major cation followed by magnesium, sodium and potassium. Downstream, sodium becomes the dominant, followed by calcium and magnesium. The most abundant anion in the basin is bicarbonate, followed by sulfate and chloride; however, sulfate concentrations increase substantially at the downstream stations. A similar pattern of upstream and downstream ion distribution is found in the mainstem Yampa River as is observed in the White (Table 25).

The concentrations and composition of dissolved solids in the study tributaries alter with stream discharge, source of salinity impact, and evaporation rates. Fluctuations in flow are a major factor for the large seasonal variations in dissolved solid concentrations observed in the basins. Dissolved solid levels tend generally to be high during low runoff times and low during periods of high flow. During fall and winter periods of low runoff, baseflow in the rivers is largely from ground-water discharges, and chemical composition closely resembles regional rock chemistry. Since ground water in this region is generally high in salt content, water quality in the basin seasonally deteriorates (U.S. Bureau of Land Management 1976b). For example, during the water years 1959-1963, mean TDS concentrations in the Yampa River at Maybell, the Little Snake at Lily, and the White River at Watson during low discharge months were 317, 532, and 601 mg/liter, respectively (U.S. Environmental Protection Agency 1971). These values can be compared to mean concentrations of 112, 147, and 303 mg/liter, respectively, at the same sites during high runoff months of the same time frame (U.S. Environmental Protection Agency 1971).

Fox (1977) states,"A large effort is currently underway by the Colorado River Basin Salinity Forum (1975) to mitigate these impacts (of high salinity) in the Colorado River Basin," including the White and Yampa River Basins. Approximately 5 percent of the annual TDS load, or 408 million kg/year, of the Upper Colorado River is contributed by the Yampa River Basin (Wentz and Steele 1976). Average annual TDS loading from the White River at Watson has been reported at 300 million kg/year (U.S. Economic Research Service et al. 1966).

Naturally saline ground-water seeps are contributing total dissolved solids in both the White and Yampa Basins. McCall-Ellingson and Morrill, Inc. (1974) state that "the aquifer that gives the White River its excellent base flow also appears to be high in TDS." Underlying the Piceance and Yellow Creek drainages is an artesian aquifer which likewise releases warm, mineralized water to the surface. Impact from this source is greatest during late summer and winter when less dilution is available from snowmelt (U.S. Economic Research Service et al. 1966). In the Yampa Basin at Steamboat Springs, approximately 22 thermal springs discharge a total of 0.2 m^3/second of saline water to the surface. This discharge, which contains average TDS concentrations of 5,000 to 6,000 mg/liters (Iorns et al. 1965), contributes an estimated 8 million kg of dissolved solids to the basin annually (U.S. Environmental Protection Agency 1971). The spring water is primarily

TABLE 25. WATER QUALITY PARAMETERS AT SELECTED STATIONS IN THE WHITE AND YAMPA RIVER BASINS, 1975 AND 1977

	South Fork White at Buford		White below Meeker		White at mouth near Ouray		Yampa at Steamboat Springs		Yampa below Craig		Yampa near Maybell	
Parameter	1975	1977	1975	1977	1975	1977	1975	1977	1975	1977	1975	1977
Conductivity (µmho/cm)	284	276	554	701	742	976	269	239	323	345	474	488
TDS (mg/liter)	---	172	384	471	484	653	187	---	187	377	332	415
Calcium (mg/liter)	---	42	69	80	63	71	36	---	29	30	40	33
Sodium (mg/liter)	---	3	34	44	67	110	11	---	20	181	43	153
Magnesium (mg/liter)	---	9	19	23	25	30	12	---	10	10	20	16
Potassium (mg/liter)	---	1	2	2	2	3	2	---	2	2	4	3
Bicarbonate (mg/liter)	---	141	178	197	228	267	148	---	115	141	176	176
Sulfate (mg/liter)	---	30	128	164	167	240	34	---	50	65	110	89
Chloride (mg/liter)	---	1	29	42	32	51	4	---	9	6	16	34

comprised of sodium, bicarbonate and chloride, but also contains significant levels of fluoride and boron.

Erosion from shale outcrops throughout the study area is also a significant nonpoint source of salinity loading. Particularly in the western arid stretches of the basins, where vegetation cover is poorly developed, large quantities of salts are released from erosion of shale formations during summer thunderstorms.

Sources--

Man's industrial activities increase TDS levels primarily through salt loading processes. Abandoned oil fields are a source of salinity increases in both the White and Yampa River Basins. In the Yampa Basin, release of saline water from the Iles Dome oil field near Lloyd, Colorado, has been reported (U.S. Environmental Protection Agency 1971) to contribute 15 thousand kg of salt/day (5.6 million kg/year). Saline contributions have also been recorded from the now abandoned Williams oil field. Fox (1977) reported that the greatest incremental increase in TDS levels in the White River occurs between Buford and Meeker. This stretch of river includes Meeker Spring (Meeker Dome), an abandoned well that was historically a major source of highly saline ground water and surface runoff. Before the well was plugged in 1968, it discharged over 143 thousand kg of dissolved residue per day (Kinney et al. 1978). Flows from the well were reduced from 0.1 m^3/second to 0.04 m^3/minute after plugging. However, by 1969 saline seeps had already developed in the surrounding area and the Bureau of Reclamation (1976) estimated that brine flow from the region contributes 52 million kg of salt to the White River annually.

Mining and milling activities can increase TDS levels both through salt loading and salt concentrating effects. The coal industry can contribute salts through seepage from waste holding ponds, tailings piles, and direct discharge of process wastes (U.S. Environmental Protection Agency 1971). Opportunity for TDS loading from mining areas will be greatest during episodic summer rainfall as a result of erosion of overburden, and runoff through spoils and coal layers high in salts and trace elements (Table 26). Some pollution of streams could result as ground water is pumped out of mine pits and discharged to surface drainages. Studies done at mines presently operated by Energy Fuels Corporation in the Yampa Basin (U.S. Bureau of Land Management 1976b) have shown that "water in Foidel Creek below the influx of water from the mining pits was measured to be higher in TDS than water upstream from the influent," and "chemical quality of water could conceivably cause a deterioration in yields from irrigated crops." Water quality data for the Edna Mine on Trout Creek shows a similar trend (Table 27). It is expected that by 1990 leaching of mine spoils from coal areas in the Yampa Basin will produce 4.5 million kg/year of dissolved solid load, resulting in a TDS increase of approximately 1 mg/liter in the Colorado River below Hoover Dam (U.S. Bureau of Land Management 1976a). Although not substantial in itself, even this small increase could be of great significance to water consumers in the lower Colorado Basin, where salinity levels are already borderline for many beneficial uses.

TABLE 26. CONCENTRATIONS OF SALTS AND TRACE ELEMENTS IN COAL AND OVERBURDEN (modified from Rusek et al. 1978)

Element	Coal (mg/liter)	Overburden (mg/liter)
Arsenic	0.30	1.8
Barium	69	425
Bismuth	0.2	0.2
Bromine	0.30	
Boron	42	10.0
Cadmium	0.19	
Calcium	4,000	
Cerium	13	60
Chlorine	130	
Chromium	4.5	100
Cobalt	2.3	25
Copper	25	55
Fluorine	5.7	
Gallium	8.7	15
Germanium	0.33	1.5
Iodine	0.20	
Iron	1,600	
Lanthanum	5.8	30
Lead	3.9	13
Magnesium	4,500	
Manganese	30	950
Molybdenum	3.0	1.5
Neodymium	8.3	28
Nickel	2.7	75
Niobium	20	20
Phosphorus	380	
Potassium	410	
Praseodymium	4.7	
Rubidium	3.0	90
Samarium	1.7	
Scandium	1.3	22
Selenium	0.32	
Silver	0.22	
Sodium	5,000	
Strontium	100	375
Sulfur	6,100	
Tellurium	0.25	
Titanium	620	
Uranium	1.9	
Vanadium	12	135
Yttrium	7.7	33
Zinc	10	70
Zirconium	76	165

Blanks indicate data not reported in reference.

Other energy developments may potentially affect salinity levels in the study area. Water withdrawals for activation of the proposed Craig Station powerplant will produce an increase of 1 mg/liter TDS in the Yampa River at Maybell (Utah International, Inc. 1974). Kinney et al. (1979) estimated that withdrawals for development of a 159 million liter (1 million barrel)/day oil shale industry in the White Basin could ultimately increase TDS levels at Hoover Dam by 10 to 27 mg/liter depending on the quality of water used. Salinity impact from this development would be more gradual than from a salt loading source; however, as surface water withdrawals increase and usable quality ground-water supplies decrease, the salinity effects of the industry would become more pronounced.

TABLE 27. WATER QUALITY DATA, MAY 1974, FROM EDNA MINE, TROUT CREEK, COLORADO (modified from McWhorter et al. 1975)

Station*	Temperature (°C)	Alkalinity (mg CaCO/ liter)	Hardness (mg/liter)	pH	Conductivity (μmho)	TDS	Calcium (mg/liter)	Chloride (mg/liter)	Potassium (mg/liter)	Magnesium (mg/liter)	Sodium (mg/liter)	Sulfate (mg/liter)
C1	4.0	90	89	7.9	208	130	50	1.7	4	10	4	18
C2	5.0	96	96	7.9	209	140	50	1.0	4	10	4	18
C3	12.0	68	1,700	7.6	2,450	2,120	480	2.5	13	150	13	160
C4	9.5	120	330	8.1	528	340	100	1.9	6	27	6	130
C5	14.0	140	2,000	7.9	3,160	2,760	440	2.7	52	240	52	190
C6	9.0	120	250	8.1	541	400	98	1.8	10	25	10	130
C7	8.0	280	2,400	7.6	5,360	4,690	470	7.8	410	230	410	190
C8	10.0	130	300	8.2	650	480	130	2.2	18	31	18	150
CP1	-	220	1,700	7.8	2,680	2,500	450	3.8	16	200	16	170
Runoff	-	-	-	-	-	3,100	440	2.4	18	290	18	-

*C1 = Surface water sample from Trout Creek above all active mining on the water shed.
C2 = Surface water sample from Trout Creek immediately above the Edna Mine.
C3 = Water sample from surface and subsurface drainage tributary to Trout Creek near the southwest limit of spoil area.
C4 = Surface water sample from Trout Creek below the south mined area and immediately above the active north mined area.
C5 = Water sample from surface and subsurface drainage tributary to Trout Creek between the south and north mined area.
C6 = Surface water sample from Trout Creek near the downstream limit of mining and immediately above irrigation diversion.
C7 = Ground-water sample from seepage face immediately below the north mined area.
C8 = Surface sample from Trout Creek at the downstream limit of mining activity.
CP1 = Ground-water sample from observation well near station G4.
May
Runoff = Direct surface runoff from a spoil bank in the south mined area.

Irrigation activities also increase salinity levels in the basin. Wentz and Steele (1976) state that "the trend in increasing salinity for the Yampa River is attributed to increasing demands using surface water for agricultural and municipal purposes." A large percentage of total water applied for irrigation may be lost to evapotranspiration, particularly in the summer months. Since this lost water is salt free, the net effect of this concentration can be two-fold or greater increases in salt levels in the irrigation return flow. Irrigation runoff in the Yampa River Basin contributes approximately 93 thousand kg of dissolved solids per day (34 million kg/year); approximately 18 thousand kg are added daily (6.7 million kg/year) to the White River drainage from irrigation return flows (U.S. Bureau of Land Management 1976a).

Impact--

The EPA water quality criteria for both chlorides and sulfates (Table 28) in domestic water supplies is 250 mg/liter (U.S. Environmental Protection Agency 1976b). The sulfate criterion was imposed due to the anion's cathartic effect especially when associated with magnesium and sodium. Chloride levels in excess of the 250 mg/liter criterion, particularly in association with calcium and magnesium, tend to produce problems in corrosiveness. Both cations affect water taste when in concentrations in excess of 300-500 mg/liter (U.S. Environmental Protection Agency 1976b).

The sulfate cirterion has been exceeded between 1971-78 at most USGS stations examined in the White River Basin downstream from Meeker. In the Yampa Basin, the criterion was exeeded at a few tributary sampling sites, and in the mainstream Yampa River immediately below the Little Snake River at a site maintained by the Colordo State Health Department. The maximum sulfate value reported in the two basins was 1,700 mg/liter, observed in Sage Creek at the mouth (Yampa Basin), and at the mouth of Douglas Creek (White Basin).

Chloride levels in excess of the EPA drinking water criterion have been reported at the mouth of Piceance Creek. The maximum recorded excess value during the study period was 1,000 mg/liter, reported during summer, 1971. It should be noted that no excessive value for chloride has been observed at that site since 1973. However, chloride concentrations are consistently higher at this site and at the mouth of Yellow Creek than at any other stations examined in the White or Yampa Basins.

Tables of water hardness in the study basins are presented in Appendix B. Sawyer's classification of water according to hardness content (U.S. Environmental Protection Agency 1976b) is given in Table 29. Although water hardness is not a direct indicator of water quality, it is a factor in the toxicity of various metals in aquatic life (Fox 1977) and should be carefully monitored in regions expected to receive increasing impact from trace elements such as from mine or oil shale areas.

In the White River Basin, all the mainstem stations, as well as the site on the South Fork White River, have mean annual hardness values which are considered moderately hard, to hard by Sawyer's classification. The stations examined in the Douglas, Yellow and Piceance Creek drainages are all very hard, with the exception of three sites in the Yellow Creek drainage which are in the moderately hard category. These latter three sites, however, were sampled once or twice during 1971-78, and are not necessarily representative of annual chemical conditions in the area. In the Yampa River Basin, stations examined generally fell into the moderately hard, to hard categories. Only four sites, those on Foidel, Middle, Fish and South Fork Williams Creeks, were classified as very hard. It should be noted that these hardness classifications are based on mean annual values, but within a given stream there are frequently large variations in hardness content across time. This variability is most likely associated with changes in ion dominance resulting from periods of high runoff.

TABLE 28. WATER QUALITY CRITERIA REDCOMMENDED BY THE NATIONAL ACADEMY OF SCIENCES (1973)*

Parameter (total form)	Criteria For: Drinking Water (mg/liter)	Livestock (mg/liter)	Aquatic Life (mg/liter)	Irrigation (mg/liter)
Aluminum	--	5.0	--	5.0
Arsenic	0.05†	0.2	--	0.1‡
Barium	1.0†	--	--	--
Beryllium	--	--	0.011-1.100‡	0.1-0.5‡
Boron	--	5.0	--	0.75‡
Cadmium	0.01†	0.05	0.0004-0.012‡	0.01
Chlorides	250‡	--	--	--
Chromium	0.05†	1.0	0.1‡	0.1
Copper	1.0‡	0.5	AF	0.2
Cyanide	0.2	--	0.005‡	--
Dissolved oxygen	--	--	5.0	--
Fluoride	1.4-2.4†	2.0	--	1.0
Iron	0.3‡	--	1.0‡	5.0
Lead	0.05†	0.05-0.1	0.03	5.0
Lithium	--	--	--	2.5
Manganese	0.05‡	--	--	0.2
Mercury	0.002†	0.01	0.05 µg/liter‡	--
Molybdenum	--	--	--	0.01
Nickel	--	--	AF	0.2
Nitrate nitrogen	10.0†	100.0	--	--
Nitrite nitrogen	1.0	10.0	--	--
pH	5.0-9.0	--	6.5-9.0	--
Selenium	0.01†	0.05	--	0.02
Silver	0.05†	--	--	--
Sulfates	250‡	--	--	--
Vanadium	--	0.1	--	0.1
Zinc	5.0‡	25.0	AF	2.0

* Those parameters for which drinking water regulations (1975) or quality criteria (1976b) have been established by the U.S. Environmental Protection Agency are specially indicated, and in this table replace the older NAS recommended levels.

† U.S. EPA (1975)

‡ U.S. EPA (1976b)

AF Application Factor. Indicates criterion for this parameter must be separately established for each water body.

TABLE 29. SAWYER'S CLASSIFICATION OF WATER ACCORDING TO HARDNESS CONTENT (modified from U.S. Environmental Protection Agency 1976b)

Concentration of $CaCo_3$ (mg/liter)	Description
0 - 75	Soft
75 - 150	Moderately hard
150 - 300	Hard
300 and up	Very hard

High salinity concentrations and hard water have several adverse effects on municipal water supplies aside from drinking water considerations. If water softening is not practiced, soap and detergent consumption increases resulting in increased nutrients and other environmental pollution, and higher treatment costs in the community. Where water softening is practiced, treatment costs rise with the degree of hardness. Dissolved solids and hardness also play a role in corrosion, scaling of metal water pipes and heaters, and acceleration of fabric wear (U.S. Environmental Protection Agnecy 1976b).

Description of the impact of total dissolved solid concentrations on irrigation waters in arid and semiarid areas is presented in Table 30 (U.S. Environmental Protection Agency 1976b). In the Yampa River Basin, mean annual TDS values at most of the stations were less than 500 mg/liter for the time period 1971-78. Those sites which exceeded this limit, Foidel Creek at the mouth, Fish Creek near Milner, and occasionally Williams Fork at mouth, and the Little Snake River near Baggs and near Lily, were all within the second impact category, i.e., water which can have detrimental effects on sensitive crops. In the White River Basin, the mainstem stations examined generally contained mean annual TDS concentrations less than 500 mg/liter, although mean values at the mouth near Ouray were double those in the headwater stretches and occasionally did surpass the recommended value. Mean TDS levels in Douglas, Yellow and Piceance Creeks were consistently in excess of this recommended value, with the highest concentrations in the basin observed at the mouth of Yellow Creek (mean range = 2,374 mg/liter to 3,070 mg/liter). However, information at a number of stations, particularly in the intermittent Yellow Creek drainage, is based on limited data which may not be representative of normal salinity conditions.

Excessive salinity in irrigation water reduces corp yields, limits the types of crops grown in an area, and can affect soil structure, permeability

TABLE 30. TOTAL DISSOLVED SOLIDS HAZARD FOR IRRIGATION WATER (modified from U.S. Environmental Protection Agency 1976b)

Description	TDS (mg/liter)
Water from which no detrimental effects will usually be noticed	500
Water which can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000

and aeration. Salt adversely impacts plants primarily by decreasing osmotic action and thereby reducing water uptake. The effects of salinity on irrigation are determined not only by the total amount of dissolved soilds present, but also by the individual ion composition of the water (Utah State University 1975). Certain plants are sensitive to high concentrations of sulfates and chlorides. Large amounts of calcium can inhibit potassium uptake. Sodium causes plant damage at high concentrations because it increases osmotic pressure and is toxic to some metabolic processes. It can also affect soils adversely by breaking down granular structure, decreasing permeability, and increasing pH values of those of alkaline soils. In 1954 the U.S. Salinity Laboratory proposed that the sodium hazard in irrigation water be expressed as the sodium absorption ratio (SAR), SAR = $Na/\sqrt{\frac{1}{2}(Ca + Mg)}$ where Na, Ca, and Mg are expressed as concentrations in milliequivalents per liter of water (McKee and Wolf 1963).

In the Yampa River Basin sodium levels were generally low. The National Academy of Sciences (1973) suggested 270 mg/liter as the maximum recommended sodium level in drinking water supplies. Mean annual sodium values never exceeded this recommended limit in the Yampa Basin, although occasionally excessive maximum values were observed in the Yampa River below Craig and near Maybell, at the mouth of Williams Fork, and at the mouth of the Little Snake River. Sodium data, however, were not collected during the 1971-78 study period at 8 of the 24 Yampa River Basin stations examined for this report, and collected only once during that time frame at 5 other locations. In the White River Basin, mean annual sodium concentrations at the mouths of the Piceance and Yellow Creeks were consistently in excess of the 270 mg/liter recommended limit. Sodium absorption ratios are generally low throughout the basins: the two maximum values reported in STORET at USGS tributary stations was 22 in Sand Creek near Baggs, Wyoming (Yampa Basin), and 15 in a tributary to Piceance Creek (White Basin). The U.S. EPA (1976b) states that 8 to 18 is considered the usable SAR range for general crops and forages. However, special USGS sampling at several coal mine and oil shale locations in both basins (Table 31) has reported SAR values well in excess of the recommended range.

TABLE 31. U.S. GEOLOGICAL SURVEY STATIONS AT MINE AND OIL SHALE SITES IN THE YAMPA AND WHITE RIVER BASINS WITH REPORTD SODIUM ABSORPTION RATIOS (SAR) IN EXCESS OF RECOMMENDED LIMITS

Latitude/Longitude	STORET Description	SAR
40°01'32"/108°15'38"	Superior RB-ST #14	620
40°25'55"/107°39'00"	Wise Hill #5 (UC=12)	52
40°51'45"/107°50'55"	Sewanee Coal Co. (UC=11)	39

Throughout many of the intermittent flowing tributaries in the study basins, water is used largely for stock watering purposes. Total dissolved solid concentrations in the basins are not generally restrictive in livestock (Table 32).

Industrial users may be severely affected through use of water for cooling or washing purposes which is high in total dissolved solids. Such water may result in corrosion and encrustation of the metallic surfaces of pipes, condensers, or other machinery parts. However, industrial reuqirements for purity of water vary considerably (Table 33). Examination of TDS levels throughout most of the Yampa and White River Basins (Appendix B) indicate that most industrial needs could be met in those areas without any water treatment efforts. However, at stations at the mouths of Piceance and Yellow Creeks, mean annual TDS levels tend to be greater than 1,500 mg/liter and some form of deionization would be required for some industrial uses. Oil shale development in the Piceance Basin is likely to produce further degradation in water quality. This factor could be limiting to future industrial advancement in these regions of the study basins.

The impact of salinity on fish and wildlife is highly variable. Many fish, for example, tolerate a wide range of total dissolved solid concentrations; the whitefish can reportedly survive in waters containing TDS levels as high as 15,000 mg/liter, and the stickleback can survive in concentrations up to 20,000 mg/liter. Fish reproduction and growth may be significantly affected during stress periods at considerably lower TDS concentrations, however. The EPA (1976b) reports that generally water systems with TDS level's greater than 15,000 mg/liter are unsuitable for most

TABLE 32. TOTAL DISSOLVED SOLIDS HAZARD FOR WATER USE BY LIVESTOCK (modified from National Academy of Sciences 1973)

TDS in Water (mg/liter)	Comment
<1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to these salinity levels or watery droppings in poultry.
3,000-4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to such salinity levels. Poor waters for poultry, often causing watery feces, increased mortality, and decreased growth, especially in turkeys.
5,000-6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
>10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

fresh-water fish. In the White and Yampa River Basins, TDS levels are well below this recommended maximum figure.

Toxic Substances

Trace Elements--

Total mercury concentrations in surface water samples from 1971-78 exceeded the EPA's recommended standard for aquatic life (Table 28) in the White River below Meeker, above Rangely, and the mouth near Ouray. The EPA (1976b) aquatic life standard of 0.05 µg/liter for mercury in water was established to insure safe levels in edible fish. Total mercury levels in excess of the criterion were reported at 10 of the 24 Yampa River Basin

TABLE 33. MAXIMUM TOTAL DISSOLVED SOLIDS CONCENTRATIONS OF SURFACE WATERS RECOMMENDED FOR USE AS SOURCES FOR INDUSTRIAL WATER SUPPLIES (modified U.S. Environmental Protection Agency 1976b)

Industry/Use	Maximum Concentration (mg/liter)
Textile	150
Pulp and paper	1,080
Chemical	2,500
Petroleum	3,500
Primary metals	1,500
Copper mining	2,100
Boiler makeup	35,000

stations examined for this report, including most of the mainstem Yampa River below Elkhead Creek (4.5 μg/liter), in the White River at mouth (2.5 μg/liter), and in the White River above Rangely (1.5 μg/liter). In the White River Basin, dissolved mercury concentrations exceeding the criterion have been reported at every station examined downstream from Meeker with the exception of several sites in the Piceance Creek drainage and at the mouth of Douglas Creek. Some of these dissolved concentrations were quite high: 1.6 μg/liter in Black Sulfur Creek near Rio Blanco, and 1.1 μg/liter in the White River above Rangely. The stations in the Yampa River below Elkhead Creek, and in the White River at Ouray were also in excess of the recommended EPA criterion for mercury levels in drinking water. Those beneficial uses impacted by mercury and other trace element levels in excess of recommended criteria throughout the Little Missouri and Belle Fourche River Basin are presented in Table 34.

Concentrations of iron in waters of the study area are highly variable. Nevertheless, between 1971 and 1978 total iron levels were reported in excess of the recommended criteria for drinking water and aquatic life at 17 of the 24 Yampa River Basin stations. Many of these reported excesses are in streams draining areas of active coal mining or past metal-mining sites (Wentz and Steele 1976). In the White River Basin, 14 of the 24 stations contained either total or dissolved iron concentrations in excess of the recommended criteria. The EPA drinking water criteria for iron was established to prevent objectionable taste and laundry staining (U.S. Environmental Protection Agency

TABLE 34. PARAMETERS EXCEEDING U.S. ENVIRONMENTAL PROTECTION AGENCY (1976c) OR NATIONAL ACADEMY OF SCIENCES (1973) WATER QUALITY CRITERIA, 1970-78 AT U.S. GEOLOGICAL SURVEY STATIONS IN THE WHITE AND YAMPA RIVER BASINS

Station Number	Cadmium	Lead	Iron	Manganese	Mercury	Sulfates	Copper
Yampa River							
2360	DW,AL,I	DW,AL,L					
2395	DW,AL,I	DW,AL,L	DW,AL	DW	AL		
2410	DW,AL,I	DW,AL,L					
2437	DW,AL,I	DW,AL,L	DW,AL	DW,I	AL*		
2439	DW,AL,I	DW,AL,L	DW,AL	DW,DW*,I*	AL	DW	
2441	DW,AL,I	DW,AL,L	DW		AL		
2000	DW,AL,I	DW,AL,L	DW,AL	DW,I			
2443	DW,AL,I	DW,AL,L	DW,AL	DW,I			
2444	DW,AL,I	DW,AL,L	DW	DW*	AL,AL*		
4100	DW,AL,I	DW,AL,L	DW,AL	DW			
4400	DW,AL,I	DW,AL,L	DW,AL	DW,I	AL	DW	L,I,L*I*
2450	DW,AL,I	DW,AL,L					
2465	DW,AL,I	DW,AL,L	DW,AL	DW,I	DW,AL		
2476	DW,AL,I	DW,AL,L	DW,AL,I	DW			
2490	DW,AL,I	DW,AL,L	DW,AL		AL		
2492	DW,AL,I	DW,AL,L					
3500	DW,AL,I	DW,AL,L		DW			
2497	DW,AL,I	DW,AL,L	DW,AL,I	DW,I	AL	DW	
2510	DW,AL,I	DW,AL,L	DW,AL,I	DW,I	AL,AL*		I
2570	DW,AL,I	DW,AL,L	DW	DW			
2500	DW,AL,I	DW,AL,L	DW				
2597	DW,AL,I	DW,AL,L					
2600	DW,AL,I	DW,AL,L	DW,AL,I	DW,I	AL	DW	L,I
26005	DW,AL,I	DW,AL,L					
White River							
3030							
3040							
3042			DW*				
3045					AL	DW	
3048	DW,AL,I	DW,L,AL	DW,AL,DW*,AL*	DW,DW*			
3060	DW,AL,I	AL*	DW*	DW*,I*	AL*		
30606	AL*		DW*	DW*,I*	AL*	DW	
3061	AL*			DW*	AL*	DW	
3062	AL*			DW*,I*	AL*	DW	
30621			DW	DW*,I		DW	
30622	AL*	DW,L,AL	DW,L,AL	DW,I	AL*	DW	
30623							
30624	AL*			DW,DW*,I*	AL*	DW	
306248							
30625	AL*		DW*		AL*		
306255	DW*,L*,AL*,I*	DW,L,AL	DW*	DW*,I*	AL*	DW	
1200	DW,AL,I	DW,L,AL	DW,AL	DW			
3063	DW,AL,I	DW,L,AL	DW,AL,I	DW,I	AL	DW	I
30638			DW	DW*		DW	
3064	AL*				AL*		
3065	AL*				AL*	DW	
3066	AL				AL	DW	
3067	AL*		DW*,AL*		AL*	DW	I*
3069		DW,L,AL	DW,AL,I	DW,I	DW,AL	DW	I,DW*,AL*,I*
2476			AL				
2600						DW,L,I	DW,AL,I

(continued)

TABLE 34. (Continued)

Station Number	Cyanide	Fluoride	Dissolved Oxygen	Beryllium	Molybdenum	Arsenic	Chromium
3048	AL			AL			
3060	AL	I*					DW*,AL*,I*
3061	AL				I*		
30606		DW*,I*			I*		
3062		I*			I*		
30621			AL				
30622		DW,L,I	AL		I,I*		
30624	AL		AL		I		
30625	AL						
306255		DW*,L*,I*			I,I*		
3063				AL		DW,I	DW,AL,I
3064	AL						
3065	AL						
3066	AL		AL				
3067	AL	DW*,L*,I*	AL				
3069	DW,AL	I*	AL			DW,I	DW,AL,I
	Selenium	Chloride	pH	Aluminum	Boron	Nickel	
2443	DW,I						
4400	DW,L,I		DW,AL		I*		
30606							
3061							
30622		DW			I*		
306255					I*		
3063				L,I		I	
3069				L,I		I	

Note: Full station descriptions are given in Tables 23 and 24. Beneficial use codes are designated as follows: AL = aquatic life, DW = drinking water, L = livestock, I = irrigation. For cadmium and lead, most observed concentrations are below detection range; minimum detection value, however, exceeds indicated criteria.

*Dissolved value; when total concentrations for a given parameter were listed in STORET, and in excess of recommended criteria, data on dissolved forms were not recorded here regardless of whether these data were available.

1976b). Iron levels in the Yampa River below Craig and near Maybell, Little Snake River near the mouth, Williams Fork at the mouth, Piceance Creek at the White River, and the White River above Rangely and at the mouth near Ouray also periodically exceeded the recommended criterion for irrigation waters. Iron criteria violations were greatest at the mouth of the Little Snake River (maximum total value = 480,000 μg/liter) and in the White River above Rangely (maximum total value = 240,000 μg/liter). High concentrations of iron can be fatal to aquatic organisms. Mine drainage, ground water, and industrial wastes are major sources of iron pollution.

Manganese concentrations were also highly variable. Similar to iron, manganese levels, in either the total or dissolved forms, frequently exceeded the recommended criteria for irrigation and domestic water supplies throughout both study basins. Excessive total manganese concentrations in the Yampa River Basin ranged from 80 µg/liter in the South Fork Williams Fork to 19,000 µg/liter in the Little Snake River at mouth. In the White River Basin, total manganese concentrations exceeding the recommended criteria ranged from 90 µg/liter in the White River below Meeker to 7,000 µg/liter in the White River above Rangely. The 50.0 µg/liter criterion for drinking water was established by the EPA to minimize staining of laundry and objectionable taste effects. These undesirable qualities of manganese may increase when in combination with even low concentrations of iron (U.S. Environmental Protection Agency 1976b).

Lead was reported at levels in "excess" of recommended drinking water, aquatic life and livestock criteria throughout the Yampa River Basin and at a number of stations in the White River Basin. Maximum concentrations were highest in the Little Snake River at the mouth (900 µg/liter), the White River above Rangely (400 µg/liter), and the Yampa River at Hayden and the White River at Ouray (300 µg/liter). However, there are problems in interpretation for much of the data on total lead as a result of interferences in analytical methods. In many cases, data points are reported as "known to be less than 100." Since the EPA criteria for drinking water, aquatic life and livestock are under this minimum detection value, it is impossible to determine in those cases whether recommended limits have been exceeded or not.

Cadmium values equal to or in excess of criteria for aquatic life, drinking water and irrigation were frequently reported at these same stations; however, there are similar problems of interpretation with cadmium data as with lead data due to limitations in analytical methods. Maximum concentrations of several trace elements and salts, including selenium, beryllium, copper, arsenic, chromium, cyanide, fluoride, molybdenum, boron, nickel and aluminum were occasionally in excess of recommended levels throughout the two study basins. Unusually high concentrations of chromium have been recorded in bottom sediments of the Yampa River below Craig (Wentz and Steele 1976) which were associated with industrial discharge from that community. Stations in the White River above Rangely, and at the mouth near Ouray, at times contained especially high levels of trace elements: total cyanide concentrations of 9,000 µg/liter, and total aluminium concentrations of 220,000 µg/liter have been reported at the latter site. It should be noted that the EPA alumium criterion of 5,000 µg/liter was established for waters used for irrigation and livestock. Bioassay tests have suggested that considerably lower concentrations (<1,000 µg/liter) may be necesary for adequate maintenance of aquatic life (Fox 1977). The Colorado Department of Health has recommended establishment of a state aluminum standard of 100 µg/liter (Table 35).

Fox (1977) observed temporal trends in the concentrations of many trace elements in the White River. Chromium, lead, and zinc were generally reported higher during "low flow," suggesting these elements are largely contributed through ground-water discharges to the river. Aluminum, cadmium, and iron were generally higher during the "high flow" events, reflecting a combination of natural erosive actions and runoff from active or abandoned mining and oil shale sites. Both arsenic and cadmium, which are highly toxic in excessive concentrations, are common constituents of rocks in the area, and Kinney

TABLE 35. PROPOSED WATER QUALITY STANDARDS FOR THE STATE OF COLORADO (modified from Fox 1977)

Parameter	Units	Proposed Standard*
Temperature	°C	30
pH	S.U.	6.5-9.0
Dissolved oxygen	mg/liter	5.0
Total suspended sediments	mg/liter	25(maximum allowed due to man's activities)
Magnesium	mg/liter	125
Chloride	mg/liter	250
Aluminum	µg/liter	100
Arsenic	µg/liter	10
Cadmium	µg/liter	0.4
Chromium	µg/liter	50
Copper	µg/liter	10
Iron	µg/liter	500
Lead	µg/liter	4
Manganese	µg/liter	200
Selenium	µg/liter	10
Silver	µg/liter	0.1
Zinc	µg/liter	50
Boron	µg/liter	750
Fluoride	mg/liter	2
Nitratem	mg/liter as N	4 ("alert" level)
Total phosphorus	mg/liter as P	0.1

* Values shown are based on the most restrictive water use and water hardness encountered in the White River study area.

et al. (1979) report they may be released to the aquatic ecosystem through weathering of the exposed bedrock, or as leachates from spent shale. Data collected during 1975 from Sage Creek at the mouth (Yampa Basin) also contained very high concentrations of cooper, lead, and vanadium (Wentz and Steele 1976). Wentz and Steele suggested these elevated values were a result of cooling tower blowdown being released from the power plant near Hayden. However, subsequent data did not show this phenomenon, perhaps due to a curtailment of plant-effluent discharges since that time.

Pesticides--

Data on pesticides in the study area covered by this report are limited. Pesticide concentrations in those samples that have been collected by the USGS in the study basins were never reported in excess of EPA recommended criteria (U.S. Environmental Protection Agency 1976b).

It might be expected that additional pesticides will be contributed to the river system as a result of expanding irrigation activities. Since many of these widely used chemicals are highly resistant to degradation and frequently persist in toxic form, this potential pollution source should be carefully monitored. Kinney et al. (1979) have stated,"In the Colorado River Basin, pesticides may constitute the greatest potential hazard of all toxic substances of nonpoint source origin." Deleterious impact from pesticides may be immediately produced as a result of localized spills, or more gradual through residual accumulation in the aquatic environment. An update of information and an expansion of stations being tested in both the White and Yampa River Basins is needed before an accurate evaluation of conditions can be made.

Organic Compounds--

The EPA (1976b) has recommended that total phenolic compounds should not exceed 1 μg/liter in waters used for domestic water supplies and to protect against fish flesh tainting. Virtually every station in the White and Yampa River Basins at which total phenols were sampled occasionally either equalled or exceeded this recommended limit. These criterion excesses were greatest in Evacuation Creek in the White Basin, where total phenol concentrations reached a maximum of 25 μg/liter. The EPA (1976b) reports that lowered dissolved oxygen concentrations, increased salinity, and increased temperatures all enhance the toxicity of phenolic compounds. In the White and Yampa River Basins this phenomenon is apparently a wide scale and natural one, certainly associated with open stretches of exposed crude oil shale, such as are found in the Evacuation Creek drainage. An expansion of the number of stations being monitored for phenolic compounds is recommended, particularly in light of proposed mine and oil shale development in this area already high in organic chemical content.

Radioactive Substances--

Radioactive elements are being monitored occasionally by the USGS at a number of stations throughout the study area. Based on these limited data, it appears that radioactivity is not a problem in surface waters of this region, since concentrations are generally below the EPA (1976a) Drinking Water Regulations for radionuclides (Table 36). However, more data are necessary before a reliable assessment of radioactivity levels in the White and Yampa River Basins can be made.

It should be noted that high levels of radioactive elements have been reported at some sites in the Upper Colorado Basin. Kinney et al. (1979) report that maxiumum gross alpha readings of 40 picocuries/liter (pCi/liter), with a mean concentration of 12 pCi/liter, have been recorded in the Green River near Green River, Utah. Greatest potential for releases of natually occurring radionuclides exists in development of the oil shale industry in the White River Basin, either through atmospheric emissions expected from the mining, retorting, and upgrading operations, or through leaching of the spent shale piles which still contain most of the uranium and radium inherent to the ore (Kinney et al. 1979).

TABLE 36. U.S. ENVIRONMENTAL PROTECTION AGENCY DRINKING WATER REGULATIONS FOR SELECTED RADIONUCLIDES (modified from U.S. Environmental Protection Agency 1976a)

Radionuclide	Allowable Level* (pCi/liter)
Tritium (H_3)	20,000
Strontium-90	8
Radium-226,228 (combined)	5
Gross alpha (excluding radon and uranium)	15

* No specific limits for allowable concentrations have been set for radionuclides not shown on this table. For those, it is merely specified that their combined dose should not exceed 4 mrem per year to the whole body or to any internal organ.

Suspended Sediments

Suspended sediments are those organic and mineral materials which are released to a watershed from a combination of channel erosion and overland runoff, and which are maintained in suspension by turbulent currents or through colloidal suspension. During periods of high flow, bank erosion is escalated and greater water velocities provide increased energy for scouring and transport of sediments. Many inorganic elements such as trace metals are absorbed and adsorbed onto moving sediment particles making suspended sediments an important transport mechanism. Sediment levels are also important because of their potential impact on light penetration, water temperature and chemical solubility, and aquatic biota (such as abrasive action on aquatic life or the elimination of benthic habitats and spawning areas by settleable solids which blanket the streambeds). In the Yampa and White River Basins, suspended sediment data are relatively sparse (Appendix B) and concentrations appear to vary substantially from drainage to drainage. However, the limited data indicate that suspended sediment levels in areas of the study basins, especially in the Piceance, Yellow, and downstream Snake River drainage, exceed the limits recommended for the maintenance of freshwater fisheries (Table 37).

The mean annual sediment load to the Yampa River at Maybell between 1950 and 1958 was reported at 272 million kg (U.S. Bureau of Land Management 1976a). Iorns et al. (1965) estimated that 1.6 billion kg/year of sediment is contributed annually by the entire Yampa Basin. Subsequent studies indicate

TABLE 37. SUSPENDED SEDIMENT CONCENTRATIONS RECOMMENDED FOR MAINTENANCE OF FRESHWATER FISHERIES (modified from Kinney et al. 1979)

Suspended Sediment in Water (mg/liter)	Comment
<25	Concentrations not expected to have any harmful effects on fisheries.
25-80	Possible to maintain good or moderate fisheries in waters with this level of supsended sediments. However, yields of fish from these waters may be lower than those yielded from lower sediment concentrations.
80-400	Unlikely to support good freshwater fisheries, although fisheries may be found at the lower concentrations within this range.
>400	At best, only poor fisheries can be expected from waters that typically contain these levels of suspended sediments.

that the suspended sediment load from the Yampa Basin is approximately 20 percent higher than originally estimated by Iorns et al. (Wentz and Steele 1976) and that the Yampa River contributes 1.5 percent of the suspended sediments in the upper Colorado Basin (Fox 1977). Suspended sediment discharge in the Upper White River at Buford is approxiamtely 30 million kg/year U.S. Economic Research Service et al. 1966) and is certainly much greater than this downstream at the mouth.

The vast majority of this loading is attributable to agricultural runoff, although municipal, industrial, and transportation activities also contribute suspended sediments to the basins. Sediment loading in the study area is cyclic, being highest during spring runoff, and lowest during summer and fall periods of low flow. In the Yampa Basin, mean annual sediment contributions from the Little Snake River are an order of magnitude greater than in the Yampa mainstem (Wentz and Steele 1976). Even though the Little Snake contributes less than 30 percent of the Yampa Basin streamflow, it provides nearly 69 percent of the sediment load (Andrew 1978). Most of the natural sediments are contributed from drier, lower elevations of the basins where insufficient ground cover exists to fully protect arid soils from erosion (U.S. Bureau of Land Managment 1976a). The problem of erosion is intensified by heavy livestock grazing that further depletes the vegetation cover.

In the Yampa River Basin, most of the coal development proposed is in upstream higher elevations that receive greater amounts of rainfall and support sufficient vegetation that erosion is presently not a problem (U.S. Bureau of Land Management 1976a). Mining and related activities including construction of haul roads and railways, population increases, and construction of power plants and mine facilities, all create a potential for an increase in sediment yield from these presently low yield areas. Energy developments in the Yampa Basin are expected to contribute 27 million kg of sediment per year by 1990 and could destroy much of the aquatic habitat at the impact locale (U.S. Bureau of Land Mangement 1976a). However, the significance of this increase sediment loading will vary depending on where within the basin it enters the stream channel. Sediment increases from projected mining activities in the Yampa Basin will be equivalent to 2 percent of the present total basin sediment load; however, the same increase would elevate the sediment load of the upstream Yampa River as much as 30 percent (Andrews 1978). In the White River Basin, oil shale development around Piceance and Yellow Creeks is expected will as much as triple sediment loadings to that drainage (Figure 13).

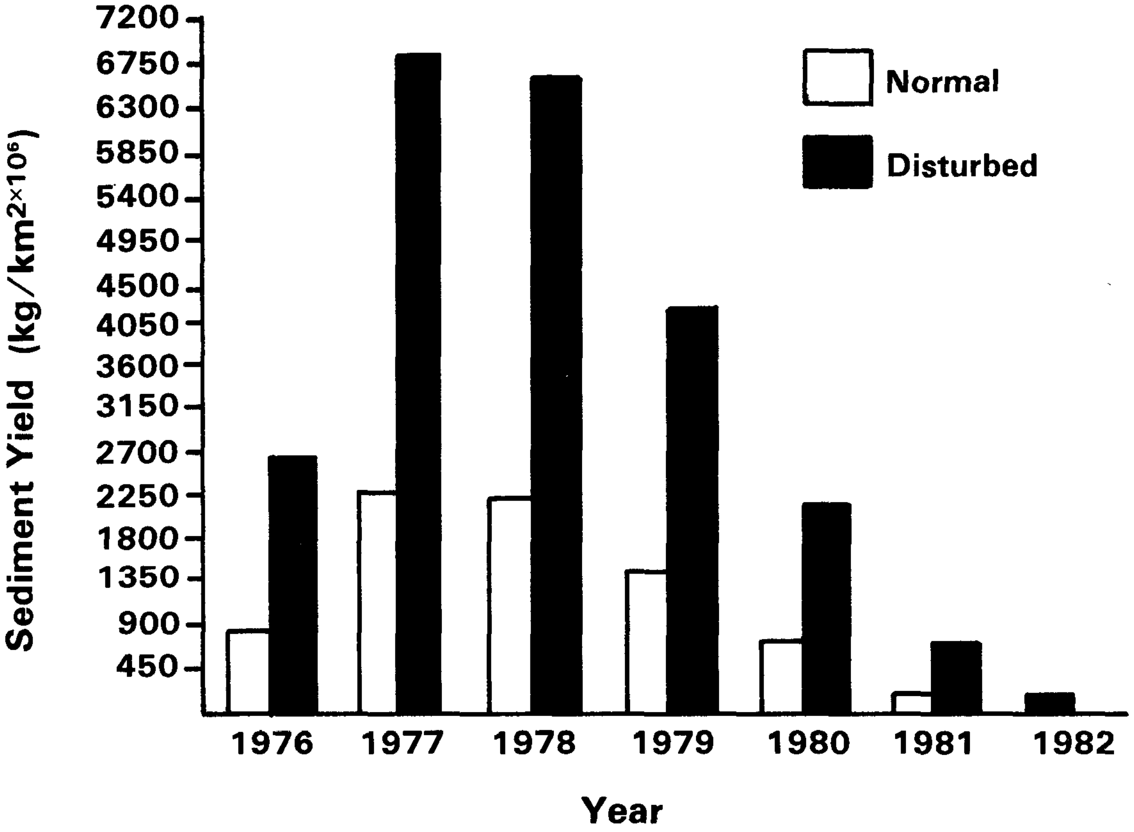

Figure 13. Possible sediment yields under normal and disturbed conditions in the oil shale region of the White River in Colorado. (modified from University of Wisconsin 1976)

Nutrients

Nutrient levels in the study area are generally low except during periods of high runoff from snowmelt and storms. In both basins, agricultural runoff and sewage are the major sources of nutrient loadings. Phosphorus concentrations in the White River tend to increase downstream; Fox (1977) reports that downstream phosphorus levels are "in sufficient concentrations to warrant concern over excessive algal growth should the waters in the lower White River be impounded." In the Yampa River Basin nutrients are largely contributed from sewage treatment discharges at Steamboat Springs, Hayden, and Craig (Utah International Inc. 1974), and from spring snowmelt when "runoff is rich in nitrogen, and probably phosphate, as it drains areas where cattle and sheep have been feeding during the winter" (U.S. Bureau of Land Management 1976b).

Any future irrigation projects will contribute additional nutrients to the study area. Nutrients may also be contributed by the oil shale industry in the White River Basin through runoff from raw and spent shales, commercial fertilizers, stack emissions, and ground-water discharges (Kinney et al. 1979). Increased sewage and urban runoff, a result of the expected population expansion from proposed irrigation projects and energy developments, could further increase nutrient concentrations in the rivers if they are not carefully controlled. McCall-Ellingson and Morrill, Inc. (1974) have reported, "The major pollution that lowers stream water quality in the [Yampa] basin is inadequately treated municipal sewage." Nutrient contamination to ground-water supplies from septic tank effluents around the communities of Yampa, Phippsburg, Milner, Maybell, Buford, and Rio Blanco has been reported as one of the top five nonpoint discharges that affect water quality in the analysis area (U.S. Bureau of Land Management 1976a).

Temperature

Temperature is a significant parameter for stable aquatic systems. It controls the geographical dispersal of biotic communities, is related to ambient concentrations of dissolved gases, and affects the distribution of chemical solutes in lentic water bodies through the phenomenon of stratification.

In general, raw data trends in the study basins indicate that water temperature increases gradually as one moves downstream, and is highest in July, August, and September and lowest in December, January, and February. Wentz and Steele (1976) noted similar annual cyclic temperature patterns in the Yampa Basin; diurnal temperature variability in the White River has been studied by Fox (1977) and Bauer et al. (1978).

It should be noted that elevated stream temperatures have been reported in the Yampa River downstream from Sage Creek (Bauer et al. 1978). These increased temperatures were attributed to thermal-heated effluent discharges that were released to Sage Creek from the Hayden Powerplant until 1976, when a cooling tower/evaporation and pond system was installed. Presently, there are no thermally heated waters being discharged into Sage Creek from the plant (Bauer et al. 1978).

Dissolved Oxygen

Waters in the Yampa and White River Basins study region are generally well aerated (Appendix B). The dissolved oxygen minimum established by the EPA (1976b) for maintaining healthy fish populations is 5.0 mg/liter. Dissolved oxygen values in the Yampa Basin from 1971-78 maintained this minimum level; Bauer et al. (1978) reported DO concentrations in the upper basin are generally within ±5 percent of saturation. USGS stations examined in the White River Basin dropped below this level at six locations: Piceance Creek near the White River (1.0 mg/liter minimum value), Piceance Creek at the White River (4.9 mg/liter minimum), Corral Gulch at 84 Ranch (4.4 mg/liter minimum), White River above Southam Canyon near Watson (2.4 mg/liter minimum), White River below Asphalt Wash near Watson (3.8 mg/liter minimum), and White River at mouth near Ouray (2.2 mg/liter minimum). For all six stations, dissolved oxygen concentrations below the recommended criterion were observed in the summer months between May and September.

Fox (1977) reported that dissolved oxygen levels in Yellow Creek were generally lower than those observed throughout the rest of the White River Basin, averaging 4.0 mg/liter. Those five USGS stations in the Yellow Creek drainage examined in this report, for which dissolved oxygen data were available between 1971 and 1978, do not support these findings, with mean concentrations ranging from 7.4 to 10.9 mg/liter (Appendix B).

pH and Alkalinity

The ionic composition of water and, therefore, biological systems are affected by pH. Waters in the study area are basically alkaline with pH values usually between 7 and 9 (Appendix B). There are a few exceptions to this: several stations in the White River Basin had minimum pH values ranging from 6.3 to 6.9, and several maximum values recorded in the Yampa Basin ranged from 9.1 to 9.3. In Sage Creek near Hayden (Yampa Basin) a single pH value of 2.1 was reported during September 1975; it is not known whether this highly acidic reading was erroneous, or due to an episodic discharge from the upstream coal-fired electric powerplant.

Alkalinity indicates the ability of water to resist wide fluctuations in pH due to the addition of acids which may be detrimental to the aquatic environment. It is influenced primarily by carbonate and bicarbonate but may also be affected by phosphates, hydroxides, and other substances to a lesser degree (Briggs and Ficke 1977). Waters in the study area are well buffered and mean alkalinity values were generally greater than 100 mg/liter throughout both basins. The EPA has not established any recommended upper limits for alkalinity. However, waters containing concentrations greater than 500-600 mg/liter as $CaCO_3$ are highly mineralized and may be unsuitable for some uses (Fox 1977). In general, alkalinity mean values in the White River Basin, particularly in the Piceance and Yellow Creek drainages where oil shale development is ongoing, were much higher than in the Yampa Basin (Appendix B), and commonly exceeded 500 mg/liter.

IMPACT OF DEVELOPMENT ON GROUND WATER

Ambient Levels

Ground-water quality throughout the Yampa and White River Basins is highly variable (Table 7) and dependent upon the geological composition of rocks surrounding each aquifer (Colorado Department of Natural Resources 1979). Ground-water aquifers derived from thick marine shales are of poor quality, although better water (i.e., suitable for livestock watering) is found in those sandstone members of shale formations which are within 61 m of the surface (U.S. Bureau of Land Management 1976a). Wells from the Glen Canyon Sandstone and Entrada Sandstone yield good quality water in the Yampa River Basin around Dinosaur, but near Rangely (White Basin), water from these same rocks is saline. Ground water from fractures in crystalline rocks is of good quality, with TDS levels generally less than 500 mg/liter. The alluvium along streams in the study area yields small amounts of fair to poor quality water. Ground water obtained from other sedimentary rocks (which includes the coal-bearing formations) is good in some locations, but generally fair to poor (U.S. Bureau of Land Management 1976a). It is Madison limestone that yields saline water at McCoy and Meeker Dome. Dissolved solids content in these aquifers is usually acceptable for livestock consumption, and can be used for domestic purposes if no other water source is available. It is, however, unacceptable for irrigation except if applied to well-drained soils and salt-tolerant crops (U.S. Bureau of Land Management 1976a).

Salinity content is one of the greatest water quality constraints to ground-water development in the region. The Piceance and Yellow Creek Basins, are of particular interest, as availability there of relatively fresh ground water is crucial to large-scale development of the oil shale industry. Quality of ground-water aquifers in the sedimentary formations of the Piceance Basin has been extensively studied:

> "The hydrologic system consists generally of an upper aquifer, above the confining Mahogany Zone, and a lower aquifer below the Mahogany Zone. Most water in the upper aquifer contains less than 2,000 mg/liter of dissolved solids; the water in the lower aquifer contains as much as 30,000 mg/liter of dissolved solids in the northern part of the basin, as well as undesirable quantities of flouride and boron throughout the basin. Various wells and test holes show that methane and hydrogen sulfide gases exist in some places." (Colorado Department of Natural Resources 1979).

The relation of these aquifers to important strata are indicated in Figure 14. The lower aquifer has been reported to contain high concentrations of barium and lithium. Ground water has also been investigated in the Utah oil shale

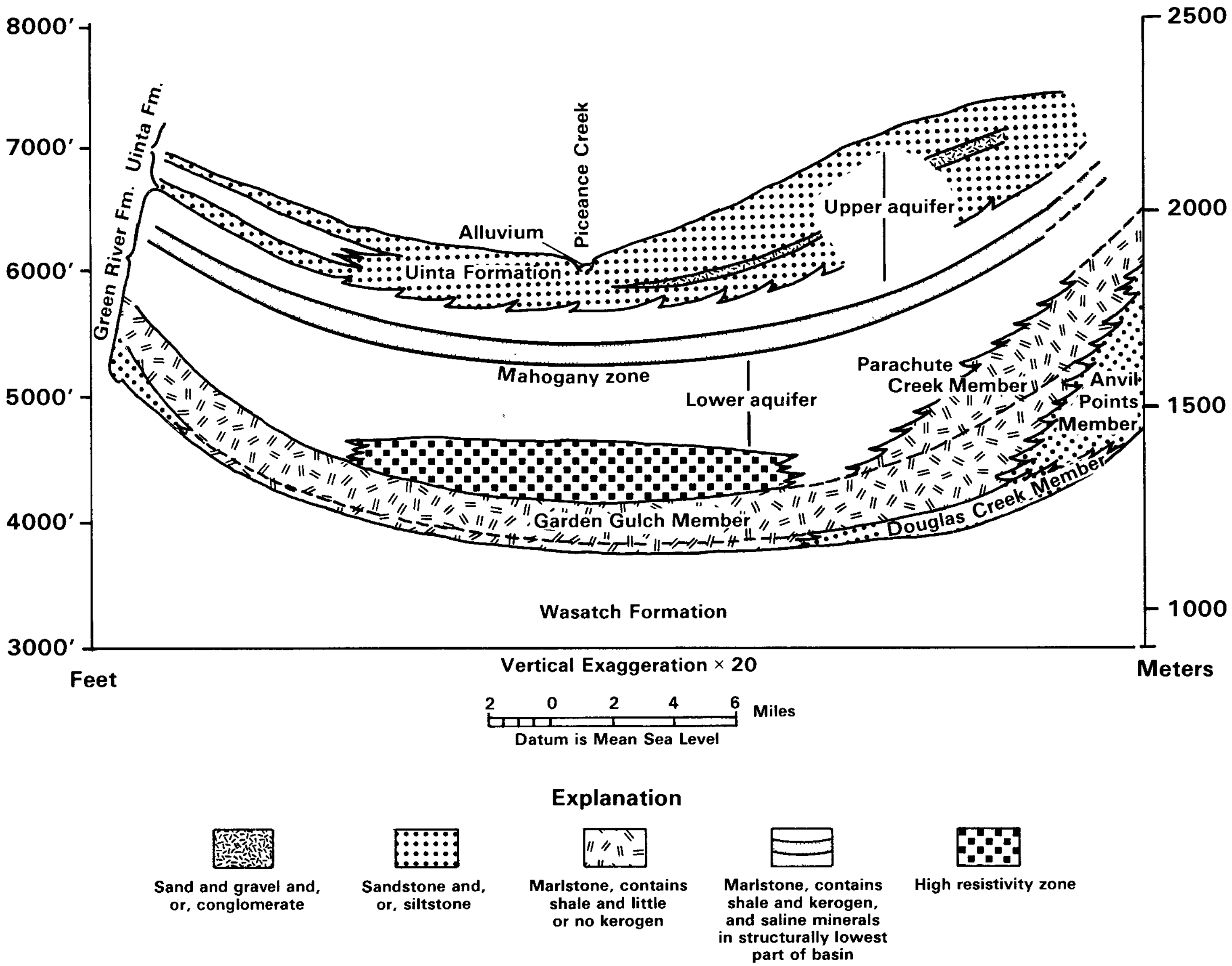

Figure 14. Diagrammatic section across the Piceance Creek Basin, Colorado. (Kinney et al. 1979)

tracts (U-a, U-b), and found to be of poor quality, with TDS concentrations frequently in excess of 2,500 mg/liter (Slawson 1979).

Man's Impact

There is a variety of industrial activities anticipated or ongoing in the Yampa and White River Basins, and virtually all of this development has the potential to severely impact regional ground-water resources. The oil and gas extraction industry is a major potential ground-water pollution source (Everett 1979). Water quality problems associated with coal mining include acidity, increased salt content, higher heavy metal concentrations, and greater sediment loads (Warner 1974). Steele (1978) reports in the Yampa Basin "adverse ground-water quality changes may be anticipated from infiltration of water that percolates through mine spoil piles, from evaporation-pond seepage at a plant site, and from pit disposal of fly and bottom ash from powerplants." Explosives, sewage effluents, associated road construction, and pit discharges are all potential sources of ground-water pollution associated with strip mining activities. Mines remain pollution sources even after closure, complicating pollution control. Dissolved solids and trace element concentrations in some wells, streams, and mine pits in the coal mining area of the Yampa Basin are presented in Table 38.

The oil shale industry is a potential pollutant source with regard to ground-water resources in the White River Basin. During shale mining, relatively good ground water above the shale layer can be contaminated by saline ground water if connection with the saline strata occurs (Slawson and Yen 1979). If in situ processes are used, ground water which reenters (black-floods) the retort site after development can become contaminated as it contacts the retorted oil shale and newly exposed minerals (U.S. Energy Research and Development Administration 1977). Contamination can also occur through aquifer exposure to substances used in well site drilling for retort operations (Slawson and Yen 1979). Jones et al. (1977) state, "there is considerable potential for contamination of ground water by both coal conversion and oil shale facilities, and the monitoring needs are greatest in this area."

TABLE 38. DISSOLVED SOLIDS AND TRACE ELEMENTS IN SELECTED WELLS, STREAMS, AND MINE PITS IN THE YAMPA RIVER BASIN (modified from U.S. Bureau of Land Management 1976d)

Parameter	Energy 1 Pit	Foidel Creek Near Tipple	Foidel Creek near Foidel School	Energy 2 Pit	Monitor Well P-2	Seneca 2 Pit	Seneca 2 Shop Well
Calcium (mg/liter)	410	71	140	75	64	250	200
Magnesium (mg/liter)	180	35	71	29	77	170	77
Potassium (mg/liter)	6	3	3	3	4	10	4
Sodium (mg/liter)	64	19	36	44	76	160	31
Bicarbonate (mg/liter)	217	313	305	314	518	416	557
Chloride (mg/liter)	7	4	6	7	4	18	21
Fluoride (mg/liter)	0.3	0.3	0.3	0.3	0.1	0.4	0.3
Sulfate (mg/liter)	1,500	84	430	80	220	1,300	420
$NO_2 + NO_3$ (mg/liter)	18	0.00	1.4	13	0.00	5.0	0.07
Silica (mg/liter)	54	8.8	5.3	11	14	5.8	14
TDS (mg/liter)	2,360	380	848	462	720	2,140	1,050
Arsenic (μg/liter)	0	2	1	0	0	0	0
Cadmium (μg/liter)	1	0	0	1	0	1	4
Cobalt (μg/liter)	0	0	0	1	0	0	0
Copper (μg/liter)	3	3	4	5	0	0	250*
Iron (μg/liter)	40	110	90	60	2,000	30	90
Lead (μg/liter)	0	0	0	0	0	1	0
Manganese (μg/liter)	20	70	110	80	50	70	17
Mercury (μg/liter)	0.0	0.0	10.2	0.0	0.1	0.0	0.0
Molybdenum (μg/liter)	1	0	0	3	0	1	0
Nickel (μg/liter)	9	4	2	3	1	14	0
Selenium (μg/liter)	47*	0	3	0	0	5	4
Vanadium (μg/liter)	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Zinc (μg/liter)	20	10	8	4	2,200*	30	20
Conductivity (μmho/cm)	2,850	600	1,200	740	1,500	2,420	1,450
pH	7.6	7.8	8.1	7.8	6.9	7.5	7.5
SAR	0.7	0.5	0.6	1.1	1.5	1.9	0.5
Water Temperature (°C)	18.5	23.8	22.0	25.0	10.0	16.0	20.5

*Excessive value (probably due to contamination of sample).

SECTION 9

ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT

IMPACT ON WATER QUANTITY

In the Yampa and White River Basins, surface water availability is expected to be the major factor limiting growth and development including development of energy resources. Surface water supplies in both basins are highly erratic and vary substantially from season to season and from year to year. The mean annual consumptive use of water during 1975-76 was 75.2 million m^3 in the Yampa Basin, and 123.3 million m^3 in the White Basin. Over 70 percent of this depletion is related to agriculture including irrigation and livestock watering.

The average annual consumptive use of surface waters in both the Yampa and White Basins is well under minimum recorded annual discharges. However, there is great variability in stream flow and future industrial developers cannot be assured of the stable, dependable quantity of water required year-round for most proposed activities. Energy development, particularly surface mining and the subsequent conversion of coal into electricity, requires enormous amounts of water. Large quantities of water are also needed for reclamation projects to restore mined areas and for planned transportation of coal out of the vicinity if a coal slurry line is used. The oil shale industry is another large consumer that uses water in virtually every stage of operation. This fact is significant since many of the streams in the shale-rich region of the Piceance Basin and the Utah oil shale tracts are dry much of the year. Water consumption for industry in the White River Basin is complicated by the absence of an interstate agreement as to what quantity of water the State of Colorado must annually deliver to the State of Utah, or to what quantity of water Indian users are entitled for irrigation of tribal lands. Ground-water supplies in both basins are generally inadequate for sustenance of the long-term high yields that would be required for most projected industrial activities and cannot be expected to be of much value in supplementing regional surface water diversions for an extended period of time. An exception to this is the ground-water supplies in reserve under the Piceance and Yellow Creek drainages. These reserves could assist future oil shale developers in satisfying annual water requirements, assuming cost-effective methods of purifying this highly mineralized water source are found in the near future.

It is sometimes assumed that all water not otherwise consumed is available for diversion and energy utilization. This attitude overlooks the many ecological needs for the "unused" water: instream flow maintenance for the preservation of critical wetlands and riparian habitats, conservation of the native environment of endangered species, etc. The Yampa and White River Basins, because they are essentially unaltered by high dams, provide the last remaining significant breeding habitat for a number of fish species in the Upper Colorado River found on the Colorado Threatened or Endangered lists. Parts of the Yampa Basin, including the Little Snake River, are also being considered for wild and scenic river designation. If accepted, maintenance of instream flows in that region would then become of primary importance, for a designation that greatly restricts future development in order to maintain the region's desirable natural qualities. Thus, an obvious conflict of interest arises. It is clear that in both the Yampa and White River Basins, the development of additional storage facilities, and perhaps diversion of water from the Colorado River, will be necessary to assure that sufficient water will be available to meet anticipated energy development, irrigation, and recreational demands. Local decisions must be made regarding priorities for preservation of natural habitats threatened by additional water impoundment and flow regulation.

IMPACT ON WATER QUALITY

Surface water quality in the Yampa and White River Basins is highly variable. Tributaries throughout the study region are ephemeral, and in these areas, water quality is dependent on seasonal variations in the primary source of flow (whether ground water or precipitation) and the quantity of discharge. In general, water quality is adequate for most irrigation, livestock watering, municipal, and industrial needs of the region. There exist, however, geographically localized problem areas, as well as some specific parameters which are of concern throughout the entire study area.

At present, salinity levels are a major concern to the White and Yampa Rivers and to the entire Colorado River Basin. Some of the salinity impact to the basins is unavoidable, because of regional rock chemistry, which is highly erodable in this semiarid geographic region. Thermal springs and naturally saline ground-water seeps contribute total dissolved solids to the Yampa and White Basins. During low discharge periods, flows in the basins are comprised to a greater extent of ground-water discharges, which are usually high in salt. However, man's industrial activities have the potential to increase natural salinity substantially. Abandoned oil fields, including sizeable contributions from Meeker Dome on the White River, are a major source of salinity in both of the study basins. Coal mining activities around Hayden contribute to elevated salt concentrations, particularly chloride, sodium, and sulfate, in the Upper Yampa River. The development of the oil shale industry in the White River Basin could ultimately increase TDS concentrations at Hoover Dam by 10 to 27 mg/liter, depending on the source and quality of water used by the developers.

Sediment loading is a problem in much of the study area, particularly in the Little Snake River, which contributes only 3 percent to the Yampa Basin stream flow but over 60 percent of the total basin sediment yield. The vast majority of this loading is attributable to agriculture runoff. However, increases in sediment-related problems can be expected as a result of growing resource development in the Yampa and White River Basins, particularly around Hayden, Meeker, and Rangely, where expanded coal mining and oil shale activities are expected. Any future industrial and agricultural projects will intensify problems with erosion through construction activities, transport roads and removal of over-burden for mining. Sediment contributions from projected coal mining activities in the Yampa Basin will be equivalent to 2 percent of the present total basin load; oil shale development on the Piceance and Yellow Creeks will triple existing sediment loads. In the Piceance, Yellow and Little Snake drainages, sediment concentrations already exceed the limits recommended for maintenance of fresh water fisheries.

Some increases in nutrient and trace element concentrations can also be expected as a result of flow reductions associated with energy development activities in the study area. Population expansion and accompanying construction could increase nutrient loading to the rivers if not carefully controlled. Nutrient contamination for ground-water supplies from septic tank effluents around the communities of Yampa, Phippsburg, Milner, Maybell, Buford, and Rio Blanco has been reported as one of the most significant impacts affecting water quality in the area. Most of the trace elements have been periodically reported in excess of recommended criteria throughout both the Yampa and White Basins. Potential for future trace element contamination to the region, particularly from the in situ oil shale and coal mining industries, is great, if proper pollution control techniques are not implemented. The effect of the planned energy developments on temperature, pH, and alkalinity are not expected to be substantial and will, in all probability, be a result of reduced flows or hydrological modifications produced by supplemental reservoir construction.

The quality of ground water in the basins is fair to poor due to high concentrations of dissolved solids. Much of the low quality water is natural to the basins, with dissolved solids and the major ions leaching into the ground-water systems form the overlying shale. However, energy developments can intensify the problem. In addition to reducing the ground-water levels to supplement variable surface water flows, contamination of the aquifers is possible, particularly as a result of the oil shale industry if in situ conversion processes are used. Contamination from organic pollutants are of particular concern, both due to the lack of available data regarding their nature and quality, and the high costs associated with organic analyses.

SECTION 10

RECOMMENDED WATER QUALITY MONITORING PARAMETERS

An objective of water quality monitoring in the Yampa and White River Basins should be to assess the impact of energy resource development, irrigation projects, and associated developments. Toward this end, a determination of those parameters which would provide meaningful data is needed. The nature and type of possible pollutants from the major activities in the basins were inventoried. The possible effects of these, as well as those parameters that are already being monitored, were reviewed and a proposed priority list of parameters of interest in the Yampa and White River Basins were prepared.

PHYSICAL AND CHEMICAL PARAMETERS

The selection of which water quality parameters should be routinely monitored in the Yampa-White study area is not obvious. Physical data provide information on temperature, quantity (flow), osmotic pressures (salinity, conductivity), and other factors that affect both the biota and the chemistry. The utility of these data must then be considered when selecting which parameters to measure. Similarly, the ambient level of a chemical and its effect upon the biota and interactions with other chemicals present must be known if a cost-effective monitoring network is to be implemented.

In addition to assessing the quality throughout the water column, the monitoring of substrate composition is also necessary. Many organic and inorganic pollutants are adsorbed onto sediment particles or organic debris. Other pollutants, such as iron, may form flocculants or precipitates, or may sink of their own accord. These materials may be deposited in areas of slower moving water or left as evaporites in the dry washes of the area. They may, however, be resuspended during periods of erosion or be released as dissolved parameters following a change in environmental conditions. The depositied sediments, therefore, represent both a pollutant sink and a potential pollution source. It is necessary to monitor bottom sediment composition in order to obtain a full picture of environmental pollution.

As a means of identifying and giving priority to those parameters most appropriate for monitoring energy development, each potential pollutant previously addressed is evaluated in terms of the projected impact on ambient water quality with respect to beneficial water use criteria. Also evaluated are those "indictor parameters" that, although not in themselves pollutants, either provide a direct or indirect measurement of environmental disturbances or are required for the interpretation of water quality data. The following symbols are used for identifying those beneficial water uses affected by existing or projected increases in parameter ambient levels:

Symbol   Beneficial Water Uses

I = Irrigation

D = Drinking water (public water supplies)

A = Aquatic life and wildlife

W = Industrial uses

L = Livestock drinking

Three priority classifications were developed based on criteria given below. These are:

> Priority I (must monitor parameters) -- should be collected regularly at energy development assessment monitoring stations (Table 39)
>
> Priority II (major interest parameters) -- would be desirable to monitor in addition to Priority I parameters if resources permit (Table 40)
>
> Priority III (minor interest parameters) -- are presently being monitored by the existing network but which will provide little useful data for monitoring energy development impacts on water quality in the Yampa and White River Basin (Table 41).

This classification represents an attempt to (a) identify those parameters that will effectively monitor the impact of energy development in the Yampa and White River Basins, or (b) permit the detection of increases in parameter levels that may be deleterious to designated beneficial water uses.* This classification scheme is not intended to preclude monitoring of low priority or unmentioned parameters for special studies or for purposes other than assessment of energy development impact. Neither does it require the elimination of those parameters already being collected for baseline data which are very inexpensive to monitor. The priority does not attempt to address sampling frequency. However, monitoring frequency is discussed briefly in Section II and will be addressed in greater detail in subsequent documents in this energy series.

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*All assessments relative to beneficial water uses are based on U.S. Environmental Protection Agency (1976b) criteria or drinking water regulations (U.S. Environmental Protection Agency 1975). In those cases where EPA established criteria have not presently been defined, National Academy of Sciences (1973) recommended criteria are used.

TABLE 39. PRIORITY I, MUST MONITOR PARAMETERS FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE YAMPA AND WHITE RIVER BASINS

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code†
Alkalinity, total (as $CaCO_3$)	Needed for interpretation of water quality data.	1
Aluminum, total	Periodically exceeded recommended criteria for irrigation and livestock in downstream White River.	2I,L
Ammonia, total as N	Exceeded recommended levels for aquatic life, expected to increase.	2A;3A
Arsenic, total*	Periodically equalled or exceeded recommended criteria for drinking water, livestock, and irrigation in the White and Little Snake Rivers, may increase with oil shale development.	2D,I,L;3D,I,L
Beryllium, total	Values occasionally reported in excess of aquatic life criterion in Yampa and White Rivers, and Yellow Creek at mouth.	2A
Bicarbonate ion	Dominant anion in basins, may be affected by energy development.	4
Biochemical oxygen demand of sediments, 5-day*	Measure of pollution increases in the basins, sediment serves as an integrative accumulator.	4
Boron, total	Exceeded irrigation criterion in Piceance and Yellow Creek drainages.	2I
Cadmium, total	Reported equal to or in excess of criteria for drinking water, irrigation and aquatic life throughout study area, and in excess of livestock criterion in the headwaters of Little Snake River; may increase as a result of oil shale development.	2A,D,I,L; 3A,D,I,L
Carbon, total organic in sediments*	Provides indication of organic contamination, many elements and compounds are preferentially absorbed onto organic debris.	4
Calcium, dissolved	Dominant cation in upstream White and Yampa Basins, may be affected by energy development.	4
Chloride	Periodically exceeded EPA criterion for drinking water at mouth of Piceance Creek, increased levels anticipated from mine spoil drainage.	2D;3D,I
Chromium, total*	Levels reported in excess of drinking water criterion in upstream Piceance Creek, and in excess of irrigation and aquatic life criteria as well in the Little Snake at mouth and downstream White River. Unusually high concentration in sediments of Yampa River below Craig have been reported which are attributable to industrial discharges from that community.	2A,D,I

(continued)

TABLE 39. (Continued)

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code†
Specific conductance, at 25°C	Useful indicator of TDS, affects overall water chemistry.	4
Copper, total	Exceeded irrigation water criterion in Yampa River at Maybell, and lower White River. Exceeded livestock criterion in Little Snake at mouth, Sage Creek at mouth, and drinking water criterion in the White River at mouth.	2D,I,L
Cyanide, total*	Levels have exceeded aquatic life criterion in the Yampa River below Little Snake River (Colorado State Health Department Station) and throughout the White River Basin. One excessively high value (9.0 mg/liter) exceeding drinking water criterion reported in 1976 in the White River at mouth.	2A,D
Dissolved oxygen	Necessary for maintenance of aquatic life and affects water chemistry. At some stations in the White River, levels during summer months (May-September) have been less than EPA recommended criterion for aquatic life.	1;2A;4
Flow	Needed for interpretation of water quality data.	1
Fluoride	Reported in excess of drinking water, livestock, and irrigation criteria throughout White River Basin, with greatest value (7.0 mg/liter) at the mouth of Piceance Creek.	2D,I,L
Iron, total*	Levels have frequently exceeded recommended criteria for aquatic life, drinking water, and irrigation throughout the study basins, may increase with expanding mining activities.	2A,D,I; 3A,D,I
Lead, total*	Exceeding drinking water, livestock, and aquatic life criteria throughout the study basins.	2A,D,L
Magnesium, dissolved	Important cation in study basins, may be affected by energy development.	4
Manganese, total*	Frequently exceeded EPA criteria for drinking water and irrigation.	2D,I
Mercury, total*	Frequently exceeded EPA criterion for aquatic life and periodically criterion for drinking water, possible contribution from powerplants.	2A,D;3A,D
Molybdenum, total	Exceeded irrigation water criterion in White River basin.	2I
Nickel, total	Periodically exceeded irrigation water criteria in the White River at mouth and above Douglas Creek.	2I
Nitrate-nitrite-N	Primary nutrient, expected to increase, could approach health limits in the future.	3D,L;4

(continued)

TABLE 39. (Continued)

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code†
Pesticides	From available data, no pesticides were reported at levels exceeding criteria for aquatic life. However, with increasing agricultural activity, levels of pesticides/herbicides may be expected to increase.	2A;3A,D
Petroleum hydrocarbons (includes benzene, toluene, oil and grease, napthalene, phenols, olefins, thiophenes, and cresols)	Can be expected to increase throughout the basin, total phenol regularly exceeded EPA recommended criteria throughout study area.	2A,D;3A,D
pH	Needed for interpretation of water quality data, value observed in Sage Creek 'at mouth more acidic than EPA recommended criteria for drinking water and aquatic life.	1;2A,D;4
Phosphorus, total*	Primary nutrient contributing to algae and macrophyte growth, expected to increase.	3A,D;4
Potassium, dissolved	Important cation in study area, may be affected by energy development.	4
Selenium, total*	Reported levels exceeded drinking water and irrigation criteria in Grassy Creek at mouth, and livestock criterion as well in Sage Creek at mouth (Yampa Basin), levels may increase as a result of stack emissions.	2D,I,L;3D,I,L
Sodium, dissolved	Dominant cation in downstream stretches of White and Yampa Basins, increased levels anticipated from mine spoil drainage and increased use of water conditioners. Sodium absorption ratios presently reported excessively high in some mine and oil shale development sites.	3D,I;4
Sulfate, dissolved	Important anion throughout study basins, particularly during periods of low surface flow, commonly exceeded EPA criterion for drinking water throughout White Basin and in tributaries to Yampa River; may be affected by energy development.	2D;4
Suspended sediments	Major transport mechanism, indicator parameter, expected to increase with energy development.	1;3A,I;4
Temperature	Needed for interpretation of water quality data, could increase with development.	1;3A;4
Total dissolved solids	Indicator parameter; downstream salinity problems anticipated with increasing irrigation and energy development, already a problem in some areas of study basins.	2D,I;3D,I,L,W;4

*Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottome sediments, unless specified for bottom sediments only.

†For full explanation of category codes, see symbols listed in Section 10.

TABLE 40. PRIORITY II, PARAMETERS OF MAJOR INTEREST FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE YAMPA AND WHITE RIVER BASINS

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code†
Biochemical oxygen demand, 5 day	May provide basic information on increased pollution.	7
Cobalt dissolved, low level	May provide an indication of pollution by oxygen consuming substances.	7
Total hardness, $CaCO_3$	Of interest to both industry and public, not a problem at present but may become so as water consumption, irrigation runoff, and trace element contributions from mining and oil shale activities increase.	6D,I,W;7
Kjeldahl - N, total	Primary nutrient, expected to increase with development limits in the future.	7
Sediment size distribution	Provides data on stream velocity, stream habitat, sediment sources.	7
Turbidity	Easy to measure, provides quick data about suspended sediment, etc.	7

*Parameters are determined in water samples only (except for sediment size distribution).
†For full explanation of category codes, see symbols listed in Section 10.

Parameters for use in the rapid detection of short duration events such as spills, monitoring for permit discharge purposes, and intensive survey or research projects are not considered in this report. These concerns are important and should not be neglected, but they require considerations that are beyond the scope of this report.

The reasons for monitoring each parameter listed on Tables 39 through 41 are categorized by the following classification scheme:

Priority I - Must Monitor Parameters

Category Code

1. Parameters essential for the interpretation of other water quality data. This consideration includes parameters, such as

TABLE 41. PRIORITY III, PARAMETERS OF MINOR INTEREST WHICH WILL PROVIDE LITTLE USEFUL DATA FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE YAMPA AND WHITE RIVER BASINS

Parameter*	Primary Reason for Monitoring	Category and Beneficial Water Use Code†
Antimony, total	Recorded values are very low (maximum 7 µg/liter).	8
Barium, dissolved	Difficult to measure, does not approach critical limits (maximum 800 µg/liter in Piceance Creek).	8
Bismuth, dissolved	Recorded values are low (maximum 100 µg/liter).	8
Carbonate	Generally low levels in basin, usually of little significance in alkaline waters.	8
Cobalt, dissolved	Levels low in basins (maximum 150 µg/liter), has few adverse effects at high levels.	8
Gallium, dissolved	Values low (maximum 40 µg/liter).	8
Germanium, dissolved	Values low (maximum 170 µg/liter).	8
Lithium, dissolved	Values low (maximum 150 µg/liter).	8
Nitrate-N and Nitrite-N	Monitored simultaneously by NO_2-NO_3. If NO_2-NO_3-N levels begin to approach 10,000 µg/liter then the NO_2 form would become a "must monitor" priority for health reasons.	8
Nitrogen, total	Provides little practical information.	8
Phosphorus, dissolved ortho	Total phosphorus considered best measure of potential phosphorus available for biological utilization.	8
Sediment mineralogy	May provide sediment source data.	8
Silica	Generally low throughout basins.	8
Silver, total	Levels very low (maximum 30 µg/liter).	8
Strontium, dissolved	Maximum levels quite high in White Basin (6,000 µg/liter in Piceance Creek), but has little biological effect.	8
Tin, dissolved	Low levels (maximum 100 µg/liter), little adverse effect.	8
Titanium, total	Reported levels moderate (maximum 2,000 µg/liter), not expected to increase.	8
Vanadium, total	Reported values very low (maximum 33 µg/liter).	8
Zinc, dissolved	Reported values moderate, but less than recommended limits (maximum 1,400 µg/liter).	8
Zirconium, dissolved	Reported values low (maximum 170 µg/liter).	8

*Parameters are determined in water samples only (except for sediment mineralogy).
†For full explanation of category codes, see symbols listed in Section 10.

temperature, pH, and flow that are necesary to determine loadings, chemical equilibria, biological response, or other factors affecting other parameters.

2. Parameters commonly exceeding existing water quality criteria. Consideration is of EPA water quality criteria for beneficial water uses (see codes presented earlier). In cases where EPA established criteria have not presently been defined, criteria recommended by the National Academy of Sciences (1973) are used.

3. Parameters expected to increase to levels exceeding water quality criteria, unless extreme care is taken. This category includes organic chemical compounds that are expected to be present in future discharges from energy developments, and that could reach lethal, mutagenic, or carcinogenic levels unless extreme care is taken. The beneficial use symbols for water quality criteria expected to be exceeded are used here.

4. Parameters that are useful "trace" or "indicator" parameters. These include parameters that, although not causing substantial impact to the aquatic environment themselves, are used to define pollution sources, estimate other parameters of concern, or provide general data on the overall quality of the water. An example would be conductivity, which reflects highly saline springs.

5. Parameters expected to be altered by energy development activities so as to present a threat to a rare or endangered species. These include parameters that do not normally affect aquatic life at encountered levels but that, under unique circumstances, may affect a threatened or endangered species. In the Yampa and White River Basins this category situation is not known to exist at present.

Priority II - Major Interest Parameters

6. Potential pollutants of concern. Parameters whose reported levels in the Yampa and White River Basins are presently within acceptable limits for beneficial water uses, but whose ambient levels could be altered by planned regional developments to levels that impair those uses. This differs from category 3 in that, while category 3 parameters are expected to produce problems (either environmental or abatement/disposal), category 6 are those that might be a problem if unrestricted development were permitted.

7. Marginal "trace" or "indicator" parameter. These include parameters that may be used to provide general data on overall quality of the water, locate pollutant source areas, or estimate other parameters. Such parameters are not presently routinely

monitored or provide little advantage over other measurements being made.

Priority III - Minor Interest Parameters

8. Parameters that are presently at very low levels and are unlikely to be significantly changed by planned regional development, are fairly easily monitored but have little effect on beneficial water uses at encountered levels, or provide little useful data for monitoring energy or other development. Many of these parameters are currently being monitored on a regular basis in the Yampa-White River study area; however, for purposes of monitoring energy impact development, these parameters are not necessary.

Priorities are arranged alphabetically within Tables 39 through 41. The order of their appearance is not intended to suggest a ranking of relative importance.

Although frequency of measurement is not addressed by the prioritized listings, whenever possible at least monthly collection is recommended for most water quality parameters. Standard analytical techniques should be utilized and the data should be processed and entered into data bases as soon as possible after collection. It should also be stressed that changing conditions within the study area may cause some changes in the priority listings, especially addition of currently unmonitored compounds for which little data are available.

Analysis of bottom sediment samples on an annual or semi-annual basis should be performed. Total organic carbon, BOD, grain size, and elemental data should be determined. Because extensive organic extractions and analyses from sediment samples are expensive, it is not recommended that analysis for specific toxic organic compounds be performed on a routine basis. These analyses should be performed as special studies rather than on a routine monitoring basis at the present time. Bottom sediment parameters of interest are included on Tables 39 through 41; prioritization of parameters for sediment samples followed the same considerations used in establishing priorities for the water column.

BIOLOGICAL PARAMETERS

The collection of biological data in the Yampa and White River Basins would be an effective complementary tool for assessing the impact of energy or irrigation development. Biological investigations are of special significance in water quality monitoring programs because they offer a means of identifying areas affected by pollution and of assessing the degrees of stress from relatively small changes in physical-chemical parameters. Aquatic organisms act as natural monitors of water quality because the composition and structure of plant and animal communities are the result of the biological, chemical, and physical interactions within the system. When only periodic physical-chemical data are collected, an episodic event such as a flash flood or spill may go undetected. The biota affected by an occasional event may require weeks or months to recover. In addition, many biological forms that accumulate various chemicals preferentially serve as both an integrative and concentration mechanism that may permit detection of pollutants not detected in the water itself. Finally, because biota are affected by all materials and conditions present in the system, they could be the first indication of a major hazard posed by some unsuspected, unmonitored compound.

Biological monitoring should be initiated in a regular fashion within the Yampa and White River systems. It should not be viewed as an alternative to other monitoring but as a complementary tool for improving the efficiency of physical/chemical monitoring programs. A comprehensive biological monitoring program is recommended to gather baseline data and permit the eventual refinement of techniques. Such a monitoring effort should be designed to obtain standardized, reproducible data that may be compared from station to station across time. Sampling methods and sites will obviously differ for the different biological communities or parameters. However, for a given community and parameter, sites should be selected that have similar characteristics and the same sampling device and technique used for collection efforts. Replicate samples should be routinely collected and analyzed separately for quality assurance purposes. Of primary interest in biological monitoring is the assessment of changes in community structure over time and space; for such comparisons a minimum of a single year of baseline data is necessary and the accumulation of several years data is generally required to demonstrate natural temporal variations in the Basin's communities.

It should be noted that there have been a number of biological monitoring programs developed in the study area, particularly around the Utah and Colorado oil shale tracts in the White River Basin. Baumann and Winget (1975) and VTN Colorado, Inc. (1976) collected fish and macrobenthos data from the Utah tracts in 1974 and 1975; VTN also gathered periphyton data as part of their sampling efforts. The EPA (Hornig and Pollard 1978; Kinney et al. 1978; Pollard and Kinney 1979) has also been collecting seasonal baseline macrobenthic and periphyton data in the White River since fall of 1975. The above sampling efforts have largely been designed to provide a generalized inventory of the principle components of lotic communities in the oil shale areas. However, the majority of the data have not been sufficient to permit assessment of community changes across time or to relate these changes to causative factors (Kinney et al. 1978). Biological data collection efforts are complicated in this region by the sparse and patchy distribution of fauna generally encountered, the highly variable flow and discharge rates of the rivers, and the large suspended sediment load which is characteristic of the area, particularly downstream. Biological monitoring techniques traditionally used in eastern regions of the country are not necessarily well suited for use in the semi-arid western river systems (Pollard and Kinney 1979). Development and testing of new, innovative sampling methodologies in these specialized aquatic systems (Hornig and Pollard 1978; Pollard and Kinney 1979) is necessary before large scale implementation of biological monitoring for point source detection can be achieved.

Taxonomic groups considered appropriate for biological monitoring in the Yampa and White River Basins are discussed below.

Macroinvertebrates

These larger forms are relatively easy to collect, quantify, and identify to a meaningful taxonomic level. Being relatively stationary, they are unable to escape oncoming waste materials, and their life cycles are sufficiently long to prevent an apparent recovery to periodic relief from pollution. Seasonal sampling (based on stream temperature and flows) should be conducted although annual or semiannual records could be beneficial. Care must be taken to allow sufficient time between sampling of identical areas to permit disturbed populations to reestablish themselves. Macroinvertebrate sampling in lakes should be investigated to determine if sufficient macrobenthos exist to make monitoring them worthwhile.

Periphyton

The periphyton, like the macrobenthos, are unable to escape pollution events. Widespread, rapidly growing, and easy to sample, they are the primary producers in flowing systems and provide basic data on the overall quality of streams and lakes.

Fish

These represent the top of the aquatic food chain and respond to the cumulative effects of stresses on lower forms. In addition, they represent an element of intense public concern. Unlike the previous communities, fish have considerable mobility and may be able to escape localized pollution events. Fish are readily sampled, and toxonomic identification is not difficult in most cases.

Phytoplankton

Present in nearly all natural waters, these plants are easily sampled and can provide basic data on productivity, water quality, potential or occurring problems, etc. Phytoplankton sampling is recommended in lakes and ponds but is not recommended for stream monitoring in these basins since populations in streams are very low and separation from suspended debris is nearly impossible.

Zooplankton

Zooplankton include organisms that graze upon phytoplankton and in turn provide a major food supply for higher forms. The zooplankton can be responsible for unusually low phytoplankton levels as a result of their grazing activities. These forms may provide basic information on environmental regimes and, because of their relatively short life spans and fecundity, may be the first indication of sub-acute pollution hazards.

Zooplankton sampling is also recommended for lentic waters in the study basins.

Microorganisms

Coliforma bacteria are generally considered to be indicative of fecal contamination and are one of the most frequently applied indicators of water quality. Criteria exist for bathing and shellfish harvesting waters (U.S. Environmental Protection Agency 1976b). Other microbiological forms may be useful in the study basins, but these have not been identified and are not discussed.

An annotated list of parameters (Tables 42 and 43) is recommended for monitoring the impact of energy resource development in the Yampa and White River Basins. The priority I category includes those parameters that generally demonstrate an observable response to the type of stress conditions anticipated as a result of increased energy development activities and for which effective monitoring techniques have been developed. It is recommended that Priority I parameters be incorporated into any aquatic biological monitoring program in the basins. The Priority II parameters are those that may be of value to the basins but that are not generally considered to be as likely to provide useful data as those in the Priority I category and should only be collected in addition to Priority I parameters if time and money are available.

It should be noted that the count and biomass determinations in the following discussion are not productivity measurements. Rather they are expressions of standing crops and, although indicative of general productivity, are really quite different. Productivity data are expressed in units of mass per volume (or area) per unit time.

TABLE 42. PRIORITY I BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE YAMPA AND WHITE RIVER BASINS

Taxonomic Group	Parameters	Expressed as:	Reason for Sampling
Macroinvertebrates	Counts and identification	Total number/taxon/ unit sampling area or unit effort	Provides data on species present, community composition, etc., which may be related to water quality or other environmental considerations.
	Biomass	Weight/unit sampling area or unit effort	Provides data on productivity.
Periphyton	Biomass	Weight/ unit substrate	Provides data on productivity.
	Growth rate	Weight/unit substrate/time	Provides data on productivity.
	Identification and estimation of relative abundances*	Taxon present	Indicative of community composition that may be related to water quality rate of recovery from a biological catastrophe, etc.
Fish	Identification and enumeration	Species present†	Provides data on water quality, environmental conditions, and, possibly, water uses. Different species respond to different stresses.
	Toxic substances in tissue	Weight/substance/ unit tissue weight (by species)	Indication of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water, may pose a health hazard in itself.
Zooplankton	Identification and count	Species present	Provides basic data on environmental condition.
		Total unit volume or biomass number/ species/unit volume	Provides data on community composition, environmental conditions, and available food size ranges.

(continued)

TABLE 42. (Continued)

Macrophytes	Species identification and community association	Areal coverage and community	Indication of stream stability, sedimentation, and other factors; spread of phreatophytes could be a problem in the basin because of their effect on water quality; initial survey and thereafter occasional examination of stream (lake) side plants is recommended.
Phytoplankton	Chlorophyll a	μg/liter	Indication of overall lake productivity; excessive levels often indicate enrichment problems.
	Identification and enumeration	Number/taxon/unit volume total number/sample (unit volume) or biomass	The presence of specific taxon in abundance is often indicative of water quality and may in itself pose a biological problem.
Microorganisms	Total fecal coliform	Number/unit volume	Indicative of fecal contamination of water supplies and probable presence of other pathogonic organisms.

*Gross estimates of the quantity or percent of each taxon should be made rather than specific count data/unit area.
†Count data should be provided for each species.

TABLE 43. PRIORITY II BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE YAMPA AND WHITE RIVER BASINS

Taxonomic Group	Parameters	Expressed as:	Reason for Sampling
Macroinvertebrates	Toxic substances in tissue	Weight substance/ unit tissue weight	Indicative of biological response to toxic pollutants may provide an "early warning" of pollutants not detected in the water itself.
Periphyton	Chlorophyll a	Unit substrate area	Indicative of productivity of area and general health of the periphyton community.
	Taxonomic counts	Number/taxon/unit substrate area	Provides additional data on periphyton community composition.
Fish	Biomass	Total weight/ sampling effort or unit volume	Indicative of secondary productivity of the water body.
	Flesh tainting	Rating scale (by species)	Indicative of high levels or organic compounds; likely to be noticed by public; could indicate pollution from several sources to be due to other causes.
	Size	Length, weight/ individual, or range and average size/species	Provides an indication of the age of the community, breeding potential, and secondary productivity rates.
	Condition factor	Weight/length (by species)	Indicative of general health of fish community and availability of food.
	Growth rate	Age/length (by species)	Provides data on overall health of the fish community and environmental conditions; could indicate the presence of subacute pollutants.
Zooplankton	Biomass	Weight/ unit volume	Basic data on abundance and overall productivity.
	Eggs, instars, etc.	Species present	Provides basic data on age distribution, presence of seasonal forms, or the existence of cyclic pollution events.
	Toxic substances in tissue	Weight/unit tissue (by species)	May serve as bioconcentrator for specific compounds.

SECTION 11

ASSESSMENT OF EXISTING MONITORING NETWORK

Estimations can be made regarding the possible impact of proposed developments on water quality, but only after operation can the actual impact be assessed. A well developed sampling network for the monitoring of environmental parameters is helpful not only in controlling and assessing pollution from existing projects, but also in providing valuable information for evaluating future projects.

Forty-eight U.S. Geological Survey sampling stations in the Yampa and White River Basins were analyzed to evaluate trends in surface water quality (Tables 23 and 24). There are literally hundereds of surface water quality stations which have been established by miscellaneous sources in the study area, including private consulting firms such as VTN Colorado, Inc., and state and federal agencies such as the Colorado Department of Natural Resources and the U.S. Bureau of Land Management. Several ground-water investigations have also been conducted in the study basins (Steele el al. 1976a; Ficke, Weeks and Welder 1974; Weeks and Welder 1974). Water quality and hydrological data are particularly abundant in the oil shale tract areas of Piceance Basin (Ficke, Weeks and Welder 1974; Weeks and Welder 1974), and in the coal development region of the upstream Yampa Basin (Giles and Brogden 1978).

However, a good number of the stations selected in this report for incorporation into a energy monitoring network are not regularly sampled. Many of the abundant monitoring sites existing in the Yampa and White River Basins were established as part of a short term, specialized survey which did not include measurement of some parameters considered in this project to have a high sampling priority. Frequency of measurement for each parameter and station is quite variable from year to year, particularly in the Yampa Basin where data are sparse for most of the parameters except for conductivity, temperature, and dissolved oxygen (Appendix B). Most of the parameters considered to have the highest selection priority for monitoring of energy development impact, particularly the trace elements and nutrients, are sampled only intermittently or infrequently. At many of the stations in the study area, trace element data are not gathered at all, and in the Yampa Basin, even data for the major anions and cations are sparse. Where data for important parameters, such as the salts, are regularly sampled, frequently the data are not collected on similar dates across the stations, making spatial or temporal comparisons difficult. A few other Priority I parameters, such as phenols (natural levels of which already commonly exceed recommended concentrations for domestic water supplies), oils, and greases are almost completely lacking from the sampling network or are sampled only rarely. Data on pesticides, which have been considered by some to be the most significant potential pollution hazard in the basins (Kinney et al. 1979), are sparse. These problems are aggravated by the unavoidable episodic nature of many of the tributaries flowing through the study area, especially in the energy development portions of the basins.

Fairly good baseline data are available from the USGS stations at Maybell in the Yampa River Basin, and in the White River near Watson, and these locations should be considered for weekly sampling of top priority parameters. More intensive sampling of the stations at the mouth of Piceance Creek and in the Yampa River near Hayden should be attempted as these stations are well situated for observation of water quality degradation due to mining and oil shale activities.

If data at many of the USGS stations examined in this report are inadequate for characterizing ambient water quality and depicting long-term trends because of sporadic sampling, they certainly are insufficient to permit assessment of short-term episodic pollution events. The ability to detect short-term variability in water quality is very important in these semiarid western streams, particularly when monitoring those tributaries with anticipated energy impact. Kinney et al. (1978) examined data in the White River at Watson (09306500) and calculated the number of samples required for the annual sample mean to be within 5 percent of the true mean. They found that, in general, a prohibitively high number of samples was necessary to characterize water quality with a high degree of confidence. Only three samples per year were needed to adequately characterize pH in the water system. However, other parameters required from 29 samples per year (carbonate) to 743 samples per year (chloride). It can be seen that data used for defining physical/chemical parameters in a water body, but which are collected in varying sample sizes, are of questionable value and, in fact, it may not even be possible to sample some parameters in most monitoring networks with desired frequency.

If program restrictions on funding and/or personnel necessitate, the number of stations regularly sampled in the basin for purposes of monitoring the impact of energy resource development could be substantially reduced. The USGS stations indicated on Table 44 are recommended as having the highest sampling priority in the Yampa and White River Basins for monitoring of energy development activities. Of the 13 priority stations recognized in the study area, sites in the Yampa River below Craig, and in the White River below Yellow Creek (both of which are situated immediately downstream from major mining and oil shale developments), are well located for the maintenance of any continuous monitoring activities. It should be noted, however, that most of the modifications recommended for the existing monitoring network in the Yampa and White River Basins are directed towards establishing a statistically viable baseline data collection program for the energy development areas. There is an additional need as well for establishment of regular source specific monitoring at the energy sites, particularly at the coal mines in the Yampa Basin, which are not so well studied as the oil shale tracts in the White Basin. Such source monitoring would determine which pollution control methods need to be implemented at each mining site, and whether those control

TABLE 44. U.S. GEOLOGICAL SURVEY STATIONS RECOMMENDED TO HAVE THE HIGHEST SAMPLING PRIORITY FOR MONITORING ENERGY DEVELOPMENT IN THE YAMPA AND WHITE RIVER BASINS

STORET Number	Station Name
09236000	Bear River near Toponas, Colo.
09244410	Yampa River below diversion, near Hayden, Colo.
09247600	Yampa River below Craig, Colo.
09251000	Yampa River near Maybell, Colo.
09260000	Little Snake River near Lily, Colo.
09260050	Yampa River at Deer Lodge Park, Colo.
09303000	North Fork White River at Buford, Colo.
09304500	White River near Meeker, Colo.
09304800	White River below Meeker, Colo.
09306222	Piceance Creek at White River, Colo.
401022108241200	White River below Yellow Creek, Colo.
09306500	White River near Watson, Utah
09306900	White River at mouth near Ouray, Utah

procedures already implemented are effective. Everett (1979) states that even where monitoring at mining sources does occur, frequently it is still directed towards assessing background water quality levels, and "once pollutants show up in background quality monitoring systems, in many cases it is too late to institute controls." As with the baseline monitoring network, any source specific monitoring would do well to limit quantity of stations in lieu of more frequent sampling.

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APPENDIX A

CONVERSION FACTORS

In this report, metric units are frequently abbreviated using the notations below. The metric units can be converted to English units by multiplying by the factors in the following list:

To convert metric unit	Multiply by	To obtain English unit
Centimeters (cm)	0.3937	Inches
Cubic meters (m^3)	8.107×10^{-4}	Acre-feet
Cubic meters/sec (cms)	35.315	Cubic feet/sec
Hectares (ha)	2.471	Acres
Liters/kilogram (liters/kg)	239.64	Gallons/ton
Kilograms (kg)	2.205	Pounds
Kilograms (kg)	1.102×10^{-3}	Tons (short)
Kilometers (km)	0.6214	Miles
Liters	6.294×10^{-3}	Barrels (crude oil)
Liters	0.2642	Gallons
Meters (m)	3.281	Feet
Square kilometers (km^2)	247.1	Acres
Square kilometers (km^2)	0.3861	Square miles

APPENDIX B

CHEMICAL AND PHYSICAL DATA

Full descriptions of station locations are given in Table 23; only the station number is shown in the tables of Appendix B. The x values in these tables represent the mean for all samples; the range is given in parentheses; n indicates the total number of samples collected.

TABLE B-1. FLOW (m /sec), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*	$\bar{x}$ (min-max) *n*
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	2.6(2.3-3.1)5	13.0(2.0-58.0)15	--	--
2410	--	--	--	--	--	--	--	--
2437	--	--	--	--	--	0.01(-)2	0.03(0.03-0.04)2	--
2439	--	--	--	--	--	0.1(0.001-0.2)4	--	--
2441	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	--	1.5(-)1	19.0(2.1-69.1)4	--
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	--	--	--	--
2465	--	--	--	--	8.8(7.5-10.3)3	37.6(2.9-145.5)9	--	--
2476	--	--	--	--	--	--	--	--
2490	--	--	--	--	--	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	--	--	--	--
2497	--	--	--	--	1.4(-)1	1.2(-)1	--	--
2510	54.5(4.9-223.4)23	31.3(3.2-105.9)24	79.1(6.4-322.8)17	76.3(3.1-257.1)8	--	--	--	--
2570	2.8(1.9-3.3)3	11.7(0.1-52.1)11	21.7(1.2-102.2)8	--	--	--	--	--
2500	--	--	--	--	--	--	--	--
2597	23.3(1.1-127.4)10	7.5(2.8-14.6)5	118.4(-)1	--	--	--	--	--
2600	28.4(0.3-138.2)23	14.7(0.02-36.8)24	35.3(0.7-161.1)17	29.4(0.4-109.6)8	--	--	--	--
26005	--	--	--	--	--	--	--	--

TABLE B-2. DISSOLVED SOLIDS, SUM OF CONSTITUENTS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station	1971	1972	1973	1974	1975	1976	1977	1978
Number	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	187(-)1	--	--	--
2410	--	--	--	--	43(-)1	--	--	--
2437	--	--	--	--	468(462-473)2	372(222-503)9	396(321-465)6	377(278-561)5
2439	--	--	--	--	--	845(651-1020)5	646(391-827)3	635(607-663)2
2441	--	--	--	--	523(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	157(49-212)7	179(38-280)12	156(40-206)12	154(37-272)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	134(-)1	--	--	--
2465	--	--	--	--	177(58-231)7	214(48-374)12	120(49-407)13	174(108-209)3
2476	--	--	--	--	187(82-259)6	222(44-393)11	377(90-1930)11	144(48-276)8
2490	--	--	--	--	117(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	376(-)1	--	--	--
2497	--	--	--	--	249(121-334)6	280(103-421)11	503(140-2250)10	228(96-353)7
2510	284(89-410)12	274(84-401)12	258(70-425)10	316(87-505)9	332(99-497)9	299(65-467)12	415(92-1670)13	361(177-704)4
2570	--	--	--	--	260(-)1	177(-)1	192(-)1	192(-)1
2500	--	--	--	--	--	--	--	--
2597	225(83-314)6	292(264-321)3	135(-)1	255(79-416)4	218(69-422)4	167(69-250)5	566(-)1	--
2600	357(108-612)12	424(135-858)12	337(95-572)10	368(99-770)9	381(105-772)10	385(93-702)12	664(216-2100)14	261(127-413)4
26005	--	--	--	--	--	--	--	--

TABLE B-3. CONDUCTIVITY (μmho/cm at 25°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	140(100-200)8	104(80-140)8	97(70-110)8	--
2395	--	--	--	--	269(90-380)18	288(55-390)24	239(65-320)7	--
2410	--	--	--	--	125(65-180)5	112(55-140)7	106(60-200)8	--
2437	--	--	--	--	810(740-850)4	678(410-800)14	583(430-725)16	518(300-840)5
2439	--	--	--	--	879(-)1	1205(980-1400)6	962(560-1260)7	930(900-960)2
2441	--	--	--	--	547(380-850)3	543(385-745)3	--	--
2000	--	--	--	--	840(830-850)2	1858(515-3200)2	--	--
2443	--	--	--	--	1600(-)1	2250(1400-3100)2	--	--
2444	--	--	--	--	297(70-380)19	334(80-480)22	265(60-360)29	237(60-444)6
4100	--	--	--	--	730(700-760)2	737(640-790)3	--	--
4400	--	--	--	--	1758(530-6000)10	752(305-1000)3	--	--
2450	--	--	--	--	228(180-260)3	219(130-300)8	200(120-300)3	--
2465	--	--	--	--	324(90-430)8	359(100-650)12	319(80-625)13	278(185-340)3
2476	--	--	--	--	323(100-440)7	364(78-610)11	345(105-570)12	234(80-420)8
2490	--	--	--	--	230(210-250)2	197(140-240)3	--	--
2492	--	--	--	--	427(400-480)3	292(160-430)8	247(200-340)3	--
3500	--	--	--	--	532(440-625)2	395(175-530)3	--	--
2497	--	--	--	--	397(220-540)7	443(175-580)12	490(220-860)13	350(128-550)7
2510	458(130-682)23	436(127-640)24	398(112-680)17	512(142-790)9	474(144-720)11	494(120-720)16	488(177-1100)19	560(295-1200)4
2570	--	--	--	--	390(340-440)2	258(85-325)4	300(-)1	330(-)1
2500	--	--	--	--	615(-)1	--	--	--
2597	405(122-630)10	471(432-516)5	197(-)1	408(129-682)4	845(-)1	--	920(-)1	--
2600	570(160-980)23	631(208-1292)24	488(153-889)17	579(156-1220)9	615(175-1190)11	586(160-1100)14	795(330-1850)17	398(200-600)4
26005	--	--	--	--	460(-)1	445(-)1	--	--

TABLE B-4. DISSOLVED CALCIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	36(-)1	--	--	--
2410	--	--	--	--	9(-)1	--	--	--
2437	--	--	--	--	81(79-84)3	66(40-84)11	70(62-80)6	68(49-93)5
2439	--	--	--	--	--	127(95-150)5	106(69-103)3	100(91-110)2
2441	--	--	--	--	75(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	26(8-33)8	28(7-40)12	25(8-31)12	25(7-35)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	29(-)1	26(-)1	--	--
2465	--	--	--	--	28(9-37)7	32(8-47)12	30(10-44)13	29(19-35)3
2476	--	--	--	--	29(13-39)6	32(7-47)11	30(11-43)11	23(10-38)8
2490	--	--	--	--	26(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	59(-)1	--	--	--
2497	--	--	--	--	42(28-50)6	45(21-60)11	43(1-61)11	41(20-58)7
2510	37(14-50)12	35(14-45)12	33(12-47)10	41(15-58)9	40(15-50)9	37(11-56)12	33(2-49)13	45(27-80)4
2570	--	--	--	--	45(-)1	35(-)1	36(-)1	39(-)1
2500	--	--	--	--	--	--	--	--
2597	38(17-51)6	45(41-51)3	26(-)1	40(20-55)4	32(13-50)4	27(12-40)5	46(-)1	--
2600	46(19-73)12	51(21-90)12	42(17-60)10	50(18-73)9	46(18-60)10	49(17-79)12	47(2-75)14	31(22-39)4
26005	--	--	--	--	--	--	--	--

TABLE B-5. DISSOLVED SODIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	11(-)1	--	--	--
2410	--	--	--	--	2(-)1	--	--	--
2437	--	--	--	--	36(34-38)3	25(11-38)11	27(17-36)6	26(17-42)5
2439	--	--	--	--	--	60(48-79)5	51(31-70)3	42(31-53)2
2441	--	--	--	--	25(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	15(3-22)8	18(2-28)12	17(3-28)12	15(2-31)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	10(-)1	9(-)1	--	--
2465	--	--	--	--	18(6-25)7	24(3-42)12	24(4-66)13	15(7-23)3
2476	--	--	--	--	20(9-29)6	26(3-46)11	181(11-1700)11	15(3-35)8
2490	--	--	--	--	4(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	24(-)1	--	--	--
2497	--	--	--	--	16(6-24)6	17(4-26)11	170(8-1600)11	13(3-24)7
2510	34(6-54)12	37(6-58)12	34(6-59)10	39(6-67)9	43(6-67)9	39(5-65)12	153(11-1400)13	44(13-93)4
2570	--	--	--	--	25(-)1	14(-)1	16(-)1	15(-)1
2500	--	--	--	--	--	--	--	--
2597	28(6-45)6	37(32-46)3	10(-)1	30(5-60)4	28(4-77)4	17(5-35)5	120(-)1	--
2600	60(10-110)12	72(15-160)12	58(10-110)10	57(8-160)9	67(10-220)10	63(9-130)12	240(28-1800)14	50(13-120)4
26005	--	--	--	--	--	--	--	--

TABLE B-6. DISSOLVED MAGNESIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	12(-)1	--	--	--
2410	--	--	--	--	2(-)1	--	--	--
2437	--	--	--	--	33(31-34)3	27(16-36)11	28(23-34)6	27(20-39)5
2439	--	--	--	--	--	60(44-73)5	43(23-57)3	48(47-49)2
2441	--	--	--	--	63(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	9(2-12)8	10(2-18)12	8(2-10)12	9(2-18)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	8(-)1	8(-)1	--	--
2465	--	--	--	--	10(3-13)7	12(2-24)12	11(2-22)13	10(6-12)3
2476	--	--	--	--	10(3-15)6	13(2-25)11	10(0-18)11	8(2-16)8
2490	--	--	--	--	7(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	37(-)1	--	--	--
2497	--	--	--	--	21(9-30)6	23(6-36)11	24(0-53)11	18(6-29)7
2510	18(4-28)12	16(4-25)12	14(3-26)10	20(5-34)9	20(5-37)9	19(4-31)12	16(0-26)13	24(12-50)4
2570	--	--	--	--	16(-)1	10(-)1	9(-)1	9(-)1
2500	--	--	--	--	--	--	--	--
2597	8(2-12)6	12(10-14)3	5(-)1	12(0-26)4	10(3-16)4	9(3-14)4	21(-)1	--
2600	12(4-20)12	13(5-22)12	12(4-18)10	14(4-23)9	13(4-17)10	14(4-23)12	13(0-24)14	8(5-12)4
26005	--	--	--	--	--	--	--	--

TABLE B-7. DISSOLVED POTASSIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station	1971	1972	1973	1974	1975	1976	1977	1978
Number	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	1.8(-)1	--	--	--
2410	--	--	--	--	0.8(-)1	--	--	--
2437	--	--	--	--	4.4(3.7-5.1)2	3.4(2.4-6.0)10	4.0(3.4-5.0)6	3.2(2.7-4.4)5
2439	--	--	--	--	--	7.5(3.0-16.0)5	5.2(3.4-7.3)3	3.0(2.1-4.0)2
2441	--	--	--	--	3.5(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	2.2(0.9-3.2)7	2.4(0.7-3.3)12	2.3(0.8-3.2)12	1.8(0.6-2.6)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	1.8(-)1	1.6(-)1	--	--
2465	--	--	--	--	3.4(1.1-9.3)7	2.8(0.8-5.3)12	2.4(0.9-3.5)13	2.4(2.1-2.9)3
2476	--	--	--	--	2.3(1.0-4.1)6	2.4(0.7-3.7)11	2.5(0-3.8)11	1.8(0.7-3.1)8
2490	--	--	--	--	0.8(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	3.0(-)1	--	--	--
2497	--	--	--	--	1.8(0.9-3.2)6	2.0(0.9-4.3)11	2.6(1.5-5.1)11	1.5(0.7-2.1)7
2510	2.4(1.1-4.5)12	2.6(1.1-4.1)12	2.3(0.8-3.4)10	2.7(1.2-4.4)9	4.1(2.6-7.8)9	2.7(0.8-5.1)12	2.9(1.3-6.0)13	3.5(1.9-7.0)4
2570	--	--	--	--	3.4(-)1	2.4(-)1	2.4(-)1	2.5(-)1
2500	--	--	--	--	--	--	--	--
2597	2.1(0.9-3.6)6	2.5(2.0-2.8)3	2.1(-)1	3.2(0.7-2.8)4	1.9(0.9-3.5)4	2.1(0.9-2.8)5	4(-)1	--
2600	2.4(0.7-4.4)12	2.9(1.2-5.3)12	2.4(0.6-4.2)10	2.7(0.8-6.7)9	3.0(0.7-6.2)10	3.4(0.7-5.7)12	3.4(1.6-7.3)14	1.7(0.6-3.0)4
26005	--	--	--	--	--	--	--	--

TABLE B-8. BICARBONATE ION (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	148(-)1	--	--	--
2410	--	--	--	--	35(-)1	--	--	--
2437	--	--	--	--	340(336-344)3	275(164-372)11	281(248-330)6	266(160-320)5
2439	--	--	--	--	--	322(205-417)5	308(184-380)3	240(190-290)2
2441	--	--	--	--	370(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	112(33-143)8	115(24-159)12	111(27-150)12	85(25-120)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	128(-)1	--	--	--
2465	--	--	--	--	155(39-157)7	127(32-172)12	127(33-190)153	104(73-140)3
2476	--	--	--	--	115(46-156)6	126(27-169)11	141(72-220)11	86(32-140)8
2490	--	--	--	--	117(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	282(-)1	--	--	--
2497	--	--	--	--	180(97-219)6	195(84-266)11	222(110-330)10	165(82-230)7
2510	161(64-236)12	154(64-204)12	148(51-200)10	168(59-255)9	176(60-223)9	161(40-269)12	176(66-250)13	165(100-280)4
2570	--	--	--	--	230(-)1	157(-)1	160(-)1	150(-)1
2500	--	--	--	--	--	--	--	--
2597	148(59-207)6	177(154-201)3	76(-)1	176(61-310)4	132(53-220)4	120(47-210)5	250(-)1	148(47-310)24
2600	191(86-311)12	184(95-266)12	182(71-244)10	189(75-290)9	199(79-254)10	193(67-312)12	218(130-305)14	136(88-180)3
26005	--	--	--	--	--	--	--	--

TABLE B-9. DISSOLVED SULFATE (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	34(-)1	--	--	--
2410	--	--	--	--	6(-)1	--	--	--
2437	--	--	--	--	130(-)1	103(50-150)10	112(73-140)6	105(74-210)5
2439	--	--	--	--	--	406(330-480)5	270(150-370)3	300(260-340)2
2441	--	--	--	--	160(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	34(7-57)8	44(6-110)12	29(6-40)12	44(5-100)6
4100	--	--	--	--	130(-)1	--	--	--
4400	--	--	--	--	1700(-)1	--	--	--
2450	--	--	--	--	15(-)1	--	--	--
2465	--	--	--	--	43(9-61)7	62(8-170)12	50(9-150)13	49(26-76)3
2476	--	--	--	--	50(11-76)6	71(10-180)11	65(27-120)11	38(6-91)8
2490	--	--	--	--	6(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	100(-)1	--	--	--
2497	--	--	--	--	63(19-100)6	81(17-150)11	122(26-500)11	57(14-110)7
2510	91(18-140)12	82(16-150)12	76(13-180)10	105(18-230)9	110(18-210)9	99(15-200)12	89(24-200)13	115(55-210)4
2570	--	--	--	--	43(-)1	23(-)1	29(-)1	36(-)1
2500	--	--	--	--	--	--	--	--
2597	54(14-83)6	82(63-120)3	38(-)1	64(7-110)4	62(8-140)4	36(13-75)5	200(-)1	--
2600	107(14-240)12	148(27-380)12	98(15-210)10	114(16-310)9	115(18-280)10	127(15-280)12	185(52-610)14	72(28-120)4
26005	--	--	--	--	--	--	--	--

TABLE B-10. CHLORIDE (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	4(-)1	--	--	--
2410	--	--	--	--	0(-)1	--	--	--
2437	--	--	--	--	7(5-8)2	4(2-6)9	4(3-6)6	4(3-6)5
2439	--	--	--	--	--	11(8-21)5	9(7-11)3	6(5-7)2
2441	--	--	--	--	4(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	7(2-10)7	9(1-15)12	10(1-15)12	6(1-10)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	2(-)1	--	--	--
2465	--	--	--	--	8(2-13)7	10(1-13)12	11(2-22)13	6(2-11)3
2476	--	--	--	--	9(3-12)6	9(1-15)11	12(6-16)11	6(1-14)8
2490	--	--	--	--	1(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	4(-)1	--	--	--
2497	--	--	--	--	3(1-4)6	4(2-6)11	6(3-16)11	4(1-6)7
2510	13(4-26)12	14(3-23)12	12(2-18)10	13(1-30)9	16(5-25)9	15(1-25)12	27(3-130)13	34(4-110)4
2570	--	--	--	--	5(-)1	3(-)1	4(-)1	4(-)1
2500	--	--	--	--	--	--	--	--
2597	9(2-19)6	10(9-10)3	4(-)1	6(2-13)4	7(2-20)4	4(2-8)5	42(-)1	--
2600	23(4-43)12	30(6-72)12	17(3-39)10	20(2-72)9	22(2-77)10	20(2-54)12	53(8-170)14	16(3-42)4
26005	--	--	--	--	--	--	--	--

TABLE B-11. DISSOLVED SILICA (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	15(-)1	--	--	--
2410	--	--	--	--	7(-)1	--	--	--
2437	--	--	--	--	8(7-9)3	9(7-11)10	9(7-12)6	8(6-10)5
2439	--	--	--	--	--	7(3-9)5	7(6-8)3	5(3-7)2
2441	--	--	--	--	9(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	8(5-12)8	10(6-15)12	9(2-16)12	11(7-16)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	5(-)1	8(-)1	--	--
2465	--	--	--	--	7(6-10)7	8(3-12)12	8(4-15)13	10(10-11)3
2476	--	--	--	--	7(4-9)6	7(3-12)11	6(0-12)11	9(7-10)8
2490	--	--	--	--	13(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	10(-)1	--	--	--
2497	--	--	--	--	12(10-15)6	10(6-13)11	10(1-15)11	12(10-14)7
2510	9(4-12)12	8(3-14)12	10(4-16)10	10(4-14)9	9(5-14)9	7(2-10)12	5(2-9)13	8(2-10)4
2570	--	--	--	--	9(-)1	12(-)1	16(-)1	13(-)1
2500	--	--	--	--	--	--	--	--
2597	14(10-22)6	16(10-20)3	12(-)1	12(7-15)4	12(10-16)4	12(7-15)5	8(-)1	--
2600	14(11-23)12	15(9-20)12	14(11-20)10	15(12-20)9	15(11-21)10	13(9-18)12	14(8-21)14	12(10-14)4
26005	--	--	--	--	--	--	--	--

TABLE B-12. TOTAL HARDNESS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	140(-)1	--	--	--
2410	--	--	--	--	29(-)1	--	--	--
2437	--	--	--	--	340(330-350)3	274(170-360)11	293(260-340)6	282(200-390)5
2439	--	--	--	--	--	568(420-680)5	443(270-560)3	450(420-480)2
2441	--	--	--	--	450(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	102(29-130)8	111(24-170)12	95(27-120)12	98(24-160)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	110(-)1	98(-)1	--	--
2465	--	--	--	--	112(36-150)7	130(30-220)12	120(32-200)13	111(73-130)3
2476	--	--	--	--	118(46-160)6	132(25-220)11	116(35-180)11	91(37-160)8
2490	--	--	--	--	94(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	300(-)1	--	--	--
2497	--	--	--	--	192(110-250)6	207(79-300)11	208(2-340)11	176(74-260)7
2510	165(53-240)12	152(52-210)12	143(44-220)10	183(58-280)9	186(60-280)9	170(43-260)12	147(6-230)13	215(120-410)4
2570	--	--	--	--	180(-)1	130(-)1	130(-)1	130(-)1
2500	--	--	--	--	--	--	--	--
2597	124(49-170)6	167(150-180)3	87(-)1	150(50-240)4	121(46-190)4	105(42-150)4	200(-)1	--
2600	160(63-260)12	180(71-320)12	151(58-220)10	184(63-280)9	169(63-220)10	177(58-290)12	172(60-270)14	112(75-150)4
26005	--	--	--	--	--	--	--	--

TABLE B-13. TOTAL IRON (μg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	180(-)1	--	--	--
2395	--	--	--	--	280(250-310)2	1297(410-3000)3	--	--
2410	--	--	--	--	120(-)1	--	--	--
2437	--	--	--	--	2300(-)1	--	--	--
2439	--	--	--	--	1600(-)1	--	--	--
2441	--	--	--	--	320(130-510)2	583(320-750)3	--	--
2000	--	--	--	--	1395(690-2100)2	980(660-1300)2	--	--
2443	--	--	--	--	2810(820-4800)2	2100(1100-3100)2	--	--
2444	--	--	--	--	135(70-200)2	372(210-680)5	507(320-670)3	--
4100	--	--	--	--	375(210-540)2	590(30-1300)3	--	--
4400	--	--	--	--	1565(630-2500)2	210(80-300)3	--	--
2450	--	--	--	--	70(-)1	--	--	--
2465	--	--	--	--	135(70-200)2	740(150-2300)5	720(470-1100)3	--
2476	--	--	--	--	250(70-530)3	1908(240-5000)4	700(-)1	--
2490	--	--	--	--	145(140-150)2	517(110-1000)3	--	--
2492	--	--	--	--	30(-)1	--	--	--
3500	--	--	--	--	410(380-440)2	1140(660-2100)3	--	--
2497	--	--	--	--	263(120-440)3	2275(240-5600)4	2200(-)1	--
2510	--	--	--	625(340-910)2	240(110-510)4	4473(170-13000)3	500(230-720)3	1700(-)1
2570	--	--	--	--	335(190-480)2	430(200-660)2	400(-)1	--
2500	--	--	--	--	150(-)1	--	--	--
2597	64(0-140)5	--	--	--	110(-)1	--	--	--
2600	--	--	--	--	18120(880-63000)4	6285(230-20000)4	*	68000(-)1
26005	--	--	--	--	250(-)1	--	--	--

*Aberrant data point

TABLE B-14. TOTAL MANGANESE (μg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	20(-)1	--	--	--
2395	--	--	--	--	40(30-50)2	63(10-120)3	--	--
2410	--	--	--	--	0(-)1	--	--	--
2437	--	--	--	--	550(-)1	--	--	--
2439	--	--	--	--	170(-)1	--	--	--
2441	--	--	--	--	40(30-50)2	47(40-50)3	--	--
2000	--	--	--	--	235(70-400)2	225(180-270)2	--	--
2443	--	--	--	--	580(570-590)2	350(300-400)2	--	--
2444	--	--	--	--	35(30-40)2	46(20-80)5	43(40-50)3	--
4100	--	--	--	--	70(40-100)2	77(20-150)3	--	--
4400	--	--	--	--	320(-)1	317(30-600)3	--	--
2450	--	--	--	--	0(-)	--	--	--
2465	--	--	--	--	35(20-50)2	58(20-110)5	60(50-70)3	360(-)1
2476	--	--	--	--	50(40-60)3	88(40-170)4	70(-)1	140(-)1
2490	--	--	--	--	5(0-10)2	27(20-40)3	--	--
2492	--	--	--	--	0(-)1	--	--	--
3500	--	--	--	--	45(30-60)2	53(30-80)3	--	--
2497	--	--	--	--	30(-)1	78(20-120)4	90(-)1	230(-)1
2510	--	--	--	30(20-40)2	20(-)4	130(20-350)3	43(40-50)3	130(-)1
2570	--	--	--	--	55(40-70)2	90(20-150)3	--	--
2500	--	--	--	--	80(-)1	--	--	--
2597	--	--	--	--	30(-)1	--	--	--
2600	--	--	--	--	155(30-340)4	158(10-460)4	4852(120-19000)4	4000(-)1
26005	--	--	--	--	20(-)1	--	--	--

TABLE B-15. TEMPERATURE (°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
2360	--	--	--	7.5(-)1	4.5(0-10.5)11	4.4(0-12.0)11	6.0(0-13.0)8	--
2395	--	--	--	--	9.4(0-17.0)20	5.1(0-19.0)26	7.1(0-17.5)7	--
2410	--	--	--	--	4.4(1.0-11.0)5	5.2(0-15.5)12	5.4(0-14.0)8	--
2437	--	--	--	--	6.8(1.0-18.0)4	5.8(0-22.0)15	9.6(0-20.0)16	11.2(0.5-17.5)5
2439	--	--	--	--	14.0(-)1	6.5(0-17.0)6	6.9(0-11.5)7	14.5(7.0-22.0)2
2441	--	--	--	--	9.0(0-18.0)3	9.0(0-14.0)3	--	--
2000	--	--	--	--	9.8(2.0-17.5)2	7.2(0-14.5)2	--	--
2443	--	--	--	--	5.0(1.0-9.0)2	13.3(0-26.5)2	--	--
2444	--	--	--	--	10.3(0-15.0)20	5.9(0-19.0)28	6.6(0-20.5)29	5.3(0-16.5)6
4100	--	--	--	--	9.0(1.0-17.0)2	11.0(0-16.5)3	--	--
4400	--	--	--	--	14.5(7.0-19.5)10	11.3(2.0-21.5)3	--	--
2450	--	--	--	--	9.3(0-17.0)3	7.2(0-21.0)10	11.7(9.0-13.0)3	--
2465	--	--	--	--	11.8(0-20.0)8	7.9(0-22.0)12	6.4(0-20.5)13	6.2(1.0-11.0)3
2476	--	--	--	--	11.4(0-19.0)7	9.3(0-22.0)11	9.5(0-24.0)12	7.6(1.0-16.0)8
2490	--	--	--	--	5.5(0-11.0)2	8.5(0-15.5)3	--	--
2492	--	--	--	--	6.9(0-18.0)4	7.5(0-23.0)10	11.2(1.0-17.0)4	--
3500	--	--	--	--	11.8(0-23.5)2	8.5(0-16.0)3	--	--
2497	--	--	--	--	11.6(1.0-22.5)2	9.0(0-24.0)13	9.2(0-26.0)14	8.6(1.0-21.0)7
2510	8.2(0-24.5)23	10.5(0-24.0)24	8.5(0-22.0)17	9.1(0-22.5)9	8.3(0-21.0)11	8.5(0-24.0)16	9.4(0-24.0)20	11.5(5.5-18.5)4
2570	3.5(0-9.0)3	4.7(0-13.0)8	7.8(0-24.0)8	14.9(2.5-21.0)4	11.6(0-20.0)9	12.8(0-25.0)11	14.4(0-27.0)8	5.0(-)1
2500	--	--	--	--	18.5(-)1	--	--	--
2597	8.2(0-20.0)10	2.0(0-8.0)5	11.5(-)1	12.1(2.0-21.0)4	10.6(6.0-15.5)5	13.4(6.0-22.0)6	14.5(-)1	--
2600	6.6(0-18.5)23	8.7(0-18.5)24	7.5(0-20.0)17	9.0(0-23.5)9	8.5(0-25.5)11	8.0(0-22.0)15	9.7(0-26.5)17	14.0(7.0-26.0)4
26005	--	--	--	--	17.5(-)1	15.0(-)1	16.2(15.0-17.5)2	--

TABLE B-16. DISSOLVED OXYGEN (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	7.8(-)1	--	--	--
2395	--	--	--	--	8.5(7.2-9.9)10	11.2(6.5-13.0)12	--	--
2410	--	--	--	--	8.1(-)1	--	--	--
2437	--	--	--	--	8.3(7.2-9.8)4	10.0(6.4-13.2)9	9.3(6.8-11.2)6	10.6(-)1
2439	--	--	--	--	6.0(-)1	8.5(6.8-11.4)6	7.8(5.0-10.2)3	--
2441	--	--	--	--	9.2(8.0-10.6)3	9.8(9.2-10.7)3	--	--
2000	--	--	--	--	8.6(8.4-8.9)2	8.8(8.5-9.0)2	--	--
2443	--	--	--	--	9.6(5.9-13.4)2	8.2(5.8-10.5)2	--	--
2444	--	--	--	--	8.6(6.8-12.6)15	9.3(7.0-15.3)12	9.6(7.5-12.6)13	10.5(8.5-11.5)5
4100	--	--	--	--	10.1(8.8-11.3)2	10.4(9.5-11.6)3	--	--
4400	--	--	--	--	7.2(6.8-7.5)9	10.1(8.8-11.1)3	--	--
2450	--	--	--	--	8.8(-)1	--	--	--
2465	--	--	--	--	9.2(7.2-12.2)7	8.8(6.0-15.0)12	9.7(5.9-13.0)12	9.8(8.3-11.1)3
2476	--	--	--	--	9.1(8.2-10.6)4	10(8.0-12.9)11	9.5(6.9-11.1)11	9.7(8.0-10.8)7
2490	--	--	--	--	9.9(8.8-11.0)2	9.4(8.1-11.1)3	--	--
2492	--	--	--	--	7.6(-)1	--	--	--
3500	--	--	--	--	8.6(6.0-11.2)2	9.4(7.8-11.2)3	--	--
2497	--	--	--	--	9.6(8.0-13.2)5	10.2(8.3-12.0)11	9.6(6.7-11.3)10	9.5(7.3-11.0)5
2510	9.9(7.8-12.2)11	10.0(8.0-13.8)12	9.5(7.4-11.8)9	9.3(8.0-11.1)8	9.0(6.8-10.6)10	9.4(7.9-11.8)12	10.7(6.9-15.7)13	8.9(7.0-10.4)3
2570	--	--	--	--	9.8(8.6-11.0)2	8.2(6.1-11.1)4	10.8(-)1	10.0(-)1
2500	--	--	--	--	8.9(-)1	--	--	--
2597	9.4(8.7-10.4)4	10.5(10.4-10.5)2	--	--	8.8(-)1	9.1(-)1	9.8(-)1	--
2600	9.1(7.2-10.4)11	9.0(7.1-11.0)12	8.7(6.1-10.8)9	9.0(7.2-12.2)8	8.8(6.8-11.1)6	8.5(6.1-10.9)12	8.8(5.3-11.2)13	7.4(6.6-8.2)2
26005	--	--	--	--	7.6(-)1	7.4(-)1	7.5(7.4-7.6)2	--

TABLE B-17. pH, 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
2360	--	--	--	--	8.2(-)1	--	--	--
2395	--	--	--	--	8.5(7.7-9.0)10	7.4(6.8-8.7)12	--	--
2410	--	--	--	--	8.0(-)1	--	--	--
2437	--	--	--	--	8.5(8.4-8.8)4	8.0(7.4-8.5)11	7.7(7.2-8.1)6	8.2(7.4-8.5)5
2439	--	--	--	--	7.7(-)1	7.9(7.4-8.2)6	8.1(7.8-8.5)3	8.2(8.2-8.3)2
2441	--	--	--	--	8.3(8.0-8.7)3	8.4(8.1-8.6)3	--	--
2000	--	--	--	--	8.2(7.9-8.6)2	8.1(7.7-8.4)2	--	--
2443	--	--	--	--	8.1(8.1-8.1)2	8.2(8.1-8.4)2	--	--
2444	--	--	--	--	8.2(7.8-8.6)14	7.8(7.4-8.4)11	7.7(7.0-8.3)13	7.7(7.2-8.3)6
4100	--	--	--	--	8.4(8.3-8.6)2	8.5(8.3-8.7)3	--	--
4400	--	--	--	--	7.2(2.1-8.3)9	8.1(7.7-8.5)3	--	--
2450	--	--	--	--	8.3(-)1	8.5(-)1	--	--
2465	--	--	--	--	8.2(7.5-8.7)7	8.1(7.3-9.2)12	7.6(7.3-8.2)13	7.6(7.4-7.8)3
2476	--	--	--	--	8.1(7.4-8.8)7	8.2(7.6-8.9)11	7.8(7.1-8.3)12	7.8(7.2-8.8)8
2490	--	--	--	--	8.3(8.2-8.4)2	8.4(8.2-8.7)3	--	--
2492	--	--	--	--	8.6(-)1	--	--	--
3500	--	--	--	--	8.2(8.2-8.3)2	8.3(8.1-8.5)3	--	--
2497	--	--	--	--	8.4(8.0-8.7)	8.2(7.6-8.6)11	8.4(7.6-8.3)11	8.0(7.1-8.5)7
2510	8.0(7.4-8.7)23	8.0(7.3-8.7)23	7.8(7.1-8.7)17	8.0(7.7-8.9)8	8.3(7.3-9.1)10	8.0(7.5-8.4)13	8.2(7.8-8.7)14	8.2(7.7-8.9)4
2570	--	--	--	--	8.4(8.3-8.4)2	7.8(7.6-8.0)4	8.1(-)1	8.2(-)1
2500	--	--	--	--	8.4(-)1	--	--	--
2597	8.0(7.6-8.4)10	7.9(7.8-8.0)5	8.0(-)1	8.0(7.8-8.2)4	8.5(-)1	7.8(-)1	8.6(-)1	--
2600	7.6(7.0-8.1)23	7.8(7.3-9.3)23	7.7(7.1-8.4)17	8.0(7.4-8.4)9	8.1(7.5-8.6)9	8.0(7.1-8.5)12	7.9(7.5-8.4)14	8.0(7.7-8.3)4
26005	--	--	--	--	8.4(-)1	8.6(-)1	8.5(8.4-8.6)2	--

TABLE B-18. TOTAL ALKALINITY (mg/liter as CaCO), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	121(-)1	--	--	--
2410	--	--	--	--	29(-)1	--	--	--
2437	--	--	--	--	279(277-282)3	228(135-305)11	230(200-270)6	218(130-260)5
2439	--	--	--	--	--	264(168-342)5	253(150-310)3	200(160-240)2
2441	--	--	--	--	303(-)1	--	--	--
2000	--	--	--	--	--	--	--	--
2443	--	--	--	--	--	--	--	--
2444	--	--	--	--	92(27-117)8	26(20-135)12	91(22-120)12	70(21-98)6
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	--	--	--
2450	--	--	--	--	105(-)1	--	--	--
2465	--	--	--	--	97(32-129)7	105(26-141)12	104(27-160)13	84(60-110)3
2476	--	--	--	--	99(38-134)6	104(22-139)11	115(34-180)11	70(26-110)8
2490	--	--	--	--	99(-)1	--	--	--
2492	--	--	--	--	--	--	--	--
3500	--	--	--	--	231(-)1	--	--	--
2497	--	--	--	--	151(80-191)6	161(69-218)11	188(90-270)11	136(67-190)7
2510	132(53-194)12	130(53-170)12	124(42-164)10	138(48-209)9	147(49-183)9	133(33-221)12	147(54-210)13	140(82-230)4
2570	--	--	--	--	189(-)1	129(-)1	130(-)1	120(-)1
2500	--	--	--	--	--	--	--	--
2597	121(48-170)6	145(126-165)3	62(-)1	144(50-254)4	108(43-180)4	98(39-172)5	210(-)1	--
2600	156(71-255)12	151(78-218)12	152(58-200)10	156(62-238)9	164(65-208)10	158(55-256)12	180(110-250)14	116(72-150)4
26005	--	--	--	--	--	--	--	--

TABLE B-19. SUSPENDED SEDIMENTS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE YAMPA RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n
2360	--	--	--	--	--	--	--	--
2395	--	--	--	--	15(6-29)3	41(6-96)7	--	--
2410	--	--	--	--	27(-)1	14(5-30)6	4(-)1	--
2437	--	--	--	--	16(-)1	143(21-748)9	50(21-146)6	--
2439	--	--	--	--	--	--	--	--
2441	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	117(13-400)8	--	--
2443	--	--	--	--	--	113(24-234)7	--	--
2444	--	--	--	--	33(7-105)4	45(0-184)22	37(6-100)7	--
4100	--	--	--	--	--	--	--	--
4400	--	--	--	--	--	100(5-668)10	--	--
2450	--	--	--	--	134(-)1	91(1-288)5	--	--
2465	--	--	--	--	9(5-12)2	28(-)1	--	--
2476	--	--	--	--	48(10-104)3	50(12-113)6	--	--
2490	--	--	--	--	--	--	--	--
2492	--	--	--	--	--	220(8-545)4	--	--
3500	--	--	--	--	--	--	--	--
2497	--	--	--	--	58(8-180)4	145(15-748)10	56(5-93)8	--
2510	--	--	--	36(31-42)2	194(2-588)5	696(492-900)2	--	--
2570	11(7-14)3	108(7-506)11	236(9-1180)9	117(8-516)6	128(8-294)7	152(4-931)8	34(5-139)8	84(-)1
2500	--	--	--	--	--	--	--	--
2597	--	--	--	--	--	--	244(-)1	--
2600	--	--	--	--	1944(55-4560)6	--	--	--
26005	--	--	--	--	--	--	--	--

TABLE B-20. FLOW (m /sec), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	4.1(-)1	3.4(3.1-3.9)6	--
3040	--	--	--	--	--	3.3(-)1	2.7(2.2-3.2)4	--
3042	--	--	11.3(7.6-15.1)2	34.6(7.7-85.0)3	--	--	--	--
3045	--	--	9.9(9.1-10.8)2	32.1(8.1-78.2)3	--	--	--	--
3048	--	--	--	30.7(11.9-77.3)5	3.7(0.01-7.4)2	8.5(7.2-9.5)3	8.3(6.4-9.4)3	--
3060	--	--	--	0.3(0.04-1.0)17	0.3(-)1	--	--	--
30606	--	--	--	0.4(0.1-0.9)16	--	--	0.2(-)1	--
3061	--	--	--	--	--	0.2(0.2-0.3)3	--	--
3062	0.6(0.2-3.5)23	0.3(0.1-1.3)24	0.9(0.3-2.3)17	0.6(0.1-0.9)8	--	--	0.7(0.3-1.2)10	--
30621	0.6(0.2-3.5)23	0.3(0.1-1.3)24	0.9(0.3-2.6)17	0.6(0.2-1.0)7	--	0.8(0.3-1.2)6	--	--
30622	0.8(0.04-4.8)23	0.9(0.03-11.8)25	1.0(0.3-2.1)20	0.8(0.2-1.1)9	--	1.3(0.6-1.9)3	1.1(-)1	--
30623	--	--	--	--	--	0.02(0-0.04)10	--	--
30624	--	--	--	--	--	<0.01(-)5	0.01(-)1	--
306248	--	--	--	--	--	0.01(<0.01-0.04)9	--	--
30625	--	--	--	--	--	--	--	--
306255	--	--	--	0.06(0.05-0.08)10	0.8(-)1	--	0.7(-)1	--
1200	--	--	--	--	--	--	--	--
3063	--	22.9(9.5-70.2)10	17.2(11.0-51.3)10	--	15.3(11.8-21.2)3	9.9(-)1	9.2(6.6-13.1)6	--
30638	--	--	--	--	--	--	--	--
3064	--	--	--	--	--	--	--	--
3065	19.6(8.5-49.8)21	18.8(5.6-61.7)24	25.0(8.4-98.3)21	79.2(15.0-251.7)4	--	--	--	--
3066	--	--	--	--	--	--	--	--
3067	--	--	--	--	--	--	--	--
3069	--	--	--	25.5(4.9-63.2)8	--	--	--	--

TABLE B-21. DISSOLVED SOLIDS, SUM OF CONSTITUENTS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station	1971	1972	1973	1974	1975	1976	1977	1978
Number	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	220(213-232)3	234(176-257)9	238(237-239)2
3040	--	--	--	--	--	174(157-192)2	172(120-209)11	163(157-169)2
3042	--	--	261(244-278)2	224(116-269)5	194(130-259)2	--	--	--
3045	--	--	327(305-349)2	274(124-353)3	--	--	--	--
3048	--	--	--	323(146-462)3	384(168-459)7	369(186-503)11	471(181-734)12	365(184-504)7
3060	--	--	--	722(578-829)25	685(502-761)22	642(528-741)11	722(659-827)8	684(566-819)5
30606	--	--	--	948(736-1090)25	866(639-1010)21	873(584-1080)11	976(877-1080)12	828(650-948)6
3061	--	--	--	--	1098(998-1200)8	1116(945-1270)10	1192(1120-1370)11	1251(1150-1380)8
3062	1064(392-1340)12	1151(527-1550)12	1077(851-1330)10	1178(964-1630)10	1024(901-1220)11	1138(862-1420)10	1143(994-1330)12	1088(769-1420)5
30621	1129(420-1520)12	1268(529-1930)12	1132(892-1460)10	1211(944-1720)10	1097(996-1320)7	1167(693-1600)6	--	--
30622	1916(378-3400)11	2705(869-5280)12	1495(1040-2140)12	1602(1260-2010)10	1385(1120-1950)13	1508(874-2610)9	1813(1310-3200)13	1960(1020-2980)4
30623	--	--	--	--	--	154(-)1	367(-)1	--
30624	--	--	--	--	1321(1210-1390)11	1283(1210-1380)9	1253(1170-1300)3	--
306248	--	--	--	--	--	149(-)1	--	--
30625	--	--	--	--	260(-)1	172(-)1	--	--
306255	--	--	3070(-)1	2374(1740-2590)12	2477(2250-2870)22	2634(2240-2860)10	2772(2650-2850)4	2690(-)1
1200	--	--	--	--	--	--	591(-)1	--
3063	--	--	--	--	497(448-617)4	461(222-575)11	574(430-858)11	466(219-621)5
30638	--	--	--	--	--	--	1274(662-3170)8	--
3064	--	--	--	528(469-618)8	442(226-578)19	442(244-522)6	--	--
3065	403(224-553)12	432(203-534)12	528(206-713)12	530(229-710)16	469(213-661)23	492(220-613)18	576(275-913)10	492(405-578)2
3066	--	--	--	544(470-718)8	456(250-665)20	366(228-571)3	--	--
3067	--	--	--	564(473-868)8	465(217-607)20	495(262-635)10	590(377-851)4	461(267-567)3
3069	--	--	--	524(199-712)15	484(212-650)23	539(269-736)16	653(391-1170)14	508(263-589)7

TABLE B-22. CONDUCTIVITY (μmho/cm at 25°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	272(160-380)8	316(175-400)10	336(240-380)26	364(362-365)2
3040	--	--	--	--	284(175-625)8	298(180-420)13	276(225-320)24	251(245-257)2
3042	--	--	401(378-424)2	353(191-418)4	316(200-400)5	413(400-430)3	401(290-480)8	--
3045	--	--	330(174-486)2	451(207-577)3	240(-)1	675(625-750)3	852(450-1350)10	--
3048	--	--	--	575(248-780)6	554(220-750)13	621(300-900)14	701(260-1100)29	573(335-775)7
3060	--	--	--	1126(900-1270)27	1070(825-1410)22	1038(850-1210)11	1059(960-1220)8	1038(825-1250)6
30606	--	--	--	1425(1140-1660)25	1283(950-1500)21	1297(940-1550)12	1366(1250-1520)14	1162(875-1500)6
3061	--	--	--	--	1550(1350-1800)9	1600(1380-1830)12	1632(1520-1860)12	1629(1450-1850)7
3062	1532(560-2040)23	1640(790-2240)24	1498(1150-1910)17	1767(1480-2210)9	1532(1300-1900)11	1623(1320-2000)10	1625(1350-2000)13	1480(1150-1700)5
30621	1598(620-2210)23	1816(780-2800)24	1600(1300-2040)17	1814(1530-2450)9	1567(1300-2100)6	1960(1440-2400)4	--	--
30622	2906(560-5440)23	3843(1250-7240)24	2136(1460-3070)19	2640(2030-4640)10	2089(1550-3000)13	2203(1330-3600)9	2660(1900-4400)13	2725(1500-3800)4
30623	--	--	--	--	--	348(180-650)4	602(-)1	--
30624	--	--	--	--	1858(1700-2000)10	1791(1700-1600)11	1700(1520-1800)3	--
306248	--	--	--	--	--	135(50-220)2	--	--
30625	--	--	--	--	380(-)1	320(-)1	--	--
306255	--	3860(3800-3920)2	3900(-)1	3463(2410-4000)13	3710(3000-5000)22	3732(2300-4500)12	4092(3720-4250)4	3800(-)1
1200	--	--	--	--	--	--	920(830-1010)2	--
3063	--	--	--	720(-)1	574(210-790)19	723(300-970)24	911(470-1730)50	738(360-974)5
30638	--	--	--	--	--	--	1781(820-4000)14	--
3064	--	--	--	822(725-900)8	696(365-927)19	692(435-863)6	--	--
3065	661(360-891)22	696(328-857)23	805(340-1160)19	848(382-1450)18	747(330-1010)23	758(360-900)19	858(445-1290)10	700(550-830)3
3066	--	--	--	855(690-1100)8	701(360-1000)20	581(370-897)3	--	--
3067	--	--	--	916(650-1650)8	714(320-962)20	768(440-970)10	744(554-1200)5	670(380-800)4
3069	--	--	--	778(340-1100)16	742(360-1000)23	840(400-1055)19	976(660-1600)15	789(450-1090)7

TABLE B-23. DISSOLVED CALCIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	52(51-55)3	55(42-61)10	56(55-56)2
3040	--	--	--	--	--	43(39-47)2	42(31-54)11	39(38-40)2
3042	--	--	60(58-62)2	53(28-65)5	48(33-62)2	--	--	--
3045	--	--	67(63-71)2	57(29-73)3	--	--	--	--
3048	--	--	--	61(33-83)3	69(39-80)7	66(37-92)11	80(43-110)12	65(40-82)7
3060	--	--	--	71(51-77)27	68(54-79)22	63(22-75)11	70(51-81)8	72(67-78)5
30606	--	--	--	78(59-87)25	79(63-88)21	73(16-85)12	83(71-91)12	71(42-84)6
3061	--	--	--	--	102(94-110)10	100(90-110)11	103(96-110)12	106(100-120)8
3062	77(41-88)12	76(51-89)12	86(79-100)10	84(50-93)10	84(51-96)12	89(78-100)10	85(69-92)13	84(78-89)5
30621	76(42-88)12	71(47-83)12	84(76-94)10	86(74-92)10	85(74-93)7	75(56-87)6	--	--
30622	52(23-72)12	44(18-71)12	68(34-82)12	60(16-79)11	70(59-84)13	58(22-79)9	59(27-78)13	64(44-83)4
30623	--	--	--	--	--	26(-)1	--	--
30624	--	--	--	--	117(110-140)11	104(84-110)9	100(99-100)3	--
306248	--	--	--	--	--	20(-)1	--	--
30625	--	--	--	--	29(-)1	22(-)1	--	--
306255	--	--	10(-)1	36(15-130)13	32(7-45)22	25(7-39)11	31(21-39)4	35(-)1
1200	--	--	--	--	--	--	50(-)1	--
3063	--	--	--	--	73(65-92)4	67(41-83)11	78(63-94)11	66(43-77)5
30638	--	--	--	--	--	--	94(59-150)8	--
3064	--	--	--	69(61-78)8	62(38-83)19	62(42-79)6	--	--
3065	62(45-82)12	65(38-100)12	66(26-83)12	70(39-120)16	63(35-76)23	67(37-81)18	72(48-94)10	70(66-73)2
3066	--	--	--	71(65-83)8	62(40-82)20	53(39-71)3	--	--
3067	--	--	--	72(61-79)8	64(36-83)20	69(42-81)10	72(56-82)4	68(49-80)3
3069	--	--	--	65(34-86)15	63(31-76)23	68(43-90)16	71(30-94)14	67(47-81)7

TABLE B-24. DISSOLVED SODIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	3(3-3)3	4(3-6)10	4(-)2
3040	--	--	--	--	--	2(2-2)2	3(1-4)11	2(2-2)2
3042	--	--	5(4-5)2	4(3-5)5	4(3-6)2	--	--	--
3045	--	--	20(18-21)2	17(4-25)3	--	--	--	--
3048	--	--	--	23(7-33)3	34(8-50)7	32(13-49)11	44(3-83)12	31(8-49)7
3060	--	--	--	130(88-160)27	120(75-140)22	115(47-150)11	131(120-150)8	114(80-140)5
30606	--	--	--	162(120-200)25	140(100-170)21	146(97-190)12	159(140-180)13	135(91-190)6
3061	--	--	--	--	143(91-160)10	146(120-170)11	159(120-190)11	166(150-190)8
3062	186(66-250)12	207(81-310)12	172(120-210)10	208(150-380)10	167(140-210)12	194(130-270)10	199(150-320)13	186(120-270)5
30621	204(70-300)12	251(85-440)12	191(140-250)10	212(150-370)10	180(160-240)7	225(120-330)6	--	--
30622	617(76-1400)12	885(180-2000)12	358(200-580)12	474(280-1100)11	325(250-540)13	389(150-840)9	498(290-1100)13	538(220-970)4
30623	--	--	--	--	--	17(-)1	--	--
30624	--	--	--	--	183(170-200)11	187(170-200)9	177(170-180)3	--
306248	--	--	--	--	--	18(-)1	--	--
30625	--	--	--	--	48(-)1	25(-)1	--	--
306255	--	--	1000(-)1	725(500-800)13	762(680-870)22	832(640-940)11	875(800-950)4	830-(-)1
1200	--	--	--	--	--	--	110(-)1	--
3063	--	--	--	--	62(54-81)4	57(18-86)11	78(57-140)11	61(15-99)5
30638	--	--	--	--	--	--	207(72-580)8	--
3064	--	--	--	75(57-110)8	57(21-84)19	53(22-70)6	--	--
3065	49(18-88)12	52(14-75)12	78(20-150)12	82(22-180)18	63(17-110)23	62(21-91)18	81(32-150)10	68(46-90)2
3066	--	--	--	77(60-130)8	60(21-100)20	42(19-78)3	--	--
3067	--	--	--	83(54-180)8	61(22-90)20	59(26-89)10	86(45-140)4	55(23-74)3
3069	--	--	--	77(18-120)15	67(20-99)23	76(23-110)16	110(58-230)14	40(23-110)7

TABLE B-25. DISSOLVED MAGNESIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x (min-max) n	x̄ (min-max) n	x̄ (min-max) n
3030	--	--	--	--	--	10(10-11)3	10(7-11)10	10(10-11)2
3040	--	--	--	--	--	10(9-11)2	9(7-11)11	10(9-11)2
3042	--	--	12(11-12)2	11(6-13)5	9(6-11)2	--	--	--
3045	--	--	14(12-15)2	13(6-17)3	--	--	--	--
3048	--	--	--	16(8-24)3	19(9-24)7	19(10-28)11	23(9-40)12	17(9-26)7
3060	--	--	--	47(38-57)27	46(34-56)22	45(33-52)11	48(43-57)8	45(38-52)5
30606	--	--	--	71(47-88)25	64(46-83)21	67(44-84)12	76(67-89)12	63(47-78)6
3061	--	--	--	--	95(84-110)10	95(84-110)11	103(94-120)12	110(97-120)8
3062	80(21-100)12	86(34-110)12	84(66-110)10	91(77-110)10	80(74-91)12	91(70-110)10	92(78-110)13	86(58-110)5
30621	83(23-110)12	88(34-120)12	86(67-110)10	90(76-120)10	85(74-100)7	85(48-120)6	--	--
30622	82(18-100)12	83(47-96)12	86(66-110)12	91(80-110)11	84(72-100)13	81(56-100)9	90(56-110)13	95(63-110)4
30623	--	--	--	--	--	7(-)1	--	--
30624	--	--	--	--	106(90-120)11	105(97-110)9	106(98-110)3	--
306248	--	--	--	--	--	6(-)1	--	--
30625	--	--	--	--	7(-)1	6(-)1	--	--
306255	--	--	120(-)1	109(50-140)13	114(96-130)22	107(97-120)11	114(85-130)4	140(-)1
1200	--	--	--	--	--	--	28(-)1	--
3063	--	--	--	--	23(20-26)4	24(11-31)11	29(20-48)11	23(12-31)5
30638	--	--	--	--	--	--	81(26-225)8	--
3064	--	--	--	27(24-31)8	23(13-32)19	24(14-31)6	--	--
3065	21(13-26)12	22(11-28)12	26(11-34)12	27(12-39)16	25(12-34)23	26(12-36)18	29(14-49)10	24(21-28)2
3066	--	--	--	28(24-36)8	24(14-35)20	20(12-30)3	--	--
3067	--	--	--	28(24-36)8	24(11-34)20	27(14-35)10	30(16-48)4	23(15-29)3
3069	--	--	--	27(10-37)15	25(9-35)23	27(14-36)16	30(10-47)14	26(15-36)7

TABLE B-26. DISSOLVED POTASSIUM (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	1.1(1.1-1.2)3	1.1(0.9-1.3)10	1.0(0.9-1.0)2
3040	--	--	--	--	--	1.0(-)2	0.9(0.7-1.3)11	0.8(0.8-0.9)2
3042	--	--	1.2(-)2	1.2(0.9-1.8)5	1.1(-)2	--	--	--
3045	--	--	1.4(1.4-1.5)2	1.5(1.1-2.0)3	--	--	--	--
3048	--	--	--	1.6(1.2-2.2)3	1.8(1.3-2.3)7	2.2(1.2-6.0)11	2.0(0.8-3.6)12	1.7(1.0-2.4)7
3060	--	--	--	3.5(2.4-5.7)27	4.0(2.3-19)22	3.0(2.2-3.7)12	2.8(2.2-3.4)8	3.1(2.7-3.8)5
30606	--	--	--	3.8(1.2-6.4)25	3.4(2.5-5.0)21	3.0(2.4-4.0)12	2.8(2.2-3.7)12	3.3(2.4-4.5)6
3061	--	--	--	--	2.5(1.9-3.8)10	2.5(1.8-3.5)11	2.0(1.7-2.4)12	2.8(2.0-5.0)8
3062	3.4(2.4-4.8)12	3.8(2.9-4.8)12	3.1(2.5-3.7)10	3.7(2.3-8.4)12	3.6(2.4-8.4)12	3.5(2.4-4.6)10	3.0(2.3-3.9)13	3.8(2.6-5.4)5
30621	3.5(2.5-4.9)12	3.6(2.6-4.7)12	3.2(2.5-3.8)10	3.6(2.0-5.1)10	4.0(2.5-7.8)7	4.0(3.1-5.2)6	--	--
30622	4.2(3.0-6.6)12	5.2(3.6-8.3)12	4.0(3.0-6.2)12	4.8(2.6-7.5)11	4.5(3.1-6.8)13	5.0(2.9-8.8)9	4.1(3.0-6.5)13	5.1(3.6-6.7)4
30623	--	--	--	--	--	5.4(-)1	--	--
30624	--	--	--	--	3.0(1.9-4.4)11	2.8(2.3-3.1)9	2.7(2.3-3.0)3	--
306248	--	--	--	--	--	15.0(-)1	--	--
30625	--	--	--	--	4.2(-)1	13.0(-)1	--	--
306255	--	--	4.6(-)1	4.4(3.6-6.2)13	4.3(3.5-7.4)22	4.8(3.9-7.0)11	4.5(4.2-5.0)4	5.2(-)1
1200	--	--	--	--	--	--	2.1(-)1	--
3063	--	--	--	--	2.8(1.6-5.3)4	2.4(1.3-6.4)11	2.4(1.6-4.5)11	2.0(1.2-2.7)5
30638	--	--	--	--	--	--	7.9(4.7-12.0)8	--
3064	--	--	--	2.2(0.9-3.8)8	2.2(1.3-4.0)19	2.1(1.4-3.2)6	--	--
3065	2.2(1.1-4.5)12	2.0(1.3-3.2)12	2.4(1.3-4.1)12	2.4(1.0-4.2)16	2.0(1.3-2.6)23	2.4(1.4-3.8)18	2.7(1.7-4.9)10	1.9(1.8-2.0)2
3066	--	--	--	2.4(1.1-5.0)8	2.1(1.3-2.8)20	1.7(1.4-2.2)3	--	--
3067	--	--	--	2.6(1.1-6.1)8	2.0(1.3-3.2)20	2.6(1.4-5.0)10	3.0(1.8-4.7)4	2.2(1.6-2.9)3
3069	--	--	--	2.3(1.2-3.3)15	2.1(1.4-3.1)23	2.4(1.4-4.4)16	3.1(1.5-6.7)14	1.9(1.4-2.7)7

TABLE B-27. BICARBONATE ION (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	107(102-112)3	112(90-122)9	104(97-110)2
3040	--	--	--	--	--	142(128-155)2	141(110-170)11	125(120-130)2
3042	--	--	136(116-156)2	128(93-148)5	122(104-139)2	--	--	--
3045	--	--	154(130-177)2	144(97-180)3	--	--	--	--
3048	--	--	--	157(107-205)3	178(116-217)7	166(119-228)11	197(140-320)12	156(130-180)7
3060	--	--	--	540(436-617)26	510(390-602)22	444(317-526)11	546(460-630)8	512(400-610)5
30606	--	--	--	599(443-690)25	554(460-678)21	490(309-610)11	585(520-690)12	518(420-580)6
3061	--	--	--	--	548(448-585)10	509(324-567)10	539(150-620)12	609(570-650)8
3062	632(258-811)12	686(327-933)12	625(523-750)10	680(559-902)10	595(525-684)12	604(458-780)10	619(546-740)12	644(490-810)5
30621	661(280-920)12	743(327-1080)12	652(546-802)10	687(575-961)10	630(563-742)7	630(412-756)6	--	--
30622	1310(292-2740)12	2011(583-4690)12	964(701-1460)12	1038(748-1310)11	881(639-1260)13	893(459-1880)9	1168(859-2100)13	1295(680-2180)4
30623	--	--	--	--	--	139(-)1	--	--
30624	--	--	--	--	617(519-658)11	588(518-638)9	614(588-633)3	--
306248	--	--	--	--	--	131(-)1	--	--
30625	--	--	--	--	115(-)1	164(-)1	--	--
306255	--	--	1690(-)1	1408(843-1760)12	1488(596-1930)22	1460(596-1990)10	1878(1730-2060)4	1830(-)1
1200	--	--	--	--	--	--	350(-)1	--
3063	--	--	--	--	220(199-238)4	215(140-266)11	251(200-340)11	218(140-270)5
30638	--	--	--	--	--	--	331(150-825)8	--
3064	--	--	--	245(225-266)8	209(145-266)19	211(143-280)6	--	--
3065	209(158-270)12	202(132-250)12	238(148-314)12	234(146-288)16	220(131-280)23	222(133-266)18	236(140-300)10	215(200-230)2
3066	--	--	--	249(223-295)8	217(153-267)20	183(141-239)3	--	--
3067	--	--	--	248(227-280)8	218(125-277)20	228(149-270)10	236(170-280)4	207(150-240)3
3069	--	--	--	238(132-306)15	228(138-280)23	240(155-321)16	267(190-360)15	224(150-290)7

TABLE B-28. DISSOLVED SULFATE (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n
3030	--	--	--	--	--	83(75-91)3	89(61-100)10	96(92-99)2
3040	--	--	--	--	--	32(26-39)2	30(15-40)11	28(27-30)2
3042	--	--	92(83-100)2	72(19-96)5	57(23-91)2	--	--	--
3045	--	--	104(99-110)2	84(22-120)3	--	--	--	--
3048	--	--	--	107(30-170)3	128(38-180)7	119(46-160)11	164(34-260)12	130(43-190)7
3060	--	--	--	170(140-200)27	160(110-190)22	164(140-190)11	166(150-190)8	164(140-210)5
30606	--	--	--	303(220-380)25	271(170-350)21	298(190-390)12	332(280-380)12	265(200-320)6
3061	--	--	--	--	458(400-510)10	480(370-580)11	506(450-610)12	532(480-600)8
3062	369(110-470)12	403(170-550)12	388(290-500)10	423(330-570)10	364(310-450)12	428(320-550)10	442(360-540)13	370(230-500)5
30621	399(120-540)12	446(170-710)12	412(300-570)10	444(310-630)10	391(360-480)7	422(240-610)6	--	--
30622	390(50-570)11	453(240-570)12	435(300-580)12	455(350-540)10	404(300-540)13	428(260-560)9	455(370-570)13	515(270-740)4
30623	--	--	--	--	--	17(-)1	--	--
30624	--	--	--	--	565(510-600)11	554(490-610)9	530(480-560)3	--
306248	--	--	--	--	--	12(-)1	--	--
30625	--	--	--	--	80(-)1	11(-)1	--	--
306255	--	660(-)1	590(-)1	566(400-750)13	557(470-660)22	568(490-630)11	558(510-590)4	580(-)1
1200	--	--	--	--	--	--	160(-)1	--
3063	--	--	--	--	182(150-280)4	158(59-210)11	196(140-310)11	158(59-220)5
30638	--	--	--	--	--	--	666(330-1700)8	--
3064	--	--	--	175(160-210)8	147(59-210)19	152(70-200)6	--	--
3065	138(61-200)12	146(52-200)12	168(51-260)12	195(59-360)18	160(59-250)23	174(59-230)18	210(75-360)10	170(130-210)2
3066	--	--	--	179(160-220)8	155(66-260)20	124(63-220)3	--	--
3067	--	--	--	178(160-210)8	159(63-220)20	175(77-240)10	215(130-340)4	164(73-210)3
3069	--	--	--	185(51-280)15	167(55-250)23	191(71-260)16	240(2-570)14	175(75-230)7

TABLE B-29. CHLORIDE (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	1(1-1)3	1(1-3)10	1(0-1)2
3040	--	--	--	--	--	1(1-1)2	1(1-3)11	1(1-1)2
3042	--	--	2(2-2)2	2(2-3)5	2(2-2)2	--	--	--
3045	--	--	24(22-25)2	21(3-33)3	--	--	--	--
3048	--	--	--	23(5-33)3	29(6-38)7	30(8-38)11	42(1-66)12	28(5-49)7
3060	--	--	--	15(10-17)27	15(9-24)22	14(10-19)11	15(12-18)8	13(10-17)5
30606	--	--	--	14(11-16)25	13(11-16)21	14(11-16)12	14(12-18)12	15(10-27)6
3061	--	--	--	--	9(8-11)10	9(8-11)11	9(8-11)12	10(8-12)8
3062	17(10-24)12	18(11-25)12	14(12-17)10	15(9-22)10	14(12-16)12	15(11-19)10	16(12-32)13	18(15-23)5
30621	18(11-25)12	22(13-32)12	15(12-19)10	16(12-27)10	15(13-18)7	20(13-26)6	--	--
30622	158(11-1000)12	150(31-370)12	44(16-75)12	52(37-78)10	40(28-61)13	49(14-130)9	66(33-170)13	84(33-160)4
30623	--	--	--	--	--	4(-)1	11(-)1	--
30624	--	--	--	--	20(17-23)11	18(16-20)9	18(15-21)3	--
306248	--	--	--	--	--	5(-)1	--	--
30625	--	--	--	--	12(-)1	4(-)1	--	--
306255	--	--	180(-)1	120(93-140)13	126(100-150)22	149(130-200)11	145(110-170)4	120(-)1
1200	--	--	--	--	--	--	38(-)1	--
3063	--	--	--	--	30(27-32)4	33(11-44)11	50(34-75)11	35(8-46)5
30638	--	--	--	--	--	--	37(13-82)8	--
3064	--	--	--	43(32-68)8	30(8-45)19	30(10-44)6	--	--
3065	28(8-83)12	35(8-54)12	54(11-140)12	41(10-87)18	32(10-48)23	35(11-51)18	50(24-89)10	38(29-46)2
3066	--	--	--	49(33-120)8	31(9-47)20	21(11-35)3	--	--
3067	--	--	--	64(34-230)8	32(9-58)20	34(13-45)10	52(29-81)4	33(15-48)3
3069	--	--	--	36(8-56)15	32(8-48)23	41(10-75)16	51(32-86)14	38(14-58)7

TABLE B-30. DISSOLVED SILICA (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	16(16-17)3	18(17-21)10	19(19-19)2
3040	--	--	--	--	--	14(13-15)2	15(10-18)11	16(-)1
3042	--	--	17(16-18)2	15(10-18)5	13(10-16)2	--	--	--
3045	--	--	17(16-18)2	9(4-12)3	--	--	--	--
3048	--	--	--	13(10-15)3	15(10-16)7	14(7-17)11	15(6-20)12	14(12-15)7
3060	--	--	--	16(13-18)26	15(12-18)22	14(13-17)11	15(12-17)8	16(13-18)5
30606	--	--	--	17(12-20)25	16(13-20)21	15(13-18)12	16(11-19)12	16(11-19)6
3061	--	--	--	--	18(16-19)8	18(16-20)11	18(16-19)12	18(15-20)8
3062	18(11-20)12	17(13-21)12	18(15-20)10	17(1-20)10	17(14-19)11	17(6-20)10	16(1-18)13	16(14-19)5
30621	18(10-20)12	17(10-21)12	18(15-20)10	17(3-20)10	18(15-28)7	16(8-20)6	--	--
30622	14(8-18)12	13(6-19)12	18(15-20)12	17(9-20)11	17(13-23)13	15(13-17)9	16(8-21)13	14(12-16)4
30623	--	--	--	--	--	5(-)1	--	--
30624	--	--	--	--	18(15-21)11	19(17-22)9	17(16-19)3	--
306248	--	--	--	--	--	5(-)1	--	--
30625	--	--	--	--	13(-)1	6(-)1	--	--
306255	--	--	3(-)1	10(7-17)13	10(0-20)22	9(3-14)11	10(5-13)4	12(-)1
1200	--	--	--	--	--	--	14(-)1	--
3063	--	--	--	--	13(12-15)4	12(11-15)11	14(10-17)11	13(12-14)5
30638	--	--	--	--	--	--	9(5-18)8	--
3064	--	--	--	13(11-14)8	13(9-17)19	13(11-16)6	--	--
3065	16(13-19)5	14(11-19)9	14(11-18)12	13(10-16)16	13(9-17)23	12(9-16)18	14(11-16)10	13(11-14)2
3066	--	--	--	13(11-15)8	13(8-17)20	12(11-13)3	--	--
3067	--	--	--	13(11-15)8	13(9-17)20	13(12-17)10	14(13-15)4	11(7-14)3
3069	--	--	--	13(10-16)15	13(10-16)23	12(9-15)16	12(0-17)14	13(12-16)7

TABLE B-31. TOTAL HARDNESS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	173(170-180)3	180(140-200)10	185(180-190)2
3040	--	--	--	--	--	145(130-160)2	144(110-180)11	140(130-150)2
3042	--	--	195(190-200)2	177(96-210)5	155(110-200)2	--	--	--
3045	--	--	225(210-240)2	196(98-250)3	--	--	--	--
3048	--	--	--	220(120-310)3	250(130-300)7	245(130-350)11	297(140-440)12	233(140-310)7
3060	--	--	--	370(320-420)27	359(290-400)22	343(270-390)11	375(330-440)8	368(330-410)5
30606	--	--	--	486(370-570)25	460(350-550)21	460(340-530)12	520(470-580)12	438(380-520)6
3061	--	--	--	--	646(590-730)10	646(580-730)11	689(640-780)12	725(670-800)8
3062	522(190-610)12	544(270-650)12	563(470-700)10	584(530-640)10	540(460-610)12	594(500-700)10	595(530-680)13	570(440-680)5
30621	533(200-630)12	538(260-660)12	562(470-690)10	587(530-680)10	566(520-640)7	538(340-690)6	--	--
30622	467(160-530)12	454(350-540)12	523(410-640)12	525(420-620)11	521(440-580)13	476(370-540)9	522(360-620)13	555(440-610)4
30623	--	--	--	--	--	94(-)1	190(-)1	--
30624	--	--	--	--	733(650-800)11	696(660-730)9	687(650-710)3	--
306248	--	--	--	--	--	73(-)1	--	--
30625	--	--	--	--	100(-)1	78(-)1	--	--
306255	--	--	520(-)1	539(420-670)13	548(440-650)22	504(450-590)11	545(400-610)4	670(-)1
1200	--	--	--	--	--	--	260(-)1	--
3063	--	--	--	--	278(260-310)4	267(150-320)11	317(240-430)11	262(160-320)5
30638	--	--	--	--	--	--	572(270-1300)8	--
3064	--	--	--	285(260-320)8	250(150-320)19	258(160-330)6	--	--
3065	242(170-310)12	252(140-340)12	271(110-340)12	285(150-460)16	262(140-330)23	275(140-340)18	300(180-440)10	275(250-300)2
3066	--	--	--	292(260-340)8	256(160-340)20	217(150-300)3	--	--
3067	--	--	--	295(250-330)8	260(140-320)20	283(170-340)10	302(210-400)4	267(180-310)3
3069	--	--	--	276(130-350)15	260(110-330)23	280(170-370)16	302(110-400)14	274(180-350)7

TABLE B-32. TOTAL IRON (μg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station	1971	1972	1973	1974	1975	1976	1977	1978
Number	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n	x̄ (min-max) n
3030	--	--	--	--	--	--	--	--
3040	--	--	--	--	--	--	--	--
3042	--	--	--	--	--	--	--	--
3045	--	--	--	--	--	--	--	--
3048	--	--	--	--	240(70-410)2	433(170-580)3	765(330-1200)2	--
3060	--	--	--	--	--	--	--	--
30606	--	--	--	--	--	--	--	--
3061	--	--	--	--	--	--	--	--
3062	--	--	--	--	--	--	--	--
30621	--	--	--	--	--	--	--	--
30622	--	--	5000(-)1	--	--	--	--	--
30623	--	--	--	--	--	--	--	--
30624	--	--	--	--	140(-)1	--	--	--
306248	--	--	--	--	--	--	--	--
30625	--	--	--	--	--	--	--	--
306255	--	--	140(-)1	--	280(-)1	--	--	--
1200	--	--	--	--	--	--	2800(-)1	--
3063	--	--	--	--	240(-)1	1445(250-2900)4	2745(290-5200)2	--
30638	--	--	--	--	--	--	--	--
3064	--	--	--	--	--	--	--	--
3065	--	--	--	--	--	--	--	--
3066	--	--	--	--	--	--	--	--
3067	--	--	--	--	--	--	--	--
3069	--	--	--	5550(1800-9300)2	4050(3200-4900)2	2850(70-7800)4	5600(1600-8100)3	26000(-)1

TABLE B-33. TOTAL MANGANESE (μg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	--	--	--
3040	--	--	--	--	--	--	--	--
3042	--	--	--	--	--	--	--	--
3045	--	--	--	--	--	--	--	--
3048	--	--	--	--	35(20-50)2	50(30-90)3	53(40-80)3	30(-)1
3060	--	--	--	--	--	--	--	--
30606	--	--	--	--	--	--	--	--
3061	--	--	--	--	--	--	--	--
3062	--	--	--	--	--	--	--	--
30621	--	--	--	--	--	--	--	--
30622	--	--	5000(-)1	--	--	--	--	--
30623	--	--	--	--	--	--	--	--
30624	--	--	--	--	100(-)1	--	--	--
306248	--	--	--	--	--	--	--	--
30625	--	--	--	--	--	--	--	--
306255	--	--	0(-)1	--	17(-)1	--	--	--
1200	--	--	--	--	--	--	120(-)1	--
3063	--	--	--	--	7000(-)1	52(20-90)4	123(60-230)3	--
30638	--	--	--	--	--	--	--	--
3064	--	--	--	--	--	--	--	--
3065	--	--	--	--	--	--	--	--
3066	--	--	--	--	--	--	--	--
3067	--	--	--	--	--	--	--	--
3069	--	--	--	110(30-190)2	3445(90-6800)2	80(10-210)4	137(40-200)3	720(-)1

TABLE B-34. TEMPERATURE (°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 x̄ (min-max) n	1972 x̄ (min-max) n	1973 x̄ (min-max) n	1974 x̄ (min-max) n	1975 x̄ (min-max) n	1976 x̄ (min-max) n	1977 x̄ (min-max) n	1978 x̄ (min-max) n
3030	--	--	--	--	8.4(1.0-12.0)8	5.5(0-16.0)13	6.5(0-16.0)28	1.5(1.0-2.0)2
3040	--	--	--	--	8.9(1.5-13.0)8	4.4(0-12.5)14	8.8(0-16.0)26	2.5(2.0-3.0)2
3042	--	--	7.5(4.5-10.5)2	4.0(0-8.0)5	5.4(2.0-10.0)5	5.2(0-10.0)4	9.6(0.5-19.5)8	--
3045	--	--	7.8(4.5-11.0)2	6.0(0-10.0)3	11.0(-)1	3.3(0.5-9.0)3	9.9(0.5-18.5)11	--
3048	--	--	--	10.4(1.0-18.0)7	6.6(0-16.0)14	6.5(0-22.5)16	9.7(0-25.0)31	8.2(1.0-15.0)7
3060	--	--	--	11.5(0-22.0)27	11.0(0-22.0)25	10.1(0.5-21.5)15	9.0(0.5-25.0)8	8.4(1.0-17.0)6
30606	--	--	--	13.9(2.5-23.0)25	8.6(0.5-21.1)21	9.8(2.5-18.0)14	10.2(0-19.5)19	6.1(2.0-13.0)6
3061	--	--	--	--	8.4(1.0-17.0)10	11.4(1.0-19.0)15	7.2(0.5-16.5)13	6.1(1.5-12.0)7
3062	5.6(0-14.5)23	7.3(0-14.0)24	6.4(0-14.0)17	9.8(0-21.0)10	8.0(0-17.0)13	12.0(0-22.0)10	8.6(0.5-22.5)23	11.9(1.5-21.5)5
30621	5.6(0-14.5)23	7.3(0-15.0)24	6.0(0-14.0)17	9.4(0-25.0)10	8.3(3.0-15.0)7	16.0(7.0-23.0)5	--	--
30622	5.5(0-15.0)23	6.8(0-15.0)24	7.9(0-20.0)19	10.2(0-23.5)11	8.1(0-17.5)5	12.8(0.5-26.0)8	10.7(0-24.5)17	14.4(8.0-22.0)4
30623	--	--	--	--	--	2.0(1.0-3.0)4	--	--
30624	--	--	--	--	13.2(6.0-23.0)11	11.8(1.0-23.0)15	7.2(6.0-8.5)3	--
306248	--	--	--	--	--	0.7(0.5-1.0)3	--	--
30625	--	--	--	--	11.8(10.5-13.0)2	0.5(-)1	--	--
306255	--	17.0(-)1	26.0(-)1	15.6(0.5-26.0)13	9.8(0-23.5)22	15.9(0-28.0)12	7.4(0.5-22.0)10	21.0(-)1
1200	--	--	--	--	--	--	9.0(9.0-9.0)2	--
3063	--	2.2(0-4.5)2	9.1(0.5-20.5)10	15.1(6.5-21.0)5	12.0(0-24.0)23	10.4(0-22.5)36	17.8(0-22.5)50	6.2(0-14.0)4
30638	--	--	--	--	--	7.0(-)1	13.5(0.5-23.5)6	--
3064	--	--	--	8.5(0-18.0)8	8.7(0-21.0)19	16.4(10.5-25.0)7	--	--
3065	10.6(0-24.0)21	10.7(0-22.0)24	10.4(0-25.0)21	10.7(0-28.5)17	10.7(0-22.0)22	10.9(0-24.0)23	13.3(0-26.0)18	12.3(0.5-22.0)3
3066	--	--	--	7.7(0-18.0)8	9.3(0-22.0)20	13.0(10.0-15.0)4	--	--
3067	--	--	--	9.8(0-19.0)7	9.2(0-21.0)20	11.2(0-23.5)10	11.9(0-22.0)5	8.1(1.5-19.4)4
3069	--	--	--	9.1(0-21.5)20	9.9(0-23.5)31	12.5(0-26.5)26	15.8(0-32.0)31	9.2(0-23.0)8

TABLE B-35. DISSOLVED OXYGEN (mg/liter), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	11.2(11.1-11.4)2	9.6(5.4-12.1)7	11.1(10.4-11.7)2
3040	--	--	--	--	--	11.1(-)1	8.9(5.4-12.6)8	11.8(11.5-12.1)2
3042	--	--	9.9(8.6-11.2)2	11.7(11.4-12.1)5	9.8(9.8-9.8)2	--	--	--
3045	--	--	10.6(9.5-11.6)2	11.9(11.8-12.2)3	--	--	--	--
3048	--	--	--	10.9(9.4-12.1)6	9.4(6.9-12.5)8	9.6(6.5-12.6)10	10.3(7.0-12.6)11	10.9(7.9-13.6)7
3060	--	--	--	9.9(7.0-13.0)26	9.7(6.9-12.4)19	10.1(9.0-11.2)11	9.1(7.0-10.5)8	9.3(6.8-10.8)6
30606	--	--	--	9.9(6.8-16.0)24	9.5(6.4-12.8)18	10.9(8.9-12.4)11	9.5(7.5-12.9)14	9.6(8.1-10.6)6
3061	--	--	--	--	9.7(6.0-11.4)8	9.7(8.2-12.5)11	8.7(7.6-10.2)11	9.1(6.2-11.3)7
3062	9.8(8.0-11.0)11	10.1(8.8-11.4)12	10.1(8.4-11.6)9	10.0(8.8-12.4)7	8.3(6.9-9.8)5	9.6(7.2-13.0)10	9.9(7.7-11.9)11	11.6(9.4-12.3)5
30621	9.0(1.0-11.2)11	10.1(8.5-11.6)12	10.1(8.2-11.8)9	11.0(9.4-12.3)6	9.7(8.7-11.0)3	7.2(6.1-9.7)4	--	--
30622	9.8(7.5-11.2)11	9.9(7.8-11.8)12	9.8(7.9-11.6)9	9.6(7.9-11.6)5	9.5(6.8-12.2)7	8.5(4.9-12.5)8	9.4(6.4-12.7)9	12.7(11.2-14.2)3
30623	--	--	--	--	--	--	--	--
30624	--	--	--	--	10.2(4.4-18.1)8	9.7(5.1-13.4)10	10.9(8.5-12.3)3	--
306248	--	--	--	--	--	--	--	--
30625	--	--	--	--	--	--	--	--
306255	--	--	--	9.5(6.9-11.9)12	9.9(7.4-12.5)21	8.5(5.6-12.6)11	10.0(9.2-10.8)2	7.4(-)1
1200	--	--	--	--	--	--	9.4(9.4-9.4)2	--
3063	--	--	--	--	9.1(6.0-12.5)4	9.3(6.0-12.7)10	9.1(6.2-11.8)10	10.9(9.2-13.4)5
30638	--	--	--	--	--	--	7.8(5.8-10.4)6	--
3064	--	--	--	8.4(8.0-8.7)2	8.6(6.0-11.1)13	7.7(-)1	--	--
3065	9.5(7.5-11.9)9	8.6(6.6-11.4)12	7.4(5.3-10.4)11	7.9(7.0-9.2)6	9.5(6.4-15.0)17	8.9(6.4-12.2)12	9.2(6.5-11.9)8	8.9(7.4-11.4)3
3066	--	--	--	8.2(-)1	8.1(2.4-11.7)14	7.8(-)1	--	--
3067	--	--	--	8.2(-)1	8.5(3.8-11.9)14	9.0(7.0-11.7)5	--	--
3069	--	--	--	9.2(6.1-12.2)10	8.9(6.2-11.8)23	8.6(5.7-11.5)20	8.2(2.2-11.4)14	9.1(6.9-11.0)6

TABLE B-36. pH, 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	--	8.3(8.2-8.4)3	8.1(7.0-8.6)10	7.9(7.7-8.1)2
3040	--	--	--	--	--	8.1(7.7-8.4)2	8.1(7.6-8.6)11	8.5(8.2-8.8)2
3042	--	--	8.4(8.1-8.8)2	8.3(7.9-8.8)5	8.3(-)1	--	--	--
3045	--	--	8.5(8.2-8.8)2	8.0(7.9-8.3)3	--	--	--	--
3048	--	--	--	7.9(6.3-8.4)6	8.2(7.1-8.6)11	8.3(7.9-8.5)11	8.2(7.7-8.5)13	8.3(7.9-8.8)7
3060	--	--	--	8.2(6.9-8.7)27	8.4(8.0-8.7)18	8.3(7.9-8.6)11	8.2(8.1-8.3)8	8.2(7.9-8.4)6
30606	--	--	--	8.2(7.6-8.7)25	8.3(7.5-9.2)20	8.3(8.1-8.5)11	8.2(8.0-8.4)14	8.2(7.8-8.5)6
3061	--	--	--	--	8.5(7.8-9.0)9	8.3(8.1-8.4)11	8.1(7.9-8.3)12	7.9(7.7-8.2)7
3062	8.1(7.4-8.8)23	8.1(7.0-8.8)23	7.9(7.3-8.4)17	8.0(7.5-8.3)10	8.3(7.1-9.0)11	8.4(8.2-8.8)10	8.4(8.1-8.9)13	7.8(7.1-8.4)5
30621	8.2(7.6-8.9)23	8.1(6.0-9.1)24	7.8(7.2-8.4)17	8.1(7.9-8.3)10	8.4(7.9-8.7)7	8.4(8.1-8.6)4	--	--
30622	8.1(7.3-9.1)23	8.2(7.4-9.0)24	7.9(7.1-8.4)19	8.2(8.0-8.6)7	8.4(8.0-8.8)13	8.6(8.3-8.9)9	8.3(7.7-8.7)13	7.8(7.4-8.2)4
30623	--	--	--	--	--	8.4(-)1	--	--
30624	--	--	--	--	8.2(7.5-8.6)11	8.1(7.4-8.4)10	8.4(8.2-8.6)3	--
306248	--	--	--	--	--	8.2(8.2-8.3)2	--	--
30625	--	--	--	--	8.6(-)1	8.7(-)1	--	--
306255	--	8.7(-)1	9.0(-)1	8.5(8.0-8.8)13	8.6(8.1-9.4)20	8.6(8.2-8.9)12	8.7(8.4-9.0)4	8.9(-)1
1200	--	--	--	--	--	--	8.4(8.4-8.4)2	--
3063	--	--	--	--	8.4(8.3-8.5)4	8.3(7.4-8.7)11	8.3(7.9-8.5)13	8.2(8.1-8.4)4
30638	--	--	--	--	--	--	8.3(7.8-8.5)7	--
3064	--	--	--	8.1(7.8-8.4)5	8.3(7.9-8.6)13	8.0(7.7-8.3)6	--	--
3065	7.6(6.6-8.2)22	7.6(6.6-8.3)21	8.0(7.1-8.4)12	8.0(7.5-8.4)13	8.3(7.4-8.8)19	8.2(7.5-8.8)17	8.0(7.3-8.4)8	--
3066	--	--	--	8.2(7.9-8.5)5	8.1(7.2-8.8)14	8.1(8.0-8.3)2	--	--
3067	--	--	--	8.3(7.9-8.6)5	8.1(7.6-8.5)11	7.9(7.6-8.2)9	7.5(6.5-8.4)5	7.8(7.0-8.6)4
3069	--	--	--	7.9(7.1-8.6)14	8.3(7.9-8.8)20	8.3(7.9-8.7)20	8.2(7.4-8.6)15	8.2(7.9-8.4)6

TABLE B-37. TOTAL ALKALINITY (mg/liter as CaCO), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station Number	1971 $\bar{x}$ (min-max) n	1972 $\bar{x}$ (min-max) n	1973 $\bar{x}$ (min-max) n	1974 $\bar{x}$ (min-max) n	1975 $\bar{x}$ (min-max) n	1976 $\bar{x}$ (min-max) n	1977 $\bar{x}$ (min-max) n	1978 $\bar{x}$ (min-max) n
3030	--	--	--	--	--	88(84-92)3	92(74-100)9	85(80-90)2
3040	--	--	--	--	--	116(105-127)2	116(90-140)11	109(98-120)2
3042	--	--	120(113-128)2	107(76-121)5	100(85-114)2	--	--	--
3045	--	--	134(122-145)2	118(80-148)3	--	--	--	--
3048	--	--	--	130(88-172)3	147(95-178)7	141(98-205)11	163(121-260)12	130(110-150)7
3060	--	--	--	443(358-506)26	422(320-494)22	367(280-431)11	447(377-520)8	418(330-500)5
30606	--	--	--	492(363-566)25	459(377-556)21	415(257-500)11	480(430-570)12	425(340-480)6
3061	--	--	--	--	451(384-480)10	420(296-465)10	442(123-510)12	500(470-530)8
3062	518(212-665)12	563(268-765)12	513(429-615)10	558(459-740)10	488(431-561)12	497(376-640)10	510(450-610)12	526(400-660)5
30621	542(230-755)12	613(268-886)12	536(448-658)10	564(472-788)10	519(462-609)7	529(338-693)6	--	--
30622	1113(239-2630)12	1774(478-3850)12	799(575-1200)12	953(614-2060)11	729(551-1030)13	797(460-1540)9	1027(705-2060)13	1062(560-1790)4
30623	--	--	--	--	--	114(-)1	120(-)1	--
30624	--	--	--	--	506(426-540)11	482(425-523)9	503(480-519)3	--
306248	--	--	--	--	--	107(-)1	--	--
30625	--	--	--	--	94(-)1	135(-)1	--	--
306255	--	--	1920(-)1	1332(894-1520)12	1437(1220-1660)22	1560(1280-1670)10	1715(1620-1830)4	1600(-)1
1200	--	--	--	--	--	--	300(-)1	--
3063	--	--	--	--	183(163-195)4	177(115-218)11	206(160-280)11	178(110-220)5
30638	--	--	--	--	--	--	276(120-677)8	--
3064	--	--	--	202(185-228)8	174(119-218)19	173(117-230)6	--	--
3065	171(130-221)12	165(108-205)12	196(121-258)12	192(120-236)16	181(107-230)23	184(109-218)18	195(110-250)10	175(160-190)2
3066	--	--	--	205(183-242)8	179(126-219)20	152(116-201)3	--	--
3067	--	--	--	204(186-230)8	179(103-227)20	188(122-221)10	193(140-230)4	170(120-200)3
3069	--	--	--	198(108-253)15	191(113-239)23	201(127-283)16	223(160-310)15	190(120-260)7

TABLE B-38. SUSPENDED SEDIMENTS (mg/liter), 1971-78, AT U.S. GEOLOGICAL SAMPLING STATIONS IN THE WHITE RIVER BASIN

Station	1971	1972	1973	1974	1975	1976	1977	1978
Number	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3030	--	--	--	--	100(-)1	12(6-18)2	15(5-46)9	--
3040	--	--	--	--	57(-)1	9(8-11)2	25(1-142)9	--
3042	--	--	--	--	524(22-1880)4	23(-)1	--	--
3045	--	--	--	--	551(192-910)2	--	--	--
3048	--	--	--	--	142(23-470)9	64(11-149)6	92(2-389)11	--
3060	--	--	--	--	635(100-2040)11	2703(842-6500)4	--	--
30606	--	--	--	118(71-165)2	549(263-1590)9	2183(219-4600)3	1670(928-3390)7	--
3061	--	--	--	--	--	842(339-1270)5	16419(478-50199)5	--
3062	--	--	--	--	323(245-415)3	849(-)1	1589(500-5730)10	--
30621	--	--	--	--	--	--	--	--
30622	--	36(-)1	--	--	757(452-1200)7	--	1235(28-2190)7	--
30623	--	--	--	--	--	--	--	--
30624	--	--	--	--	--	13168(2840-23900)7	1584(308-2860)2	--
306248	--	--	--	--	--	190(37-410)5	--	--
30625	--	--	--	--	16820(7840-25800)2	133(-)1	--	--
306255	--	--	--	--	648(44-2560)9	2179(442-4790)5	505(200-850)6	--
1200	--	--	--	--	--	--	--	--
3063	--	179(36-641)10	222(73-848)10	301(75-909)4	455(17-2430)23	319(34-1020)28	318(20-2910)29	--
30638	--	--	--	--	--	--	--	--
3064	--	--	--	--	--	--	--	--
3065	--	--	--	--	--	152(80-288)3	1475(133-5310)8	754(-)1
3066	--	--	--	--	--	--	--	--
3067	--	--	--	--	--	--	--	--
3069	--	--	--	289(223-328)3	3177(131-13100)15	1289(48-5220)16	5627(71-51700)25	3150(-)1

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16. ABSTRACT

The Yampa and White River Basins are key areas in the Nation's search for untaped resources to supplement increasing energy demands. The basins contain vast beds of low-sulfur, strippable coal that potentially will support a large number of coal-fired powerplants as well as some of the richest oil shale deposits in the United States. However, conversion of these energy resources into commercially usable power and fuel is expected will have considerable impact on water resources in the Yampa and White River Basins, especially if maximumm levels of expansion are realized. It appears unlikely that there are sufficient surface or ground-water supplies to meet projected needs in the area without creation of additional reservoir storage or diversion of surface water from other sources. Decreased flows from energy developments will accompany increased salt and sediment loadings. The resultant lowered water quality will further reduce water usability for municipal, industrial, and irrigation purposes and will have adverse impacts on the aquatic ecosystem. Water quality monitoring needs in the basins are addressed with priority listings of parameters for measurement to detect changes in water quality as a result of energy resource development, and through definition of those U.S. Geological Survey sampling stations that are best situated for monitoring activities.

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Water pollution	Yampa River Basin	13B
	White River Basin	17B
	Coal Strip Mining	48A
	Oil shale development	68D

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