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THE YAMPA RIVER BASIN, COLORADO AND WYOMING--A PREVIEW TO EXPANDED COAL-RESOURCE DEVELOPMENT AND ITS IMPACTS ON REGIONAL WATER RESOURCES

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Expanded coal production and conversion in the Yampa River basin, Colorado and Wyoming, may have substantial impacts on water resources, environmental amenities, and socioeconomic conditions.

Preliminary results of a 3-year basin assessment by the U.S. Geological Survey are given for evaluation of surface- and ground-water resources using available data, modeling analysis of waste-load capacity of a Yampa River reach affected by municipal wastewater-treatment plant effluents, and semiquantitative descriptions of ambient air and water-quality conditions. Aspects discussed are possible constraints on proposed development due to basin compacts and laws regulating water resources, possible changes in environmental-control regulations, and policies on energy-resource leasing and land use that will influence regional economic development.

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By Timothy Doak Steele, Daniel P. Bauer,
Dennis A. Wentz, and James W. Warner

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information, write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Denver, CO 80225

FOREWORD

A major concern of the American public is the enhancement and protection of the environment at minimal social costs, particularly with respect to development and utilization of the Nation's energy resources. The substantial investments made over recent years to protect and to improve air and water quality are being evaluated critically for effectiveness and social desirability. A review of existing and pending legislation which establishes acceptable national goals for environmental protection (including air- and water-quality standards, and land-use planning) is being conducted with the intent of setting more realistic goals in response to changing policies on economic development and energy consumption.

The Yampa River basin assessment is one of a series of multidisciplinary studies supported by the U.S. Geological Survey. Each study has considered unique circumstances regarding the physical setting and forms of economic development affecting the environment. In the case of the Yampa River basin, coal resources, population growth, limited water availability, and associated economic development pose as potential problems affecting existing conditions and lifestyle in the region. These studies will help to determine the types and forms of hydrologic, geologic, and other information useful to decision-making administrators in their analyses of policies affecting development and use of natural resources.

Decisions affecting energy-resource development need to consider the environmental and economic impacts of such development. Expanded energy-resource development will lead to increased generation and discharge of residual waste materials to the land, surface and ground waters, and the air. Through modification or treatment, some residuals may be converted to commercial products of economic value. Discharged residuals generally will have an impact on environmental quality. Any plan to modify or reduce these discharges may affect the basin's water resources in terms of water withdrawals, water consumption, and assimilative capacity. Planning for the development and management of the natural resources of the Yampa River basin needs to be conducted in the context of the uncertainties associated with a range of possible development alternatives and the effects of each in terms of water use and discharge of residuals.

This report describes the environmental setting of the Yampa River basin and documents various alternative proposals for energy-resource development in the basin, primarily in terms of increased mining and conversion of near-surface coal. The approaches to ongoing data collection and investigative studies initiated under the assessment-project design will be summarized in this report. Specific study results are discussed in more technical detail in other reports. The intended audience of this report includes those regional and basin planners and managers, working in areas of expanding energy development, who are concerned with water use and environmental impacts.

J. S. Cragwall, Jr.
Chief Hydrologist

PREFACE

"* * * communication to the public and its representatives of knowledge of alternative opportunities for water management and use will result in more rational decisions."

National Academy of Sciences, 1968, p. 81

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The inch-pound units used in this report may be converted to metric units by the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.0733	cubic meter per second per square kilometer [(m^3/s)/km^2]
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second (m^3/s)
barrel	0.1590	cubic meter (m^3)
ton (short)	0.9072	metric ton (t)
ton per day (ton/d)	0.9072	metric ton per day (t/d)
pound (lb)	0.454	kilogram (kg)
British thermal unit	1,055	joule (J)
British thermal unit per pound (Btu/lb)	2,324	joule per kilogram (J/kg)

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ABSTRACT

Expanded coal production and conversion in the western United States may have substantial impacts on water resources, environmental amenities, and socioeconomic conditions. The U.S. Geological Survey currently (1978) has completed a 3-year assessment of the Yampa River basin, Colorado and Wyoming, where the impacts of expanded coal-resource development are beginning to affect the environment and people in the basin. The objectives of this assessment are: (1) To evaluate the environmental and economic impacts of alternative development plans for regional water and energy resources, and (2) to apply and document various assessment methodologies that might be readily transferable to other regions of the United States with abundant energy resources and limited water resources.

Preliminary results are given of the following basin-assessment investigations: (1) An evaluation of surface-water and ground-water resources using available data, (2) a modeling analysis of the waste-load assimilative capacity of a reach of the Yampa River affected by municipal wastewater-treatment plant effluents, and (3) semiquantitative descriptions of ambient air- and water-quality conditions. Aspects of the following factors also are discussed briefly: (1) Possible constraints on proposed development due to basin compacts and laws regulating water resources, (2) possible changes in environmental-control regulations, and (3) policies on energy-resource leasing and land use that will influence regional economic development.

INTRODUCTION

Increasing concern for greater national independence with regard to energy resources has generated interest in coal as a resource for meeting a larger part of the overall national energy demands. In contrast, there are continuing concerns regarding the water demands associated with coal-development alternatives (Davis and Wood, 1974). Anticipated direct environmental impacts associated with coal mining, processing, conversion, and transportation and also indirect impacts associated with shifts in economic activities, such as from agriculture to industry and commercial services in regions affected by such development, are important considerations (Diemer and Wengert, 1977). These impacts are of particular interest in the Rocky Mountain States which have small populations, limited water resources, and relatively abundant coal reserves (U.S. Department of the Interior, 1976a; VanDerwalker, 1975; and Thomas and Anderson, 1976).

The major energy resource in the Yampa River basin is the near-surface coal deposits. However, other energy resources, consisting of oil and gas, oil shale, uranium, and geothermal springs, occur in the basin. Since the early 1900's, about 70 small coal mines have operated in the basin; however, current (1977) coal-mining operations involve 8 surface and 2 underground mines. Total coal production in 1977 was nearly 7.4 million tons (6.7 million t) which was double the production for 1974, and coal production is expected to increase to 20 million tons (18 million t) per year by 1990. Increased production will be obtained primarily from lands controlled by federally leased mineral rights. The increasing rate of coal-resource development in the Yampa River basin will result in several environmental stresses on land, water, air, and other natural resources. Examples include changes in land and water use and increased levels of discharged residuals (noneconomic byproducts) to be assimilated in the environment. In addition, potential impacts of impending oil-shale and coal development in nearby areas may affect water availability in the Yampa River basin.

As a result of increased coal-resource and economic development, population in the basin is anticipated to nearly triple in 16 years (from 18,000 in 1974 to as many as 53,500 by 1990), causing water-resources impacts of an indirect nature (that is, in addition to water demands directly due to coal mining, transport, or conversion to other energy forms). The bulk of withdrawals and consumptive use of water in the basin traditionally has involved surface-water diversions for irrigated croplands. Given the limited availability of water in the region, increasing competition is anticipated among agricultural, mining-related, and municipal-industrial uses in the near future.

Assessment Objectives

Objectives of the Yampa River basin assessment are: (1) To evaluate the environmental and economic impacts of regional energy- and water-resource development for existing and feasible alternative policies, and (2) to describe the assessment methodologies used so that they may be applied to other energy-rich regions of the Western United States where water resources are limited.

The Yampa River basin assessment is concerned with evaluating the direct and indirect impacts of this development on the basin's water resources. Identification of hydrologic-information needs and delineation of existing or potential problem areas which suggest the need for further in-depth investigations are of primary concern.

Regional Setting

The Yampa River basin is located in northwestern Colorado and south-central Wyoming (fig. 1) and encompasses an area of approximately 8,080 mi^2 (20,900 km^2). Major references to the basin's regional setting are depicted on figure 1. The assessment studies involve that part of the basin lying to the east of Dinosaur National Monument. Approximately three-fourths of the basin lies in Colorado and one-fourth in Wyoming. Included in the basin boundaries are parts of seven counties: Garfield, Grand, Moffat, Rio Blanco, and Routt Counties in Colorado, and Carbon and Sweetwater Counties in Wyoming. The combined basin areas in Moffat and Routt Counties constitute about two-thirds of the total drainage area of the basin. Moreover, the majority of the population and economic activity within the basin is located in these two counties. The basin averages 75 mi (120 km) in width and extends about 100 mi (160 km) from the Continental Divide in the east to Dinosaur National Monument in the west.

The Yampa River basin constitutes the first three cataloging units of accounting unit 140500 of the Upper Colorado River region as defined by the U.S. Water Resources Council (1970). The Yampa River lies within the Green River division [subbasin of the Upper Colorado River (region) Basin (Iorns and others, 1965)].

Between 1930 and 1960, the population of the Yampa River basin ranged from about 13,000 to slightly more than 16,000 (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969, table 7, p. 46). The basin had been losing population from the 1940's until recent years, primarily as a result of reduced coal mining in Routt County. Starting in the early 1970's, the declining population trend was reversed. Recreational development in the Steamboat Springs area and considerable coal mining and powerplant construction activities in Routt and Moffat Counties caused the basin population to increase to between 17,000 and 18,000 in 1974 and to more than 20,000 by the end of 1975 (adjusted data from U.S. Department of the Interior, 1976a; Colorado Water Conservation Board and U.S. Department of Agriculture, 1969; and Wyoming State Engineer's Office, 1970).

Population distribution is highly variable over the basin. The major population centers are indicated on figure 1. The county seats of Steamboat Springs in Routt County and Craig in Moffat County serve as major urban centers. Using 1975 population estimates, about two-thirds of the basin inhabitants (a combined population of 13,870 out of 20,720) live in these two towns (U.S. Department of the Interior, 1976a, table RII-37, p. II-121). Other towns in the Yampa River basin with 1975 population estimates are: Hayden (1,840), Oak Creek (1,290), Yampa (360), Milner (200), Baggs (200), and Dixon (70). A recently completed census in Routt County (The Steamboat Pilot, May 5, 1977) indicated that the population was less than that indicated for 1975--41 percent less for Oak Creek, and 5 percent less countywide. This discrepancy reflects to a large extent the seasonal nature of population in the basin and the dependence of recreational activity in the basin on favorable climate and national economic conditions. The remaining inhabitants live in other small communities or on ranches scattered throughout the basin.

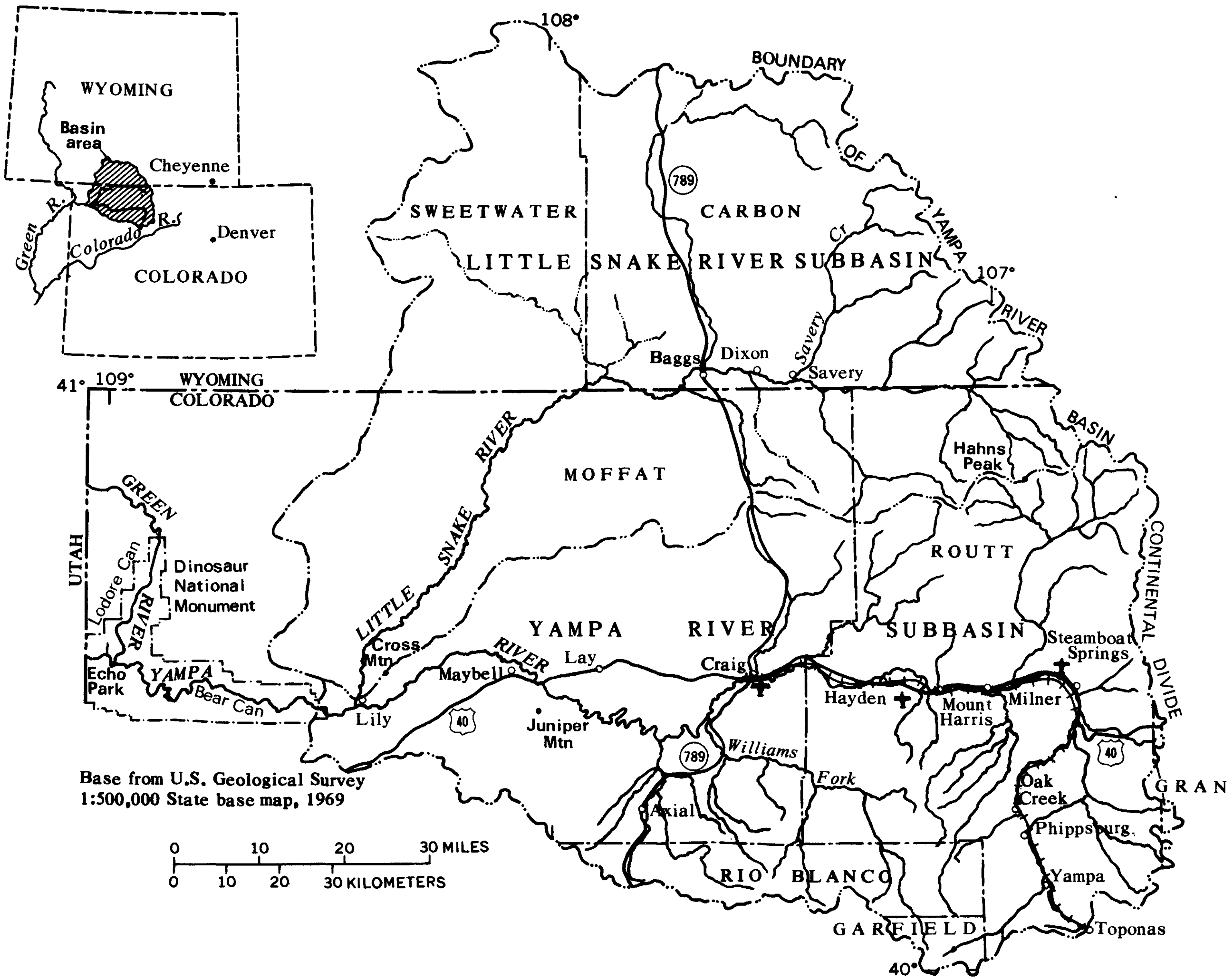

Figure 1.--Location of the Yampa River basin east of Dinosaur National Monument, Colorado and Wyoming.

Principal economic activities in the basin include agriculture (irrigated crops, dryland farming, and livestock), recreation, extraction of oil and gas, mining of coal and uranium, and numerous wholesale and retail services. Economic growth is anticipated to increase significantly over the next 15 years, due in part to increases in related service activities.

The basin economy is quite dependent upon tourist trade, and availability and condition of transportation linkages are important. Regional air service plus two major highways provide access to the region. As shown on figure 1, there are two major highways crossing the Yampa River basin: U.S. Highway 40, an east-west route that basically parallels the Yampa River from Steamboat Springs to near Dinosaur National Monument; and U.S. Highway 789, a north-south route through the towns of Craig, Colo., and Baggs, Wyo. A limited network of secondary paved or graded gravel roads exists within the basin. Unimproved dirt roads and jeep trails are numerous, particularly in the more arid western part of the basin.

A rail line operated by the Denver & Rio Grande Western Railroad enters the Yampa River basin from the south at Toponas near the southeastern corner of the basin. The rail line passes through the towns of Phippsburg, Oak Creek, and Steamboat Springs and then parallels the Yampa River until it terminates near Craig. Short spurs of the rail line exist to a coal-loading tipple on Middle Creek south of Milner and to the Colorado-Ute Electric Association, Inc., coal-burning powerplant near Hayden. An extension of this rail line recently was completed for access to the new coal-burning powerplant being constructed in Craig, and another is proposed for access to a major surface-mine site near Axial (U.S. Department of the Interior, 1976a). Major railroad coal-loading facilities are located at Craig and near Oak Creek.

Coordination with Related Studies

River-Basin Assessments

The U.S. Geological Survey continually strives to make its data-collection and investigative programs manpower-efficient, cost-effective, and more responsive to both current and anticipated demands for environmental information covering a wide range of uses. In order to advise the U.S. Geological Survey in evaluating current and projected needs for water-resources data, a non-Federal committee on water data for public use was created. This committee consists of 26 representatives from organizations and professional societies on national, regional, State, and university levels. To better identify critical and relevant uses of hydrologic information, an ad hoc working group of this committee has recommended that a series of river-basin assessments be conducted. These assessment projects strive to apply various methods that would enable better communication between resource scientists and those regional planners responsible for formulating policy and for directing development.

The Yampa River basin assessment, one of a series of multidisciplinary projects supported by the U.S. Geological Survey and implemented in response to the committee recommendations (Greeson and others, 1977b), began in April

1975. This follows an initial prototype assessment conducted in the Willamette River basin, Oregon (Rickert and Hines, 1975; Rickert and others, 1976). Selection of the Yampa River basin was made, in part, because of the impending expanded development of coal resources and the need to anticipate direct and indirect effects of this development on the water resources in the region. The project was scheduled to be completed in approximately 3 years. Detailed work-plan reports for the project have been written (Steele and others, 1976a; 1976b). The components of the project's first phase have been completed and are summarized in this report.

Other Studies in the Yampa River Basin

Activities of the Yampa River basin assessment are being coordinated with related ongoing Federal, State, and local studies. Presently, cooperative projects are being conducted by the U.S. Geological Survey in Colorado in cooperation with the U.S. Environmental Protection Agency, the U.S. Bureau of Land Management, Routt County, and the Colorado Department of Natural Resources. Through these studies, basic data are being collected on the availability and quality of surface waters and ground waters, including areas of the Yampa River basin where most of the coal-resource development will occur (U.S. Geological Survey, 1976; Brogden and Giles, 1977). Also, certain modeling applications and specific-site investigations are part of the studies. The Yampa River basin assessment, being regional in scope, complements these longer term, cooperative data-collection programs and other interpretative activities.

Results of basin-assessment studies and areawide waste-treatment management planning studies by the two Council of Governments Regions in northwestern Colorado are being coordinated. These latter planning studies are required by Section 208 of Public Law 92-500 and are funded by the U.S. Environmental Protection Agency. As an example of cooperative efforts, a reevaluation of an earlier analysis of the waste-load assimilative capacity of a reach of the Yampa River was conducted (Bauer and Steele, 1976). Data pertinent to depicting effects of treated wastewater discharges on stream quality were collected to use in comparative modeling studies (Bauer and others, 1978). Biological aspects of the waste-load assimilative-capacity modeling analysis were also studied by the staff of the Region VIII Surveillance and Analysis Division of the U.S. Environmental Protection Agency (Eddy, 1975), in coordination with the basin-assessment project staff.

Additional biological (aquatic macroinvertebrate and fish) studies were conducted by graduate students in the Department of Zoology, Colorado State University, with funding support from the U.S. Bureau of Land Management (Prewitt and others, 1976; Ames, 1977). Sampling methods and results are being compared with those used in the basin-assessment project program. A specific-site analysis of dissolved-solids increases and related changes in trace-metal and biological characteristics of streams draining areas of coal-mining waste spoils recently has been completed by the Department of Agricultural Engineering, Colorado State University (McWhorter and others, 1975; McWhorter, 1977). Several additional studies by universities, consultants, or governmental agencies are in the planning or implementation stages.

A regional residuals-management analysis is being conducted by a systems-analysis group of the U.S. Geological Survey headquartered in Reston, Va. This research-oriented analysis will seek to define the relationship between water use, costs of raw materials, and the costs of modifying residual discharges to meet environmental standards for coal-resource development industries. The first phase of this analysis (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas; written commun., 1976) evaluated plant-level processes to provide a basis for assessing the impact of energy development on water use and environmental quality. Results of this first-phase analysis by the systems-analysis group have been utilized in the Yampa River basin assessment.

The Colorado Department of Natural Resources, Division of Water Resources, in cooperation with the U.S. Geological Survey, has assessed certain legal and institutional aspects of water-resources development in the Yampa River basin. The State Engineer's office is providing the Geological Survey with current information on surface-water rights and ground-water well permits in the basin. In addition, computer files of the Colorado State Engineer's water-data bank (Colorado State University and Colorado Division of Water Resources, 1977) are being updated to provide historic data on surface-water diversions used for irrigation, municipalities, and industries in the Yampa River basin.

Economic studies are being conducted as part of the basin assessment, using methods documented by researchers at the University of Colorado (Udis and Hess, 1976; Udis and others, 1973; 1977). These studies investigate socioeconomic aspects of development and assist in projecting increasing demands for water and needs for wastewater treatment. A recently completed environmental statement on northwest Colorado coal development contains detailed information on coal-resource development projections, demographic forecasts, and related water-resources information (U.S. Department of the Interior, 1976a).

In Wyoming, the U.S. Geological Survey is conducting a project on water-related impacts of economic development in the Green River and Great Divide basins in Wyoming. A detailed work plan has been prepared for this project (Lowham and others, 1976). The project area includes the Wyoming part of the Yampa River basin, and project studies are being coordinated with the basin-assessment studies.

Project Phases and Approach

Two project phases of the Yampa River basin assessment have been identified. Primary emphasis throughout the assessment is placed upon evaluation of water-resources impacts; however, these interact with other parts of the environment, such as land and air (Reiquam and others, 1975). The first phase (Steele and others, 1976a) consisted of describing the existing environmental conditions, primarily in terms of the hydrologic and physical characteristics, and describing a set of coal-development alternatives for the basin. The first-phase efforts were concerned with analyzing existing data. Deficiencies in information were identified for consideration in the second-phase assessment studies. This report includes summaries of study findings for this first phase and provides much of the background information for the second-phase assessment.

In the second phase (Steele and others, 1976b), the direct and indirect environmental impacts of the various proposed plans for coal-resource development will be evaluated. Direct impacts include the effects of coal mining, processing, conversion to electricity or gas products, and transport by rail or pipeline. Indirect impacts are concerned with effects of increased population and other associated economic development as influenced by the energy-resource development.

A generalized approach to regional assessments (fig. 2) will be used as a guide to second-phase assessment studies. Any basin-planning process should be considered iterative (Bennington and others, 1974), cycling through the "management strategies" component (fig. 2). This conceptual approach

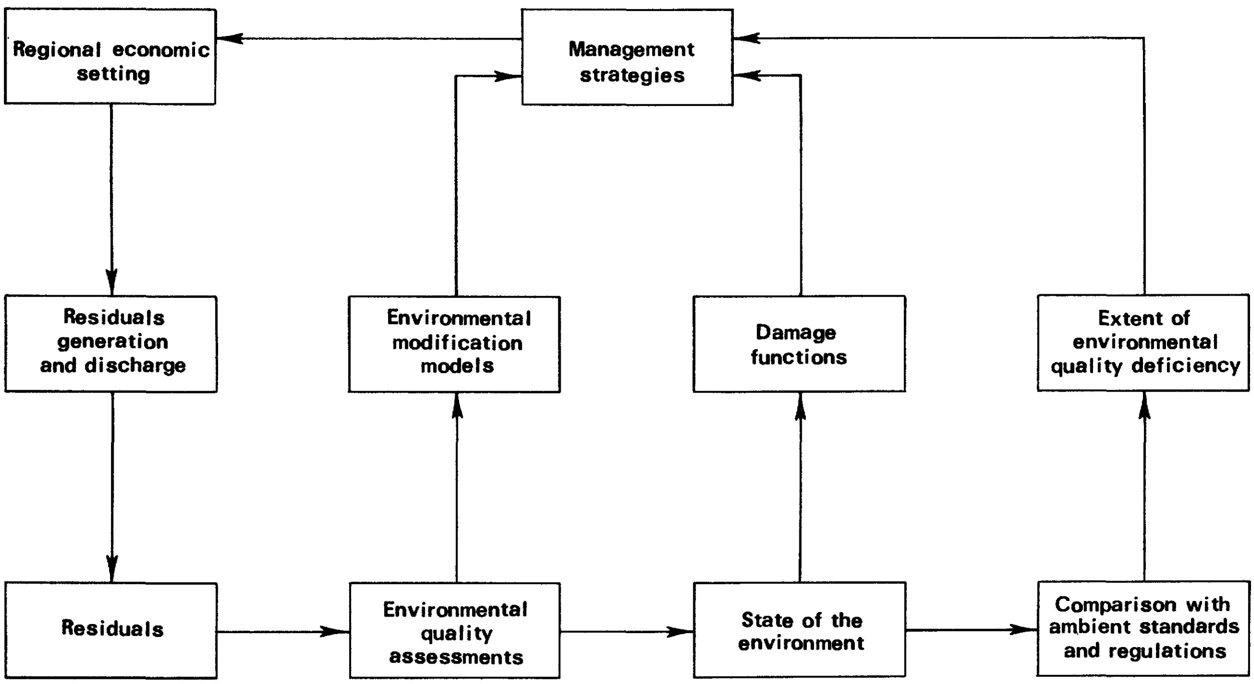

Figure 2.--Flow diagram for regional assessments (U.S. Geological Survey, 1976).

will be emphasized in varying degrees in the basin assessment. Methodologies developed by the residuals-management analysis will assist the basin-assessment project staff in generating the proposed residual loadings resulting from the alternative energy-resource development plans identified for the basin. Additional data will be collected as needed for specific study components. Hydrologic data and demographic, economic, and land-use information will be utilized in the assessment for evaluating interactions between resource development and environmental quality (Environment Canada, 1975). Forecasting methodologies will couple available data inputs with quantitative techniques or utilize descriptive or empirical methods (Rickert and others, 1975). For modeling applications, current techniques have been reviewed. The method selected for a given analysis will reflect a balance of data requirements and other resource needs.

Acknowledgments

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ENERGY-RESOURCE DEVELOPMENT

Abundant energy resources, including coal, oil and gas, and uranium, occur within the Yampa River basin. Hot mineral springs in the basin indicate some limited geothermal-power potential. Oil-shale resources occur in the northern part of the basin in Sweetwater County, Wyo. (fig. 1), but they contain less recoverable oil than those located in the Piceance Creek basin which lies south of the Yampa River basin. Small deposits containing gold, silver, copper, and lead have been mined in the Hahns Peak area (fig. 1). This section includes brief discussions of the basin's physiography and geology, and a discussion of past, present, and future (proposed) energy-resource development in the basin.

Physiographic Provinces

Most of the Yampa River basin lies within the southern part of the Wyoming Basin physiographic province (Fenneman, 1928), a plateau area underlain by widespread deposits of relatively soft sedimentary rocks, bordered in part by abrupt mountain slopes, and containing isolated ridges. The Park Range formed by the Sierra Madre uplift and White River Plateau formed by the White River uplift are in the southern part of the Rocky Mountains physiographic province. These features occupy narrow areas along the eastern and southeastern margins of the basin. The Uinta Mountains are in the Middle Rocky Mountains physiographic province and are formed by an uplift bearing the same name which comprises an area at the southwestern edge of the basin. The Axial basin and the Elkhead Mountains are two additional major physiographic features in the basin. These physiographic features can be related to the major regional structural units (fig. 3).

The part of the Yampa River basin lying within the Wyoming Basin physiographic province is an area of diverse topography containing broad plains, gently sloping ridges, and badlands interspersed with ridges and low mountains. Most of the area lies between altitudes of 6,500 and 7,500 ft (1,980 and 2,290 m). Low dunes of sand and silt are locally prominent features, especially in alkali areas where the scarcity of vegetation permits the soil to drift into low hummocks.

The Park Range and White River Plateau areas form the headwaters for most of the major streams of the Yampa River basin. The Park Range, extending along the eastern edge of the basin, consists mainly of broad mountain slopes about 10,000 ft (3,050 m) high. However, for a distance of about 20 mi (32 km) south of the Wyoming border, the center of the Park Range is an extensively glaciated ridge with peaks rising to more than 12,000 ft (3,660 m). The high mountain valleys that drain the majority of the mountain slopes are generally broad and open.

The White River Plateau, which forms the southeast margin of the basin, consists mainly of basalt uplands with altitudes between 10,000 and 11,500 ft (3,050 and 3,500 m) and a few peaks with altitudes greater than 12,000 ft (3,660 m). The surface of the plateau is dotted with numerous shallow, flat-bottomed depressions, many of which contain lakes. The borders of the plateau are approximately 1,000 to 2,000 ft (305 to 610 m) above the surrounding terrain and contain vertical cliffs, angular mesas, and steep-sided canyons.

The eastern end of the Uinta Mountains extends eastward across the southwest corner of the basin (fig. 3). This area consists of a central platform with broad slopes about 8,000 ft (2,440 m) high and is bordered by abrupt slopes on the north and south. The most outstanding features of this area are the canyons cut through the mountain range to depths of as much as 3,000 ft (920 m) by the Green and the Yampa Rivers. The Green River flows southward through the Lodore Canyon, and the Yampa River flows westward through the Bear Canyon to their confluence at Echo Park in Dinosaur National Monument (fig. 1).

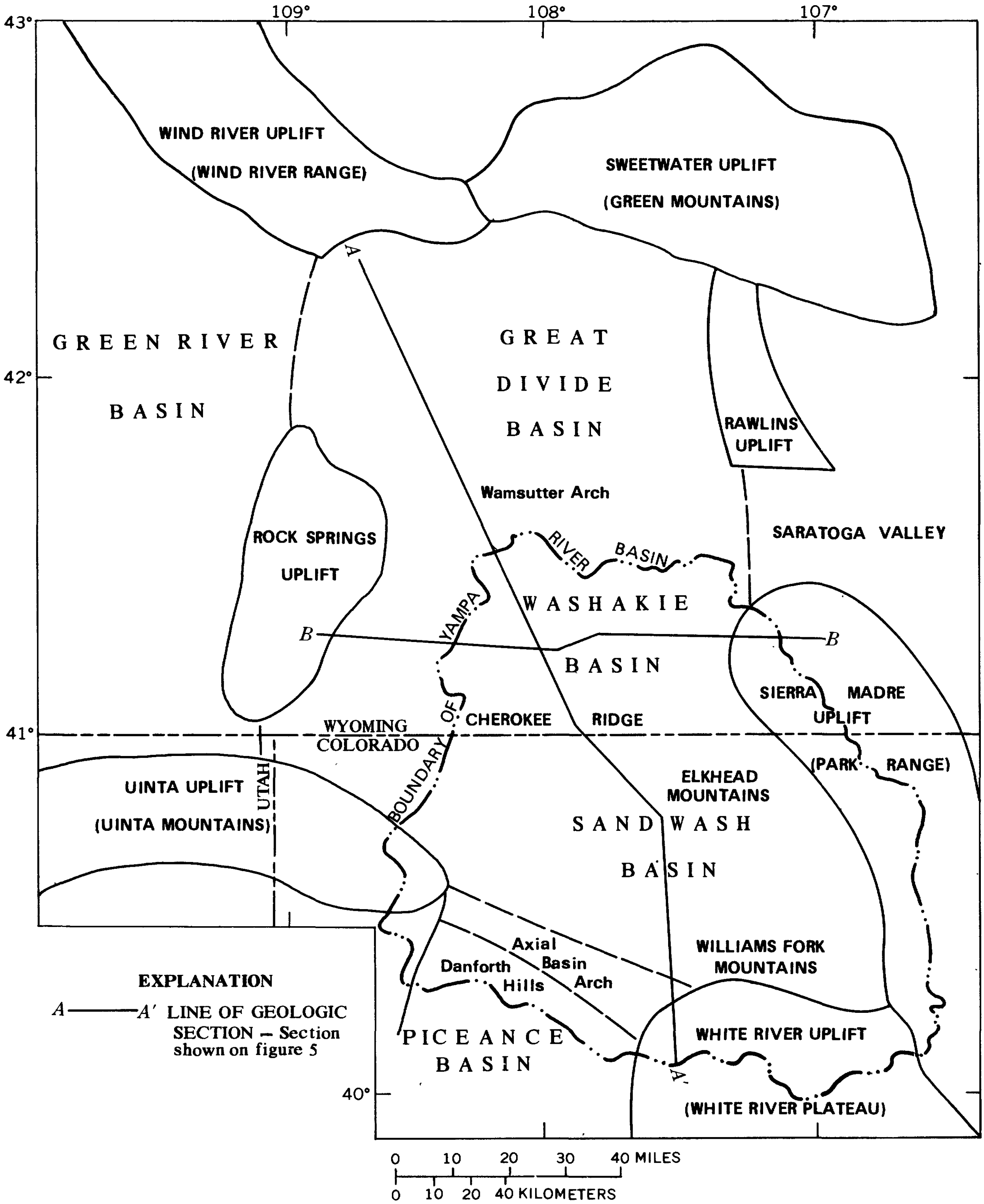


Figure 3.--Major structural units and physiographic features.

The Axial basin, located along the south-central margin of the Yampa River basin, is a prominent topographic feature formed by the Axial uplift (fig. 3). The Axial basin's axis trends northward, and the basin has been deeply eroded, thus exposing underlying soft rocks and forming a sharply outlined trough. Two isolated mountains, Juniper Mountain and Cross Mountain, rise abruptly from the floor of this trough. The Yampa River cuts between both of these mountains in deep canyons. The low Danforth Hills form the south margin of the basin and they rise about 2,000 ft (610 m) above the adjacent valleys. The Williams Fork Mountains, located northeast of the Axial basin, are a ridge formed by resistant sandstone layers.

The Elkhead Mountains in the east-central part of the Yampa River basin consist mainly of flat-lying soft sedimentary rocks protected by basalt flows. The highest peaks reach altitudes of 10,000 to 11,000 ft (3,050 to 3,350 m).

Geology

The generalized geology of the Yampa River basin is shown on figure 4. Rocks exposed in the basin range from Precambrian to Holocene age. Ten generalized geologic units have been identified. Several of these relate to potential availability of ground-water resources (Brogden and Giles, 1977) (see p. 90) and to the principal coal-bearing units (table 1). In this report, the Colorado name designation is used for these units with the accompanying Wyoming name equivalent shown in parentheses.

Most of the Yampa River basin is located on the southern part of a regional structural depression. This regional structural downfold consists of three major shallow synclinal basins: the Sand Wash basin in Colorado, and the Washakie and Great Divide (also known as Red Desert) basins in Wyoming (fig. 3). This regional downfold is bounded on the north by the Wind River and the Sweetwater uplifts, on the east by the Rawlins and the Sierra Madre (Park Range) uplifts, on the south and southwest by the White River and Uinta uplifts and the Axial basin arch, and on the west by the Rock Springs uplift. These geologic structures do not coincide with the surface-water drainage divides. The Yampa River basin occupies all of Sand Wash basin and a sizable part of Washakie basin (fig. 3).

The axis of the regional downfold described above trends eastward. The regional dip of the bedrock strata is to the north. A generalized geologic section through Sand Wash, Washakie, and Great Divide basins is shown in figure 5A. The regional dip of the bedrock strata is from the south at +6,000 ft (+1,830 m) altitude in the Sand Wash basin to more than -5,000 ft (-1,520 m) altitude in Great Divide basin to the north. Superimposed on the regional downfold are a number of smaller scale structures, such as anticlines and synclines, particularly along the margins of the basins. The Sand Wash basin is separated from the Washakie basin by the Cherokee Ridge and the Washakie basin is separated from the Great Divide basin by the Wamsutter arch (figs. 3 and 5A).

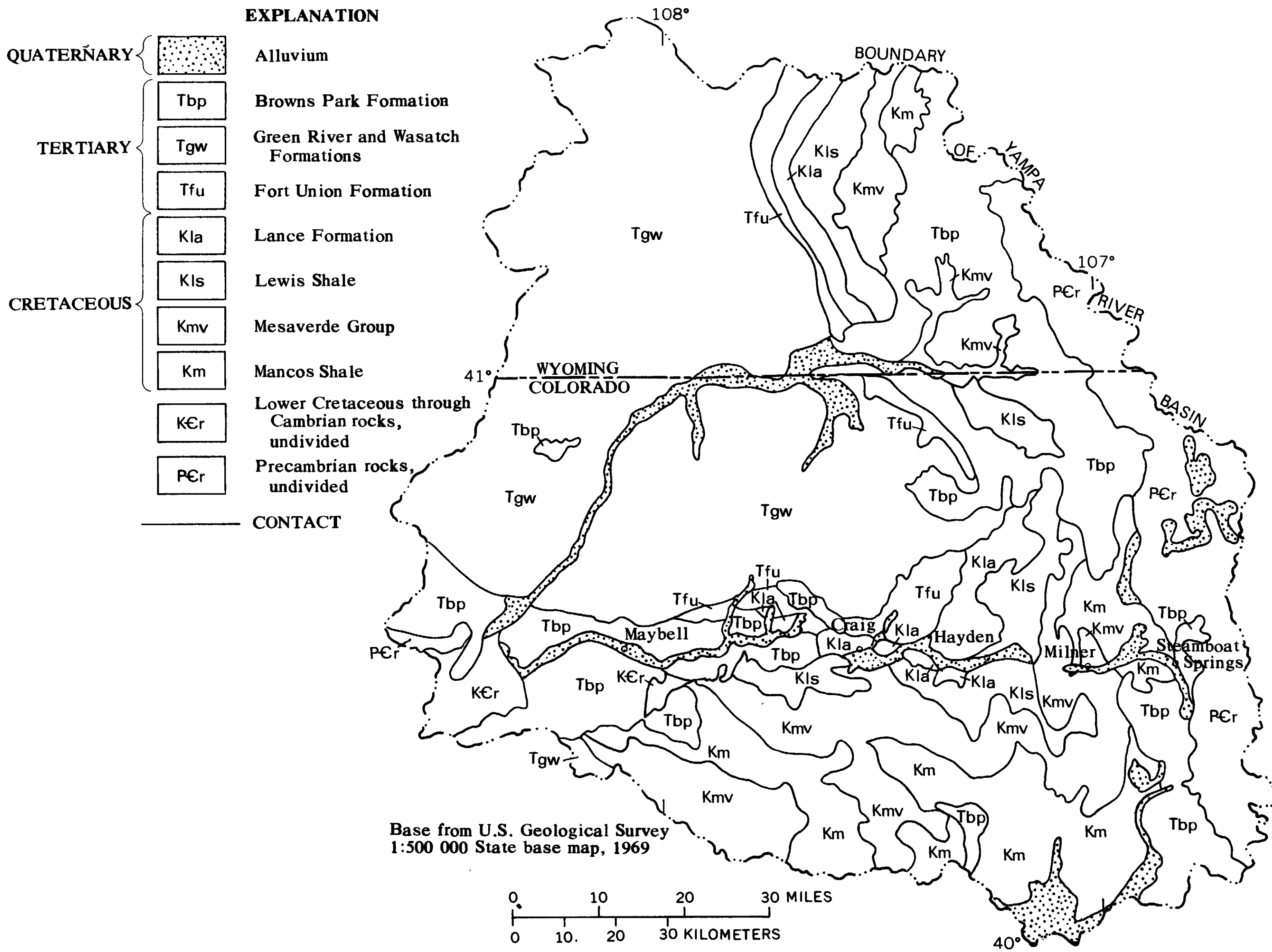


Figure 4.--Generalized geology (adapted from Tweto, 1975, 1976, and Welder and McGreevey, 1966).

Table 1.--*Summary of the generalized geologic units and their physical characteristics*

[Adapted from Boettcher, 1972; Brogden and Giles, 1977; Tweto, 1975, 1976; and Welder and McGreevey, 1966]

System	Series	Geologic unit	Symbol	Occurrence	Thickness (feet)	Physical characteristics
QUATERNARY	Holocene / Pleistocene	Alluvium	Qa	River-channel deposits occur primarily along the main stems of the Little Snake River and the Yampa River and along some of the major tributaries to these two rivers	Generally less than 30 ft	Unconsolidated surficial deposits, including river-channel deposits, lake deposits, landslide deposits, glacial deposits, gravel deposits, and windblown sand. These deposits consist of clay, silt, sand, gravel, and boulders.
TERTIARY	Miocene and Oligocene	Browns Park Formation (North Park Formation and Bishop Conglomerate)	Tbp	Occurs primarily in a large area around the Yampa River in the southwest part of the basin, along the Sierra Madre uplift in the northeast part of the basin, and in a smaller area just south of Steamboat Springs	May be as much as 2,000 ft thick but generally is 200 to 500 ft thick	Included with the Browns Park is the North Park Formation and Bishop Conglomerate in Wyoming. Consists primarily of loosely consolidated fluvial siltstone and sandstone, conglomerate, and locally contains volcanic ash. Weathers with a characteristic jagged surface.
	Eocene	Green River and Wasatch Formations	Twg	Green River Formation mostly overlies the Wasatch and is exposed primarily in the Washakie basin in Wyoming. The Wasatch is exposed primarily in the Sand Wash basin in Colorado and occurs below the Green River Formation in the Washakie basin	Green River is as much as 3,000 ft thick. Wasatch is about 1,000 to 5,000 ft thick	The Green River Formation is of lacustrine origin, whereas the Wasatch is primarily fluvial sediments. Where exposed, weathering has resulted in a badlands-type topography. Wasatch consists chiefly of sandy mudstone, calcareous sandstone, carbonaceous shale, and conglomerate. Green River Formation consists chiefly of marlstone, shale, oil shale, and sandstone.

Table 1.--*Summary of the generalized geologic units and their physical characteristics*--Continued

System	Series	Geologic unit	Symbol	Occurrence	Thickness (feet)	Physical characteristics
TERTIARY	Paleocene	Fort Union Formation	Tfu	Exposed primarily north of Craig along the Yampa River, along the west edge of the Park Range, and in the Rock Springs uplift. Generally found along with the Lewis Shale and Lance Formation and occurs at depth in the Sand Wash and Washakie basins	1,500	Consists of interbedded carbonaceous shales,sandstone, and coal beds.
CRETACEOUS	Upper Cretaceous	Lance Formation	Kla	Generally exposed in the same areas as the Fort Union Formation and Lewis Shale. Found at depth in the Sand Wash and Washakie basins	1,000 to 1,500	Consists of a series of nonmarine shales interbedded with occasional sandstone and coal beds.
		Lewis Shale	Kls	Generally exposed in the same areas as the Fort Union and Lance Formations. Found at depth in the Sand Wash and Washakie basins	1,500 to 2,000	A homogenous marine shale with discontinuous sands in upper part.
		Mesaverde Group { Williams Fork and Iles Formations	Kmv	The Mesaverde Group is exposed primarily in the Williams Fork Mountains in Colorado, in the Rock Springs uplift in Wyoming, and adjacent to the Sierra Madre uplift along the east margin of the study area. Found at depth in the Sand Wash and Washakie basins	Williams Fork (1,100 to 2,000); Iles (1,500);	Included in the Mesaverde Group in Colorado is a lower unit,the Iles Formation, and an upper unit, the Williams Fork Formation. The Iles Formation is marked at the top by a persistent 100-ft thick sandstone bed called the Trout Creek Sandstone Member and marked at the base by the Tow Creek Sandstone Member. A persistent 100-ft thick massive sandstone, the Twentymile Sandstone Member, occurs approximately in the middle of the Williams Fork

Table 1.--*Summary of the generalized geologic units and their physical characteristics*--Continued

System	Series	Geologic unit	Symbol	Occurrence	Thickness (feet)	Physical characteristics
CRETACEOUS	Upper Cretaceous	Mesaverde Group (Almond, Ericson, Rock Springs, and Blair Formations)	Kmv		Almond (1,000); Ericson (1,000); Rock Springs (2,000); Blair (2,000)	Formation. Included in the Mesaverde Group in Wyoming are four units(descending), the Almond, Ericson, Rock Springs, and Blair Formations. The Almond Formation is equivalent to the Williams Fork Formation and the Ericson Formation is equivalent to the Iles Formation. The Rock Springs and Blair Formations are found only in the Rock Springs uplift in Wyoming. Eastward and southward from the Rock Springs uplift, these two formations thin out to the underlying Mancos Shale. In the central part of the Sand Wash and Washakie basins, the Mesaverde Group is undivided. The Mesaverde Group consists of interbedded marine sandstones, shales, and coal layers.
		Mancos Shale (Baxter, Cody, and Steele Shales)	Km	Exposed extensively in Colorado along the southern margin of the Yampa River basin in the Rock Springs uplift, and in the Rawlins uplift in Wyoming. Found at depth in the Sand Wash and Washakie basins	5,000	A homogenous marine shale. The upper 1,000 ft contain a discontinuous series of sandstone layers which are transitional with the overlying Mesaverde Group. The lower part contains some sandstone and limestone beds.

Table 1.--*Summary of the generalized geologic units and their physical characteristics*--Continued

System	Series	Geologic unit	Symbol	Occurrence	Thickness (feet)	Physical characteristics
LOWER CRETACEOUS through CAMBRIAN		Lower Cretaceous through Cambrian rocks (undivided)	K€r	Exposed only along the eastern and western margins of the Yampa River basin and presumably occur at depth in the Sand Wash and Washakie basins	Unknown	Includes all deposits from the Dakota Sandstone through the rocks of Cambrian age. In general, these rocks consist of sandstone, siltstone, mudstone, and shale. The Mississippian rocks, preferably either the Leadville or Madison Limestones, are grouped in this unit.
PRECAMBRIAN		Basement complex (Precambrian rocks, undivided)	P€r	Exposed only along the eastern margin of the Yampa River basin where it forms the Park Range and in the Uinta Mountains to the west of the basin. In most of the basin, the basement complex underlies a thick sequence of sedimentary rocks as much as 23,000 ft	Unknown	Consists of Precambrian igneous and metamorphic rocks, mainly granite, schist, and gneiss.

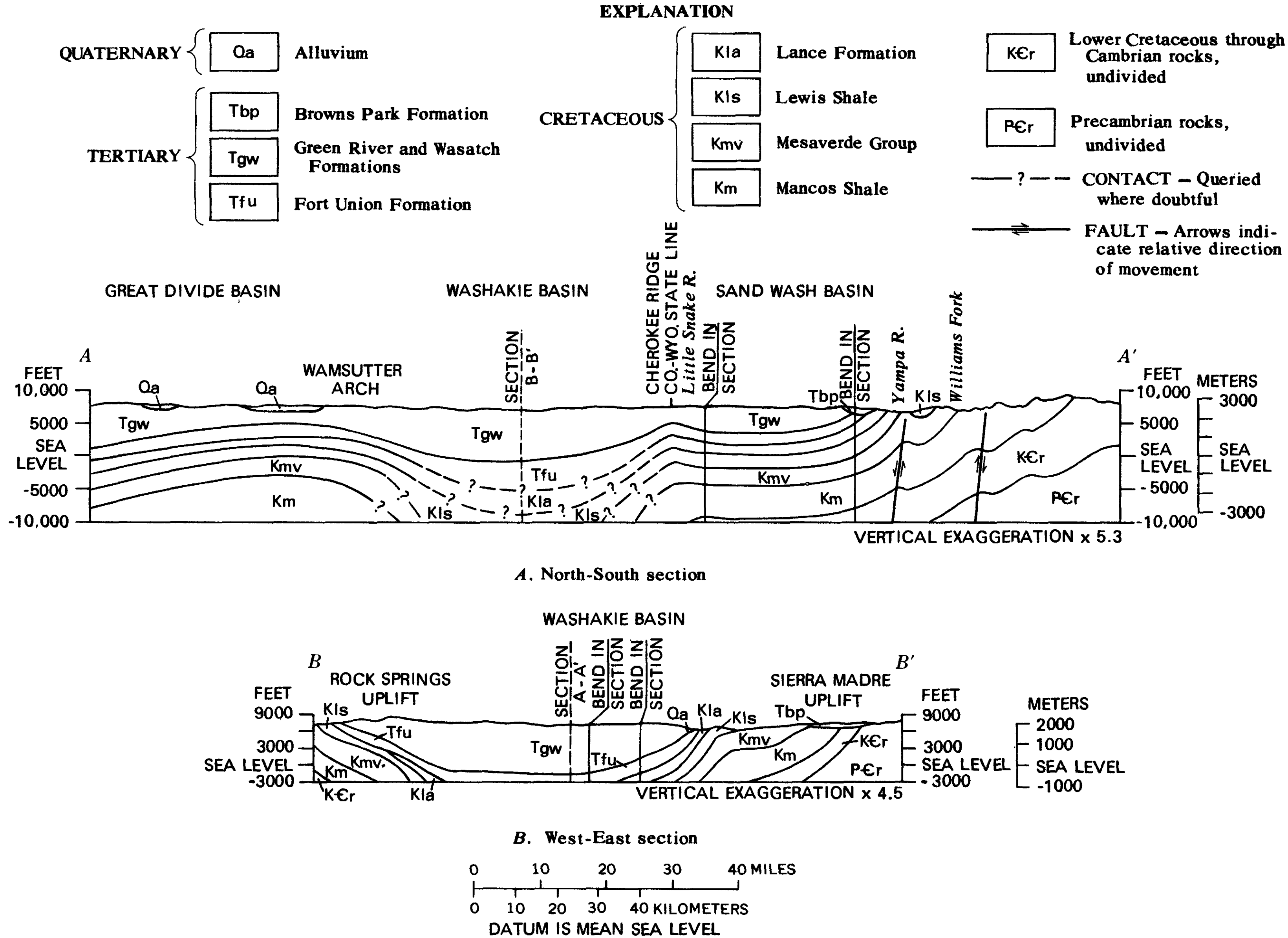


Figure 5.--Geologic sections through the Yampa River basin.

A generalized geologic section trending eastward through the Washakie basin is shown in figure 5*B*. This section extends from the Sierra Madre uplift on the east to the Rock Springs uplift on the west. The section shows a general dip of the bedrock strata into the central part of the basin. The depth of the sedimentary deposits in the central part of the Washakie basin is not known, but indications are that it is more than 25,000 ft (7,620 m).

The structure contours on the top of the Mesaverde Group are shown on figure 6 for the Sand Wash, Washakie, and Great Divide basins. The contours provide a three-dimensional representation of the regional depression's structure. In the Sand Wash basin, the contours not only decrease in altitude regionally to the north but also decrease toward the west from a high of +8,000 ft (+2,400 m) on the east margin of the area to a low of -7,000 ft (-2,130 m) near the juncture of the Uinta uplift and the Axial basin arch (fig. 6). The contours show that the Green River basin is connected through the gap north of the Rock Springs uplift, with the Sand Wash, Washakie, and Great Divide basins. This connection is probably both geologic and hydrologic and should exist in both the deeper aquifers, such as the Mesaverde Group, and in the near-surface aquifers, such as the Fort Union and the Wasatch Formations (table 1).

Mineral Resources

The principal mineral resources of the Yampa River basin include fuels, such as coal, oil, gas, and oil shale, and other metallic and nonmetallic minerals, including gold, silver, copper, gypsum, uranium, and trona (sodium salts) (Vanderwilt, 1947). Areas in the Yampa River basin with potential leasable minerals owned by the Federal Government have been *classified* or have been withdrawn from exploration and development *pending classification*. These areas are indicated on maps published by the U.S. Geological Survey (Bateman and others, 1974; 1976; and Smith and others, 1976). The principal areas of energy resources (U.S. Geological Survey and Colorado Geological Survey, 1977) and of metallic and nonmetallic minerals are indicated on figure 7.

The value of mined and extracted minerals in the Yampa River basin has been quite small compared with other economic activities. The largest production has been in the Hahns Peak region (fig. 7) in Routt County, where gold and some silver, copper, and lead have been mined intermittently since the middle 1800's (Gale, 1906; Young and Segerstrom, 1973). These metals are mined as a complex sulfide ore from small irregular veins in intrusive Tertiary rocks. In Moffat County, placer gold deposits occur in the alluvial sands and gravels of river-channel deposits, particularly in the area north of the town of Lay. Placer gold also has been recovered along the Little Snake River in Wyoming between Dixon and Baggs. In Carbon County, Wyo., near the headwaters of Battle Creek and Little Sandstone Creek (not shown), potentially valuable deposits of gold, silver, copper, iron, and gypsum occur, and considerable mining activity has taken place near this area.

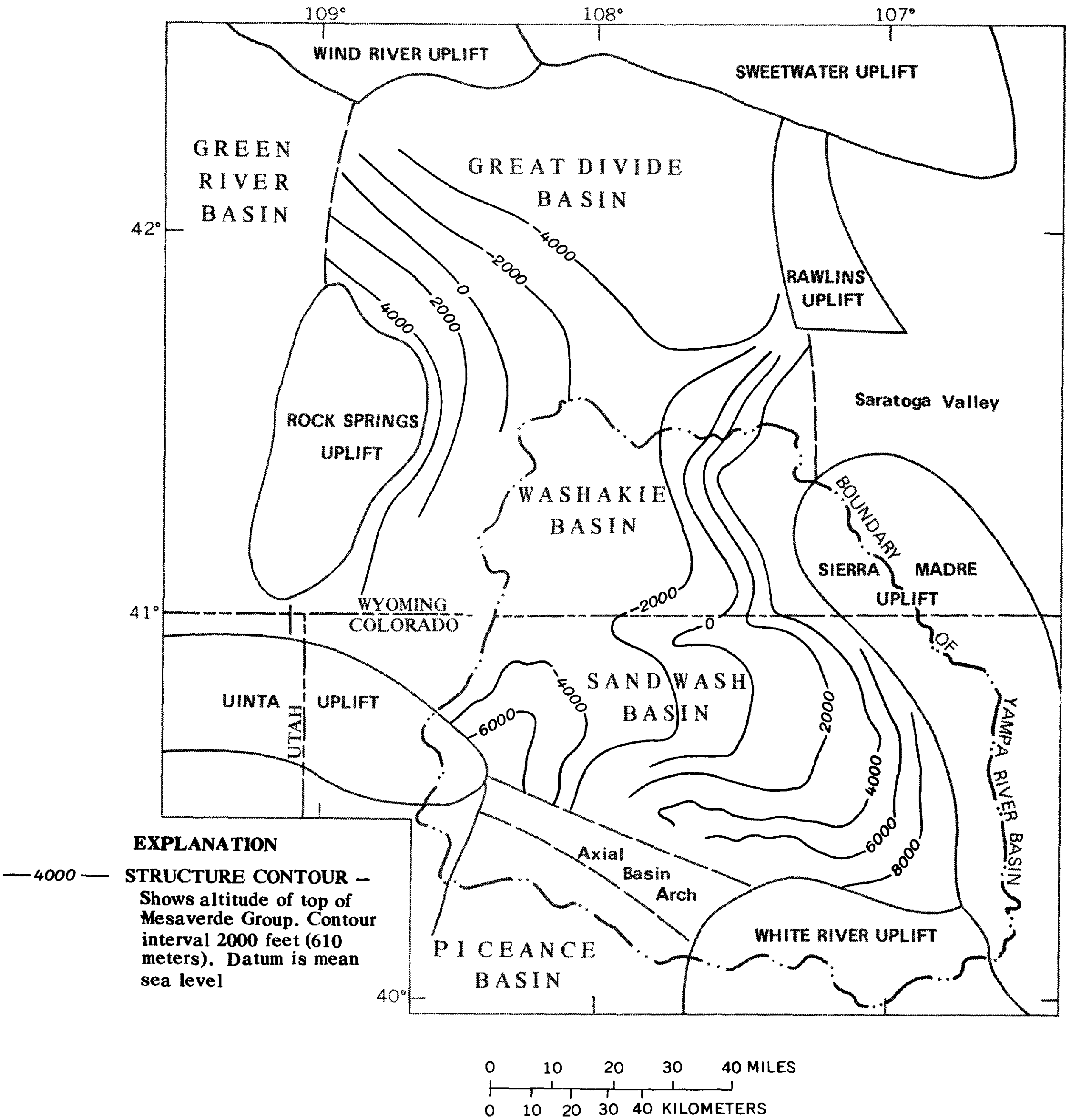


Figure 6.--Structure contours on top of the Mesaverde Group.

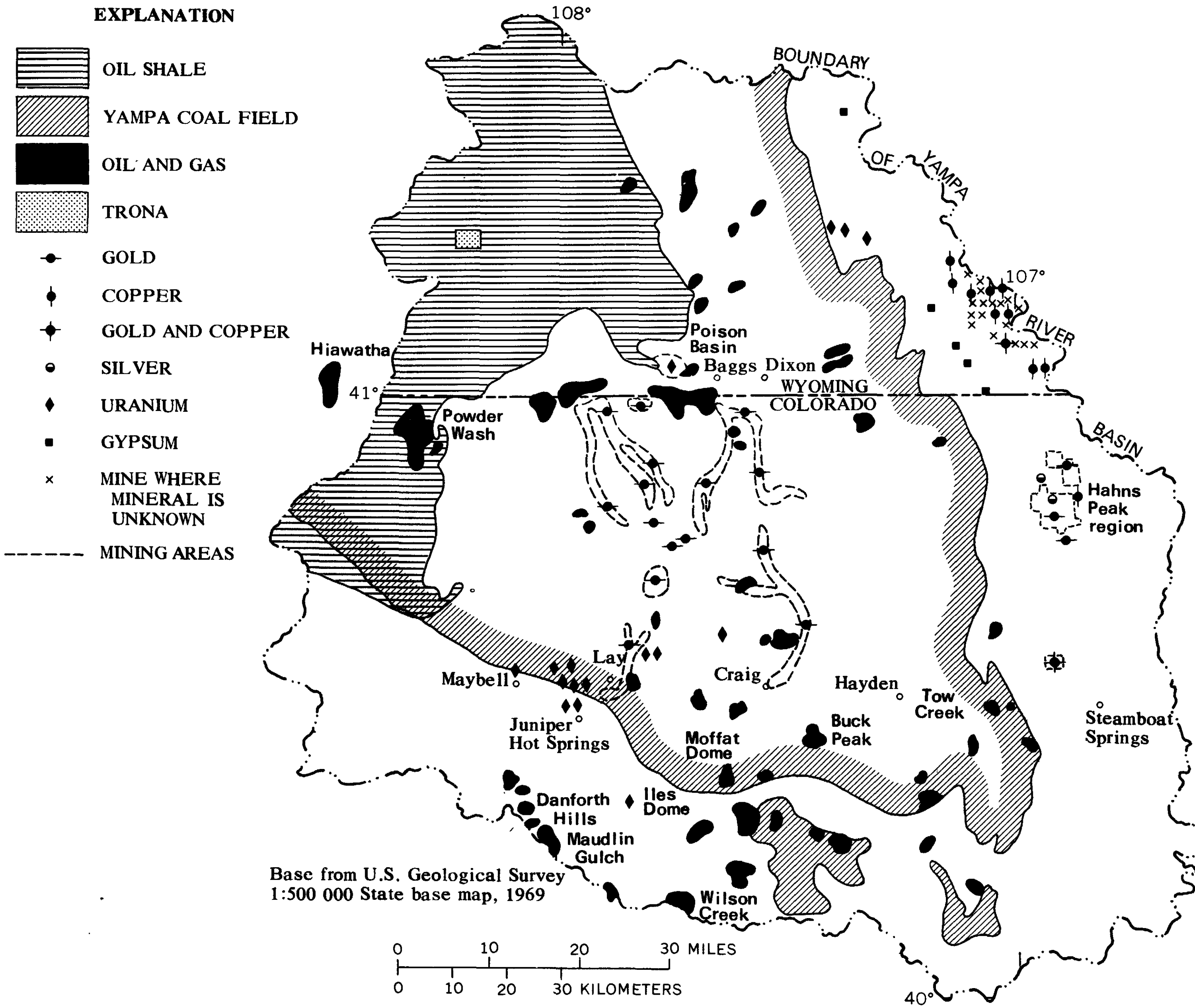


Figure 7.--Principal areas of energy and mineral resources.

Uranium mineralization is widespread throughout the basin, occurring primarily in the Browns Park Formation. Most of the uranium ore is low grade but mining has occurred in the Maybell-Lay-Juniper Springs area (fig. 7) in Colorado and in the Poison Basin (fig. 7), Miller Hill (not shown), and Browns Hill (not shown) areas in Wyoming. Although uranium has been mined in the basin, recent mining was negligible until 1975. Spoil piles containing low-grade ore are being reworked near Maybell, Colo., and commercial uranium production is planned for the near future near Maybell, Colo., and Baggs, Wyo. Estimated resources of 1.2 million pounds (0.54 million kg) of uranium are located in the Poison Basin near Baggs, Wyo. (U.S. Bureau of Mines, 1977).

Trona from the Green River Formation in Wyoming supplies the majority of the world's soda-ash industry. It is estimated that 40 billion tons (36 billion t) of trona ore are recoverable from easily-mined beds in the Green River Formation (Lowham and others, 1976). Most of the economic trona deposits occur outside of the Yampa River basin; however, those deposits (fig. 7) within the basin may represent a valuable economic mineral resource.

Mineral-Rights Ownership

Federal ownership of coal, oil-shale, uranium, oil, and gas mineral rights within the Yampa River basin is much more extensive than Federal ownership of land. Ownership of mineral rights and land ownership for the basin have been compiled graphically by the U.S. Bureau of Land Management (1974-75) in a series of "Surface-minerals management quadrangle" maps at a scale of 1:126,720. An earlier land-ownership map for the basin was compiled by the Colorado Water Conservation Board and U.S. Department of Agriculture (1969). Privately owned mineral rights are concentrated primarily in homesteaded agricultural lands along the Yampa River valley (fig. 1). During early settlement of the basin in the mid-1800's, mineral-rights ownership was included with homesteaded land. Subsequently, the Federal Government has retained the mineral rights of land transferred to private or State ownership. The U.S. Bureau of Land Management is responsible for administering Federal mineral rights.

In the northern part of the basin, a checkerboard pattern of private and Federal ownership of alternate township-range sectioned lands and minerals resulted from land and mineral grants to the Union Pacific Railroad (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969, fig. 5). The areal extent of State and local government ownership of mineral rights in the basin is minor, relative to private and Federal ownership. However, in some areas, a consolidation of Federal, State, and private mineral rights is necessary to efficiently mine the available coal resources.

Geothermal Energy

The geothermal-energy potential in the basin is largely unknown. Some limited geothermal-energy potential is indicated by hot springs in the basin (Smith and others, 1976).

The largest potential geothermal area is centered near the town of Steamboat Springs. Within this area, two groups of hot springs occur--Routt Hot Springs and Steamboat Springs. The Routt Hot Springs occur along Hot Springs Creek, approximately 7 mi (11 km) north of Steamboat Springs. The waters from these springs issue from Tertiary age basaltic rocks and have an average temperature of 64°C (Celsius). The springs have a total discharge of approximately 100 gal/min (0.006 m^3/s). The Steamboat thermal springs consist of approximately 15 large and 120 small springs along the Yampa River at the base of the Park Range (fig. 3). The springs occur near the contact between the Precambrian rocks which form the Park Range and the overlying sedimentary rocks. Most of the smaller springs have a temperature of 24°C while the large Bath House Spring has a temperature of 39°C. The springs have a combined discharge of about 2,000 gal/min (0.13 m^3/s).

Another area of geothermal potential is near Juniper Hot Springs. Water from hot springs near there issues from shales and sandstones of Cretaceous age with a temperature of 39°C. These thermal springs have an estimated combined discharge of about 50 gal/min (0.003 m^3/s). No plans to develop geothermal resources in the basin for energy are known at present.

Oil and Gas

Oil and gas fields are located throughout the basin. These occur in structural traps, such as anticline closures, or in stratigraphic traps, such as lenticularity in the producing sands. The major known oil and gas fields are shown on figure 7. Numerous oil and gas fields have been found along the Cherokee Ridge arch, which occurs approximately along the border between Colorado and Wyoming.

Oil reservoirs occur mainly in the marine Cretaceous sandstones. The nonmarine Cretaceous sandstones are unlikely oil prospects due to the lack of source beds and the generally poor reservoir qualities. The vast oil-shale deposits (fig. 7) found in the Green River Formation in the Wyoming part of the Yampa River basin and in the Piceance Creek structural basin (not shown) south of the Yampa River basin have been recognized as a possible source of hydrocarbon fuels.

Gas and minor oil reservoirs are common in the Late Cretaceous and Tertiary formations (fig. 4, table 1). The lenticular beds of the Wasatch, Fort Union, and Lewis Formations are the location of the major gas discoveries in the basin.

Most of the oil and gas production in the Yampa River basin (table 2) has occurred in Moffat County, Colo., with lesser amounts produced in Routt County, Colo., and in Sweetwater County, Wyo. The principal gas-producing fields have been the Powder Wash and Hiawatha fields along the Colorado-Wyoming border (U.S. Department of the Interior, 1976a, table RII-4). Both of these fields are important oil-producing fields also. Oil- and gas-production figures for that part of the basin in Wyoming were not readily available.

The Powder Wash field (fig. 7), along the southern flank of the Cherokee Ridge (fig. 3), was discovered in 1931 and consists of 66 wells producing mostly gas. The wells tap the sands in the Wasatch and Fort Union Formations. Accumulation is due to anticlinal closure in combination with lenticularity in the Wasatch sands. Total gas production of this field through 1974 was about 123 billion ft^3 (3.48 billion m^3) with current annual production about 9 billion ft^3 (0.25 billion m^3). This field also has produced about 5.5 million barrels (0.87 million m^3) of oil with a current (1976) annual production of about 158,000 barrels (25,100 m^3).

Table 2.--*Oil- and gas-production statistics, Colorado part of the Yampa River basin*
[Source: The Steamboat Pilot, September 1, 1977]

County	1976 Production		Cumulative production through 1976	
	Oil (thousands of barrels)	Gas (thousands of cubic feet)	Oil (thousands of barrels)	Gas (thousands of cubic feet)
Moffat[1]-----------	732	19,482,475	53,044	460,828,226
Routt-------------	154	22,502	4,394	538,239
County totals---	886	19,504,977	57,438	461,366,465
Percent of State total---	2	10	5	12

[1]Includes some fields outside of the Yampa River basin.

The Hiawatha field (fig. 7) was discovered in 1926 and in 1974 consisted of 49 producing wells. The Hiawatha field is on the crest of the Cherokee Ridge arch (fig. 3). Total gas production from the Hiawatha field through 1974 was about 194 billion ft^3 (5.49 billion m^3) with 1974 annual production of nearly 9 billion ft (0.25 billion m^3). This field also has produced about 3.7 million barrels (0.59 million m^3) of oil.

The principal oil-producing fields have been the Iles Dome and the Wilson Creek fields in the southern part of the basin. Other important oil-producing fields, excluding those that concurrently produce gas, included Maudlin Gulch, Moffat Dome, Danforth Hills, and Tow Creek fields. The Iles Dome (eight producing wells) and the Moffat Dome (four producing wells) fields (fig. 7) both were discovered in 1924. The Iles Dome field has produced almost 18 million barrels (2.9 million m^3) of oil through 1974 and the Moffat Dome field produced more than 9 million barrels (1.4 million m^3)

of oil. The Iles Dome field is currently producing about 115,000 barrels (18,300 m^3) of oil per year and the Moffat Dome field less than 10,000 barrels (1,600 m^3) per year. Currently, Buck Peak (fig. 7) is the major oil-producing field in the basin, with a 1974 production of about 370,000 barrels (58,800 m^3) of oil (U.S. Department of the Interior, 1976a).

In the past, economic factors were the primary deterrent to more active exploration of oil and gas in the basin, and many gas wells were shut-in, due to the lack of a market outlet. In 1974, about 40 wells in the basin were still shut-in.

Practically all of the known obvious structural traps, such as anticlinal closures, have been explored. Most of the new discoveries of oil and gas have been in stratigraphic traps, resulting primarily from lenticularity in the producing sands. These stratigraphic traps can occur just about anywhere. The marine sandstones of the Mesaverde Group and Mancos and Lewis Shales are the most promising prospects for stratigraphic traps. Source beds for oil within these marine deposits are likely, and the sandstones generally should have good reservoir qualities.

Recent oil- and gas-exploration activity in the basin is already at a high level and is expected to continue in the near future. Currently producing fields, the discovery of new fields through exploration, and the anticipated addition of new and better recovery methods should sustain oil and gas operations in the basin for at least another 40 years (U.S. Department of the Interior, 1976a).

Coal Mining

Fossil fuels constitute the most important mineral resource within the basin. Of these, the coal resources are the most abundant and valuable. The major coal resources within the basin are located mainly in the Yampa coal field of the Green River coal region (fig. 7). A small part of the Danforth Hills coal field extends into the southern part of the basin. Coal beds occur in the Mesaverde Group, and in the Lance and Fort Union Formations, but most coal mining is from the Mesaverde Group (Hornbaker and Holt, 1973). In Wyoming, most of the mineable coal beds in the Mesaverde Group (Almond, Ericson, Rock Springs, and Blair Formations) occur in the Rock Springs Formation. Considerable mining activity has taken place in the area of the Rock Springs uplift, located to the northwest of the Yampa River basin (fig. 3).

In Colorado, coals in the Mesaverde Group (Iles and Williams Fork Formations, fig. 4 and table 1) are commonly divided into the lower, middle, and upper coal groups. The lower coal group includes all coal beds from about 400 ft (120 m) above the base of the Iles Formation upward to the Trout Creek Sandstone Member. The coals in the lower coal group are found mainly in the Oak Creek area. These coal beds thin northward and westward from the Oak Creek area. The middle coal group includes all coal beds between the Trout Creek and Twentymile Sandstone Members. The middle coal group contains three principal coal beds: Wolf Creek, Wadge, and Lennox. Of the three principal coal beds, the Wadge generally is mined most extensively in the Yampa River basin. These coal beds are in the 400-ft (120-m) interval immediately above the Trout Creek Sandstone Member. The upper coal group includes the coal beds in the Williams Fork Formation above the Twentymile Sandstone Member. From 9 to 16 coal beds are contained within the upper coal group, with a maximum reported thickness of a single seam of about 14 ft (4.3 m).

Several small mines have obtained coal from seams in the Lance and Fort Union Formations in the Yampa River basin in the past, but little is known about these beds. The U.S. Geological Survey presently is investigating the coal-resources potential of the Mesaverde Group (Ryer, 1977) and of the Lance Formation in an area north of Baggs and Dixon, Wyo. (C. S. Venable Barclay, written commun., 1977) (fig. 1).

All of the coals in the Mesaverde Group are noncoking and are low in sulfur content. Commonly, the sulfur content is less than 0.5 percent. Typical analyses of coal from the Mesaverde Group have a mean British-thermal-unit value of 11,500 Btu/lb (26.7 million J/kg), ash content of about 5 percent, moisture content of about 10 percent, and a mean sulfur content ranging between 0.3 to 0.9 percent (Speltz, 1976). In general, the moisture content decreases and the heating value increases in the older and deeper coals (Speltz, 1976). Coals in the upper coal group are ranked as subbituminous, and the coals in the lower and middle groups are ranked as bituminous.

The existence of extensive coal deposits has been recognized since settlement of the basin began in the late 1800's. By 1900, small wagon mines were operated to supply coal to local inhabitants. Transportation of coal was difficult at this time and limited development of coal-mining activities. However, in the early 1900's, the arrival of the railroad in the basin (fig. 1) resulted in a significant increase in coal production. Coal subsequently was used to fuel railroad locomotives in addition to being exported outside the basin. Information on coal production has been compiled by the State of Colorado. Annual production levels in the Colorado part of the basin from 1908 through 1977 are given in figure 8. Small coal mines have operated in the Savery Creek area east of Dixon, Wyo. (fig. 1), but no information could be found regarding their production levels.

Coal production increased gradually from 1908 and peaked in 1919 with an annual production of more than 1 million tons (0.9 million t) (fig. 8). In the early 1920's after World War I, the demand for Yampa-basin coal decreased, and many mines closed. From 1920 to the early 1960's, a plot of annual coal production exhibited a fluctuating series of increases and decreases, with maximum production occurring during World War II (fig. 8). During short intervals when the demand for coal increased, many small mines were operated, and coal production was relatively large. During periods when the demand for coal declined, most of these small mines closed. Since the early 1960's, coal production has increased from less than 0.5 million tons (0.45 million t) per year in 1962 to nearly 7.4 million tons (6.7 million t) in 1977 (fig. 8), due to increasing demands for western low-sulfur coal.

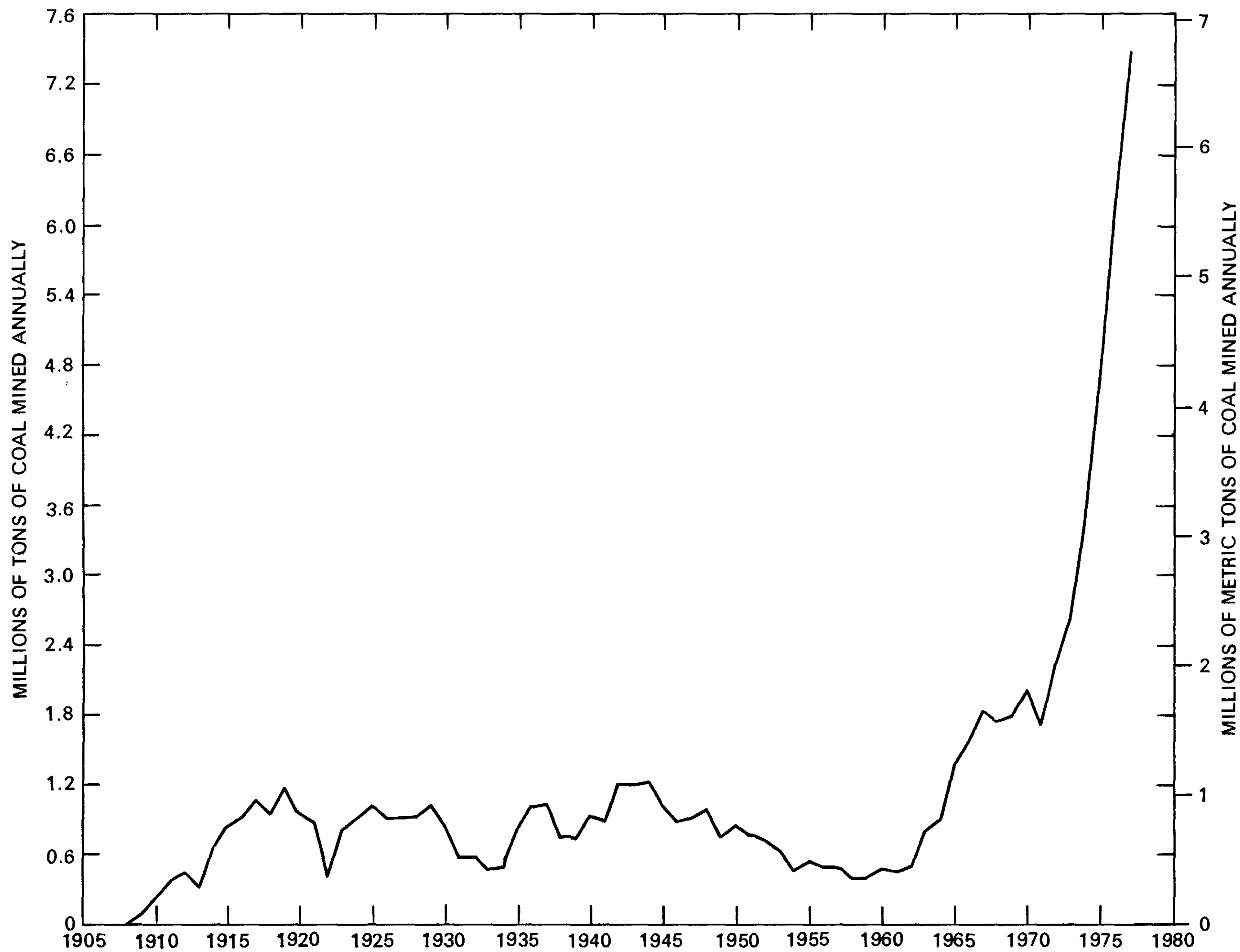


Figure 8.--Annual coal production, 1908–77.

At various times, more than 70 separate coal mines have been in operation in the Colorado part of the basin (Speltz, 1976). The annual coal production at 10-year intervals from 1908 through 1977 is given in table 3. Production values for mines in Moffat and Routt Counties which produced more than 100,000 tons (90,200 t) during their operations are listed separately. These mines have accounted for approximately 98 percent of the total coal production in the basin. Sites of major mining activity are located on figure 9 (Jones, 1976). The majority of mining has taken place in Routt County. This includes the Oak Creek area southwest of Steamboat Springs and both sides of the Yampa River between Milner and Hayden (fig. 9). Almost all of the coal production has been from coal seams in the Mesaverde Group (fig. 4). Present (1977) coal production in the Yampa River basin involves only 10 mines--8 surface mines and 2 underground mines. The two underground mines are small relative to the surface mines, accounting for only 6 percent of the total 1977 coal production. The Edna strip mine was the first mine in the basin to produce more than 1 million tons (0.9 million t) of coal in a single year (1973). A brief description of each of the active mines is given below.

The Edna mine (fig. 9) has been operated since 1961 by Pittsburg & Midway Coal Mining Co., a subsidiary of Gulf Oil Corp. The operation encompasses Federal, State, and private lands situated in the Oak Creek district about 4 mi (6 km) northwest of Oak Creek. This surface mine has been in existence since 1946 and is the oldest currently active mine in the basin. Mining is from the Lennox and Wadge coal seams in the middle coal group of the Williams Fork Formation. Annual production in 1977 was nearly 1.1 million tons (1.0 million t). Production is projected to remain fairly constant until after 1985. Present plans are to close this mine in 1991, unless proposed plans for underground operations are approved.

The Energy Strip Nos. 1, 2, and 3 mines (fig. 9) are situated on Federal and private lands in the Oak Creek district about 10 mi (16 km) northwest of Oak Creek. Energy Strip No. 1 started in 1962, No. 2 in 1972, and No. 3 in 1975, by Energy Fuels Corp. Mining at Energy Strip Nos. 1 and 3 is from the Wadge coal seam of the middle coal group, and mining at Energy Strip No. 2 is from the upper coal group of the Mesaverde Group. Annual production for 1977 was more than 3.0 million tons (2.8 million t) for Energy Strip No. 1, 0.42 million tons (0.38 million t) for Energy Strip No. 2, and 0.39 million tons (0.35 million t) for Energy Strip No. 3. The combined production of these three mines is projected to increase to a peak of about 4.5 million tons (4.1 million t) annually by 1980 and remain at this level during the following 10 years.

The Seneca Strip No. 2 mine (fig. 9) is operated by Peabody Coal Co. on Federal, State, and private lands located about 8 mi (13 km) southeast of Hayden. Mining began in 1964 at Seneca Strip No. 1 north of U.S. Highway 40 and shifted south to the present site, Seneca Strip No. 2, in 1968. Coal is mined from the Wadge seam in the middle coal group. The 1977 production was nearly 1.3 million tons (1.2 million t). The entire production is transported by truck to supply the Hayden Powerplant situated about 5 mi (8 km) northwest of the mine site (fig. 9). A second surface pit was opened in 1976

Table 3.--*Coal-mining production, Yampa River basin, Colo., 1908-77*

[All mining production is given in tons]

Mine name	1908-17	1918-27	1928-37	1938-47	1948-57	1958-67	1968-77	Mine total
				MOFFAT COUNTY				
Wisehill 1, 2, 3, 4, 5, 9-----	0	5,735	7,134	0	0	439,665	2,494,649	2,947,183
Red Wing---------------------	0	0	0	237,588	904,552	1,108,677	1,376,530	3,627,347
Mt. Streetor-----------------	0	0	3,991	104,343	0	0	0	108,334
Streetor 1, 2----------------	0	0	7,687	469,744	139,604	0	0	617,035
Williams Fork strip 1, 2, 3---	0	0	0	0	0	0	368,648	368,648
Utah International------------	0	0	0	0	0	0	345,948	345,948
Small mines-------------------	950	38,300	54,659	84,880	21,358	0	59,623	259,770
Period totals-----------	950	44,035	73,471	896,555	1,065,514	1,548,342	4,645,398	8,274,265
				ROUTT COUNTY				
Oak Hills 1, 2---------------	1,197,360	1,964,844	665,425	0	0	0	0	3,827,629
Pinnacle 1, 2, 3, 4-----------	1,040,298	1,169,617	1,067,275	1,223,336	85,051	0	0	4,585,577
Juniper and Federal-----------	342,418	0	0	0	0	0	0	342,418
Yampa Valley 1, 2, 3, 6-------	504,923	0	0	0	0	0	0	504,923
Harris------------------------	723,462	2,200,807	1,646,098	2,613,244	1,543,370	15,255	0	8,742,236
Bear River--------------------	114,297	487,786	529,821	60,558	0	0	0	1,192,462
Mac Gregor and McNeil---------	115,908	530,585	206,736	88,177	0	0	0	941,406
Hayden 1, 2, 3, 4-------------	87,626	760,916	1,241,425	1,224,469	399,117	0	0	3,713,553
Wolf Creek--------------------	47,398	200,155	0	0	0	0	0	247,553
Moffat 1, 2, and Jones--------	606,822	601,870	876,919	1,512,031	0	0	0	3,597,642
Routt Pinnacle 1, 2-----------	20,757	90,940	0	0	0	0	0	111,697
Wadge 1, 2--------------------	930	592,463	478,824	944,544	175,601	0	0	2,192,362
Ramsey 1, 2, and Babson-------	0	10,179	21,492	77,161	4,549	5,537	0	118,918
Keystone----------------------	0	38,069	536,595	986,750	712,656	38,038	0	2,312,108
Pinnacle-Kemmerer and Regal---	0	19,427	232,686	0	0	0	0	252,113
Moffat 3 and Arrowhead--------	0	0	27,075	116,658	277,989	0	0	421,722
Apex 1, 2---------------------	0	0	2,695	54,666	14,514	23,678	127,268	222,821
Crow Bar----------------------	0	0	0	117,148	259,189	10,065	0	386,402
Osage and Black Dan strip-----	0	0	0	41,926	1,421,113	847,617	0	2,310,656
Edna strip--------------------	0	0	0	291,001	1,543,956	3,784,688	8,774,006	14,393,651

Table 3.--*Coal-mining production, Yampa River basin, Colo., 1908-77*--Continued

Mine name	1908-17	1918-27	1928-37	1938-47	1948-57	1958-67	1968-77	Mine total
ROUTT COUNTY--Continued								
Cardinal	0	0	0	0	0	368,486	17,107	385,593
Energy strip 1	0	0	0	0	0	1,995,226	10,263,197	12,258,423
Seneca strip 1	0	0	0	0	0	1,487,602	217,916	1,705,518
Seneca strip 2	0	0	0	0	0	0	7,121,284	7,121,284
Energy strip 2	0	0	0	0	0	0	3,449,891	3,449,891
Energy strip 3	0	0	0	0	0	0	1,431,484	1,431,484
Small mines	150,389	270,700	173,714	321,756	112,950	25,774	71,169	1,126,452
Period totals	4,952,588	8,938,358	7,706,780	9,673,425	6,550,055	8,601,966	31,473,322	77,896,494

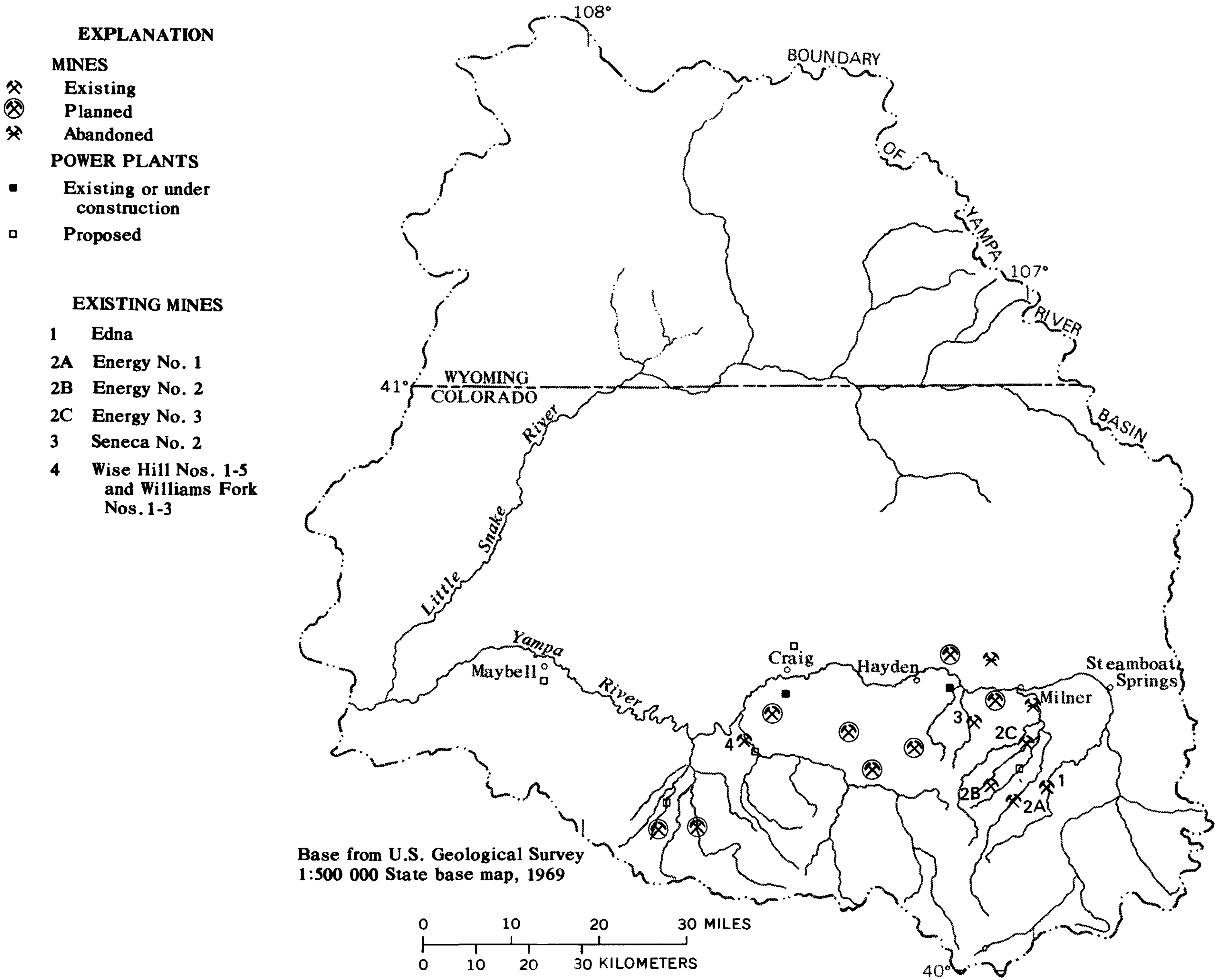


Figure 9.--Location of major c[illegible]l mines and coal–conversion facilities.

to accommodate the recent expansion (from 180 to 430 megawatts) of the Hayden Powerplant. The combined annual production of these two pits is projected to be about 1.5 million tons (1.4 million t), which would be required to meet the increased coal consumption of the Hayden Powerplant.

The Apex mine (table 3) is a relatively small underground mine which is operated by Routt Mining Corp. on Federal land located in the Oak Creek district about 5 mi (8 km) west of Oak Creek. Mining at this site began in 1932. Coal is mined from the lower coal group in the Iles Formation. The 1977 production of about 10,000 tons (9,400 t) was used primarily to supply the local domestic market for heating fuel.

The Wise Hill No. 5 mine (fig. 9) is an active underground mine owned by the Empire Energy Corp. It is located on Federal, State, and private lands about 8 mi (13 km) south of Craig. Mining at this site began in 1919; currently (1977), it is the major producing mine in Moffat County. Since Empire Energy Corp. acquired the mine in 1971, production has been steadily increasing with a current (1977) annual production of more than 0.44 million tons (0.40 million t). In February 1975, a new surface mine, Williams Fork Strip No. 1, was started northwest of the existing underground mine by Empire Energy Corp. Mining is from the upper coal group in the Williams Fork Formation. However, no production from this mine was reported in 1977.

All forecasts indicate that coal production within the Yampa River basin will continue to increase rapidly in the near future. The generally high British-thermal-unit rating and low sulfur content make the coal resources of the Yampa River basin economically desirable (p. 26). The large coal reserves present in the basin coupled with the central location of the Rocky Mountain region relative to markets in the west and midwest are further reasons why coal production in the Yampa River basin should increase markedly in the near future.

Speltz (1976) estimated the strippable coal resources of the Colorado part of the Yampa coal field to be approximately 951 million tons (863 million t). This estimate was based on a minimum coal thickness of 2 ft (0.6 m) and a maximum overburden thickness of 150 ft (46 m). However, this estimate is probably conservative, primarily because of the lack of detailed information on the coal beds of this region. Large parts of some areas planned for mining are not included in Speltz's calculations of strippable reserves; for example, most reserves of the proposed W. R. Grace mine southwest of Craig and much of the expanded Seneca mine south of Hayden are excluded (fig. 9). Also, no estimate of the strippable coal resources in the Wyoming part of the basin was included in Speltz's report.

Landis (1959) estimated 9.3 billion tons (8.4 billion t) of bituminous coal and an additional 19.3 billion tons (17.5 billion t) of inferred reserves in Moffat, Routt, and Rio Blanco Counties. Large reserves of subbituminous coal and lignite also were believed to be present in these counties.

Lands in the basin have been classified as having coal-resources potential, and other lands have been withdrawn pending future classification of coal-reserve potential (see p. 19). Almost the entire basin is underlain by coal reserves (fig. 7). However, coal deposits in the central part of the basin occur at depths too great to be mined with current technology and provide sufficient monetary return on the necessary capital investments. In the future when the easily accessible near-surface coal reserves are depleted by strip-mining techniques, a large part of the coal reserves in the basin may be mined using underground-mining techniques (U.S. Department of the Interior, 1976a, table RI-1, p. I-4).

Industry projections, based on coal-lease applications and letters of intent filed by companies, estimate coal-mining production within the basin to reach about 18.5 million tons (16.8 million t) per year by 1980, and 20.0 million tons (18.1 million t) per year by 1990 (adapted from U.S. Department of the Interior, 1976a, table RI-1, p. I-2). Through 1990, about 80 percent of this production will be strip mined. These estimates represent nearly a fivefold increase in the 1974 production of 3.7 million tons (3.4 million t) per year and are a threefold increase of the 1976 production (6.0 million tons or 5.4 million t). Present projections are subject to serious distortion because of several possible economic or technological factors. If a growth economy exists, then coal production almost certainly will exceed those projected. Also, the planned expansion of coal production in the basin reflects present demand for low-sulfur coal, primarily for use by coal-fired electric-power generating plants. Development of desulfurization methods or removal of sulfur compounds from stack emissions of powerplants could reduce the demand for low-sulfur coal. The extent to which alternative energy resources, such as nuclear power, are utilized regionally or nationally could cause either an increase or a decrease in coal-production projections (Federal Energy Administration, 1974).

Coal Utilization and Alternative Development Plans

In this section, the various anticipated alternatives of coal-resource development applicable to the Yampa River basin during the next 15 years are described. These alternatives are based on coal-production projections described in the Northwest Colorado Coal Environmental Statement (U.S. Department of the Interior, 1976a) and adjusted for those mines operating or proposed in the basin. Most of the anticipated coal-resource development will be taking place in areas south of the Yampa River between the towns of Steamboat Springs and Craig (fig. 9). Areas of existing and pending Federally leased coal are indicated in the Environmental Statement (U.S. Department of the Interior, 1976a, fig. RI-3, p. RI-7 and 8). A description of the range of alternatives with respect to mining, processing, energy conversion, and transportation is required in order to anticipate the ramifications of development in terms of residuals and water use. Residuals are noneconomic byproducts of a given industrial process or other economic activity which are discharged to the environment. The fate of residuals and the ability of the environment to assimilate them constitutes an integral part of any regional assessment (fig. 2).

Uncertainties of coal-production projections exist because of economic factors and the various Federal, State, and local regulations and Federal policy affecting rate of leasing and development (U.S. Department of the Interior, 1976a). Moreover, environmental-control measures may change in the future. Regional planners and resource managers have to cope with these uncertainties (see p. 121).

The majority of coal development in the Yampa River basin, at least during the next 15 years, is expected to be in the form of surface mining rather than underground mining (see p. 33). Factors affecting residuals in the environment resulting from coal-extraction alternatives include the following: (1) Depth of overburden; (2) physical and chemical properties of the overburden; (3) thickness of coal seams, including the number of seams in the section mined; (4) physical and chemical properties of the coal; (5) size of the operation, including number of working sections; and (6) types of equipment used. Some of the surface-mine operations will be using drag lines; others will be using shovels (for details, see U.S. Department of the Interior, 1976a). Residuals-management alternatives and water use in mining will vary with mining technique and required level of land reclamation (Keefer and Hadley, 1976).

The one existing major underground mine (table 3) operating in the Yampa River basin is the Wise Hill No. 5 mine southwest of the town of Craig. It is anticipated that other underground mines will be operating in the coming years (U.S. Department of the Interior, 1976a; Udis and others, 1977); however, most of these will produce less coal than surface mines. Mass- and energy-balance studies are being conducted by the U.S. Geological Survey using assumptions as to surface-mine size and quality characteristics of coal similar to the Williams Fork Formation coals (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976, chap. 3). Based on their analyses, the net energy-balance efficiency for a hypothetical mine site approaches 99 percent (that is, 100 times as much energy is produced as is consumed). Residuals generated from mining operations include the following: Waterborne sediment, windborne sediment (fugitive dust), various gaseous pollutants, scrap iron, and other equipment that deteriorates with use.

Water-use requirements related to coal mining primarily involve rehabilitation of disturbed lands. More than two orders of magnitude more water is used in mining if reclaimed lands require irrigation (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976, table 3-1). Presently, there is some question as to whether State or Federal mining regulations, or both, apply to coal mined from Federally owned leases. Indications are that the more stringent of the Federal and State requirements will apply. There is a time delay after processing overburden until revegetation of grasses and shrubs can take place. Case studies in which no reclamation has been attempted indicate that water use for surface mines is in the order of 1.5 gal (5.7 L) per ton of coal produced (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976). The bulk of this water is used for wetting of unpaved haul roads, and most of the water can be supplied from a small well or surface-water source. Depending on rehabilitation practices, larger amounts of water may be required after mining, particularly if any irrigation is needed. At a stringent level of reclamation with irrigation, an estimated 450 gal (1,700 L) per ton of coal produced would be used.

Various degrees of processing are required, depending upon the ultimate use of coal mined. Most of the processes described here reflect possible utilization for in-basin power generation using coal-fired steam-turbine plants or coal gasification. Coal of the Williams Fork Formation has a relatively high moisture content, averaging 11 percent by weight. This coal may have to be dried during crushing and pulverizing stages in preparation for either gasification or power generation. Coal transported by slurry pipeline may have to undergo other forms of processing. For example, in slurry pipelines, coal must be ground to a very fine particle size and mixed with water to form the slurry. Coal transported by rail generally requires a minimum of additional processing. Clean mining operations in the Yampa River basin do not require washing of coal (Energy Fuels Corp., written commun., 1976).

Realistic alternatives for conversion of coal resources in the Yampa River basin to other energy forms include electric-power generation coal-fired steam turbines, or possibly coal gasification. Proposed coal-gasification alternatives include several processes that provide various quantities and qualities of gases (Freudenthal and others, 1974). In this basin assessment, the residuals-management consequences of the SYNTHANE process are used as an example (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976). Each gasification plant is assumed to produce 250 million ft^3 (7.1 million m^3) of gas daily under standard conditions.

One electric-power-generation plant using coal-fired steam turbines is currently operating in the Yampa River basin near Hayden. A second unit was added to this plant in 1976, increasing total capacity to 430 megawatts. A second two-unit plant with a total capacity of 760 megawatts is being constructed near Craig, Colo. The total generating capacity of these two plants will be nearly 1,200 megawatts by 1979. Further expansions of both of these plants have been proposed, with a total generating capacity of nearly 2,200 megawatts by 1982 (U.S. Bureau of Mines and U.S. Environmental Protection Agency, 1975). In addition, an electric-power-generating facility (Oak Creek Power Co., 1976), comprised of as many as eight units of 800 megawatts each, has been proposed southwest of Steamboat Springs for utilizing as many as 24 million tons (22 million t) of coal annually (fig. 9). These size factors and facilities have been considered in formulating the various coal-development alternatives described later.

The quantities and forms of residuals generated from gasification and electric-power generation vary considerably. Details for standard-sized operations are described in some detail by I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas (written commun., 1976).

They also have developed preliminary figures regarding ranges of water-use requirements as functions of assumed processes and environmental controls, including levels of treatment required to meet environmental standards for air and water. Additional guidelines regarding water requirements are given in Freudenthal, Ricciardelli, and York (1974). According to the U.S. Geological Survey study (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976), capital costs invested in a standard-size coal-gasification plant (250 million ft^3 or 7.1 million m^3 per day) are slightly less than those for a 2,000-megawatt powerplant using coal-fired steam turbines for generating electricity. The various coal and water requirements are dependent upon assumptions regarding plant-loading factors (percent of time operating at capacity), efficiency of conversion, scale of the plants, cooling systems, and other factors. The environmental ramification of these will be studied in more detail in the second phase of this assessment.

The traditional mode of transportation of mined coal in the basin is by truck and rail. A report prepared by the Senate Interior Insular Affairs Committee in August 1974 suggests a significant role of coal-slurry pipelines in transporting western coal to energy markets. One proposal was to construct a slurry pipeline from northwest Colorado to a powerplant near Houston, Tex. (Freudenthal and others, 1974). Later modifications of this proposal included transporting the coal by rail from northwest Colorado to Walsenburg, Colo., south of Pueblo, and constructing a slurry pipeline from there to Texas (U.S. Bureau of Mines and U.S. Environmental Protection Agency, 1975).

Estimates for raw-water requirements for a slurry pipeline are about 1 ton (0.9 t) of water for each ton of coal transported. For a proposed slurry pipeline from Wyoming to Arkansas, water requirements range from 15,000 to 20,000 acre-ft (18.5 million to 25 million m^3) per year. The required quality of water for slurrying is not known; water containing less than 100 mg/L (milligrams per liter) of dissolved solids appears to be desirable; however, existing slurry pipelines have used water with higher concentrations of dissolved solids (Freudenthal and others, 1974). Manpower requirements for maintenance of a slurry pipeline are quite small; most operations require preparation of the coal for the slurry at the initial point of the pipeline and then processing at the end of the pipeline. Environmental impacts of slurry pipelines also may be relatively small. Water requirements need to be considered, however, as there is a net loss of water from the initial point (Palmer and others, 1977). Also, there is concern about treatment of liquid residuals (water extracted from slurry) at the terminal point.

The various components affecting coal-mining development alternatives in the Yampa River basin have been described above. These are depicted in a set of seven assumed coal-resource development alternatives for the base year 1975 and projected to the year 1990 (table 4). These substantially modify preliminary development alternatives reported by Steele (1976). The alternatives are based upon 1975 coal production of 4.6 million tons (4.2 million t) allocated between electric-power generation (1.5 million tons

Table 4.--*Coal-resource development alternatives, Yampa River basin, 1975-90*

[Modified from Udis, Adams, Hess, and Orr (1977). Development alternatives assume coal utilization for electric-power generation to average 3,500 tons per year per megawatt of generation capacity. In reality, coal utilization will be affected by such factors as plant efficiency, plant size, quality of the coal, and environmental controls imposed on residuals. The 1975 base reflects a 430-megawatt capacity at the Hayden Powerplant]

Type of growth and alternative[1]	Coal utilization, in millions of tons per year						
	1975		1980		1985		1990
Slow:							
7 Electric powerplants (760 megawatts)--	1.50	([2]1980)	4.20		4.20		4.20
Railroad exports----------------------	3.10		1.80		3.80		5.80
Total---------------------------	4.60		6.00		8.00		10.00
Moderate:							
1 Electric powerplants (760 megawatts)--	1.50	([2]1980)	4.20		4.20		4.20
Railroad exports----------------------	3.10		5.80		10.80		15.80
Total---------------------------	4.60		10.00		15.00		20.00
2 Electric powerplants (760 megawatts)--	1.50	([2]1980)	4.20		4.20		4.20
Coal gasification plants (250 million standard cubic feet each)-----------	0		0	([2]1985)	6.25	([2]1990)	12.50
Railroad exports----------------------	3.10		5.80		6.60		3.30
Total---------------------------	4.60		10.00		17.05		20.00
3 Electric powerplants (760 megawatts) (1,200 megawatts).	1.50	([2]1980)	4.20	([2]1982)	8.40		8.40
Railroad exports----------------------	3.10		5.80		6.60		11.60
Total---------------------------	4.60		10.00		15.00		20.00
4 Electric powerplants (760 megawatts) (1,200 megawatts).	1.50	([2]1980)	4.20	([2]1982)	8.40		8.40
Slurry pipeline-----------------------	0		0		0	([2]1989)	10.00
Railroad exports----------------------	3.10		7.80		6.60		1.60
Total---------------------------	4.60		12.00		15.00		20.00
Rapid:							
5 Electric powerplants (760 megawatts) (2,800 megawatts) (4,800 megawatts).	1.50	([2]1980)	4.20	([2]1985)	14.00	([2]1990)	30.80
Railroad exports----------------------	3.10		7.80		10.00		0
Total---------------------------	4.60		12.00		24.00		30.80
6 Electric powerplants (760 megawatts) (1,200 megawatts) (3,200 megawatts).	1.50	([2]1980)	4.20	([2]1985)	8.40	([2]1990)	19.60
Coal gasification plant (250 million standard cubic feet)----------------	0		0	([2]1985)	6.25		6.25
Railroad exports----------------------	3.10		7.80		9.35		4.95
Total---------------------------	4.60		12.00		24.00		30.80

[1]Sequence code as given in Udis, Adams, Hess, and Orr (1977).
[2]Year in which additional capacity becomes fully operational.

or 1.4 million t) and the remainder primarily for out-of-basin transport by railroad. The coal allocation for electric-power generation assumes full operations for the first two units of the Hayden Powerplant of 430 megawatts, which actually did not take place until mid-1976 (Robert M. Heard, oral commun., 1976). The four moderate-growth alternatives (1-4, table 4) assume a maximum coal production of 20 million tons (18 million t) per year by 1990 as adapted from projections by the U.S. Department of the Interior (1976a). The other three alternatives (5-7, table 4) reflect a 50-percent uncertainty in this assumed projection of 1990 coal production. Economic aspects of each of these seven alternative plans were analyzed by Udis, Adams, Hess, and Orr (1977); interim conditions for 1980 and 1985 also were included in this analysis.

A primary consideration in the construction of table 4 was satisfaction of the demand by power-generation plants using coal-fired steam turbines, because this currently is the major use of coal in the basin. The first two moderate-growth alternatives (table 4) utilize the power-generation capacity by coal-fired steam turbines in existence or under construction. These would include the Hayden and Craig powerplants (fig. 9). Various uses of the remaining coal produced are then allocated to transportation out of the basin by rail or slurry pipeline, and coal gasification. In the third and fourth moderate-growth alternatives, plans for the proposed expansions of the Hayden and Craig powerplants, doubling the capacity that is existing or under construction, are assumed to be implemented, with the remaining coal production being utilized as cited in the table. The fifth and sixth rapid-growth alternatives assume that part or all of the Oak Creek electric-power generation facility might be constructed by 1990. These alternatives assume a 1990 coal-production rate of more than 30 million tons (27 million t) and would leave sufficient coal for only one coal-gasification plant for alternative six, with the remainder being transported out of the basin. A seventh slow-growth alternative depicts a lower than projected rate of development (table 4). Uncertainties regarding the rate of Federal coal leases will affect the extent to which the alternatives described herein are realistic for determining the range of water-resources impacts.

Using this basic set of coal-development alternatives in the Yampa River basin (table 4), specific studies are being conducted to design methods to deal with residuals generated from each of these alternatives. Interactions among economic and environmental-control factors, water use, and demand for various forms of energy are considered in these analyses. Interim staging of construction of facilities was assumed in several of the development alternatives (table 4). This was necessary to assess short-term fluctuations in construction, related employment, and the associated water-resources impacts (Udis and others, 1977).

EVALUATION OF THE BASIN'S EXISTING WATER RESOURCES

Generally, water availability in the Yampa River basin is abundant compared with other areas of the western slope of the southern Rocky

Mountains. To date, water-resources development primarily has utilized surface-water supplies. Most stream-diversion structures deliver water through a simple network of irrigation ditches for flooding grasslands and hay meadows during the summer months. Due to the short growing season in the basin, higher valued crops, such as corn, generally are not grown in the basin. Numerous streams are impounded by earthfill dams to provide water for stock, irrigation, municipal-water supplies, and powerplant cooling. To date, these structures have barely altered the high-flow pattern from spring snowmelt runoff in the Yampa River main-stem and tributary streams. However, the seasonal pattern of streamflow may be altered appreciably by construction of several major reservoirs which have been proposed for the basin.

Recharge to major aquifer systems occurs in the basin. As water demands increase and surface-water supplies are used fully, greater utilization of potential ground-water resources of the basin may be considered.

Climatic Conditions

The climate varies from the arid desert of the lower western part of the basin to the cold moist alpine zones along the Continental Divide to the east (fig. 1). These extremes result from the wide variations in altitude and exposure. The eastern boundary of the basin reaches altitudes of more than 12,400 ft (3,780 m) above sea level; whereas, the valley floor at the confluence of the Yampa River with the Green River in Dinosaur National Monument is at an altitude of about 5,000 ft (1,520 m). The mean annual air temperature at Steamboat Springs is 4°C, with extremes of 37° to -48°C. In both Craig and Dixon, the mean annual air temperature is 6°C, with extremes of 38° to -42°C at Craig and 36° to -46°C at Dixon. Irrigated lands near Yampa and Steamboat Springs have an average annual growing season (period of year with mean air temperatures above 2°C) of 102 days and areas near Craig average 125 days (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). Seasonal variations of air temperatures at Craig, Hayden, and Steamboat Springs are depicted in figure 10.

Gages for measuring total precipitation have been operated at more than 15 locations throughout the basin. The 15 longer-record precipitation stations are plotted on figure 11. Records for most sites have been published by the U.S. National Weather Service and predecessor agencies. Average annual precipitation ranges from more than 50 inches (1,300 mm) along the Continental Divide, to less than 9 inches (230 mm) in the western, arid areas. Areal variations in average annual precipitation for the basin are shown on figure 11 (adapted from Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). The majority of precipitation falls on the basin during November-April in the form of snow. Total annual snowfall averages 164 inches (4,170 mm) at Steamboat Springs and 101 inches (2,560 mm) at Yampa, while Echo Park in Dinosaur National Monument receives approximately 30 inches (760 mm) of snow annually (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). Seasonal distributions of snowfall at Steamboat Springs and Yampa are given as examples in figure 12.

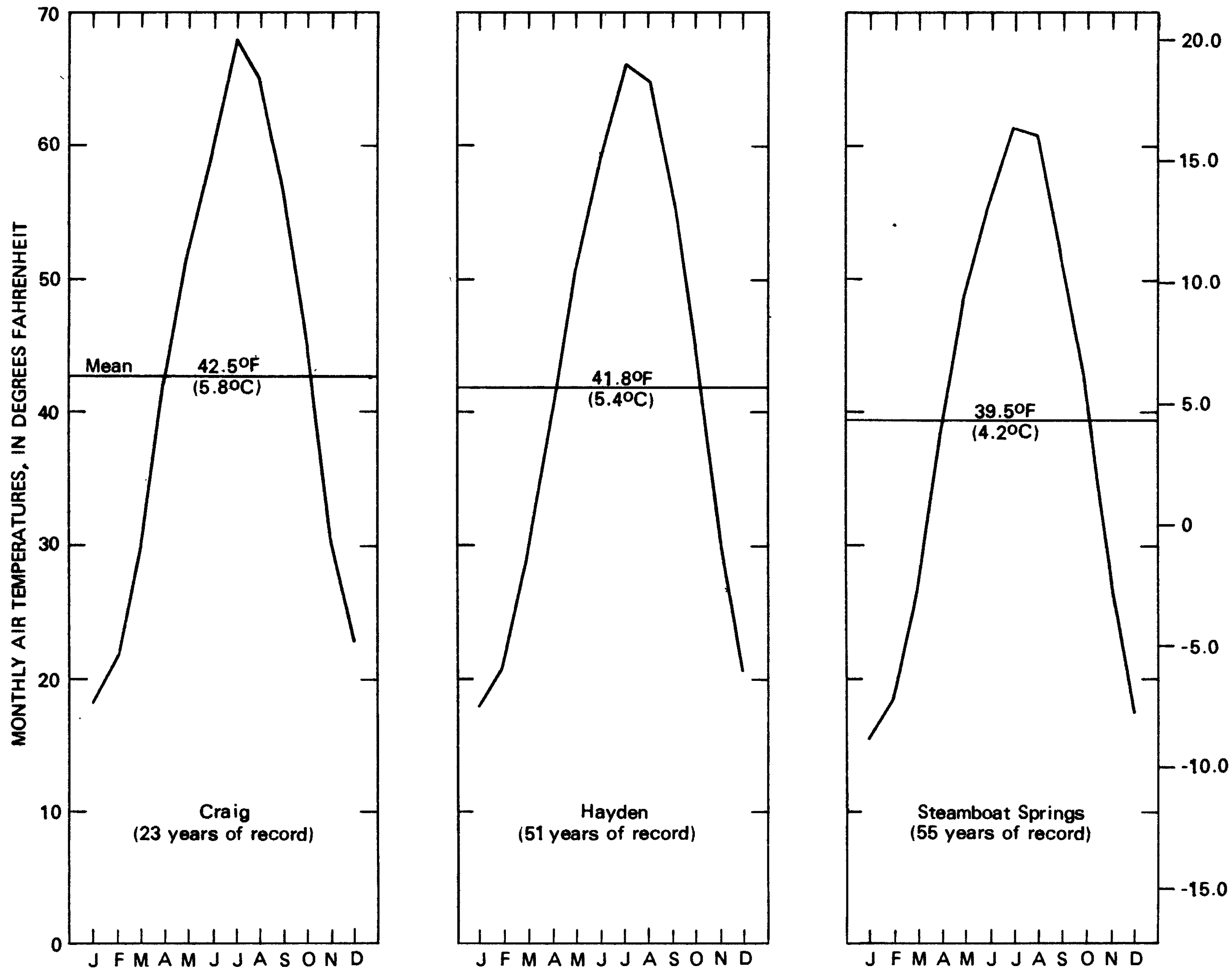
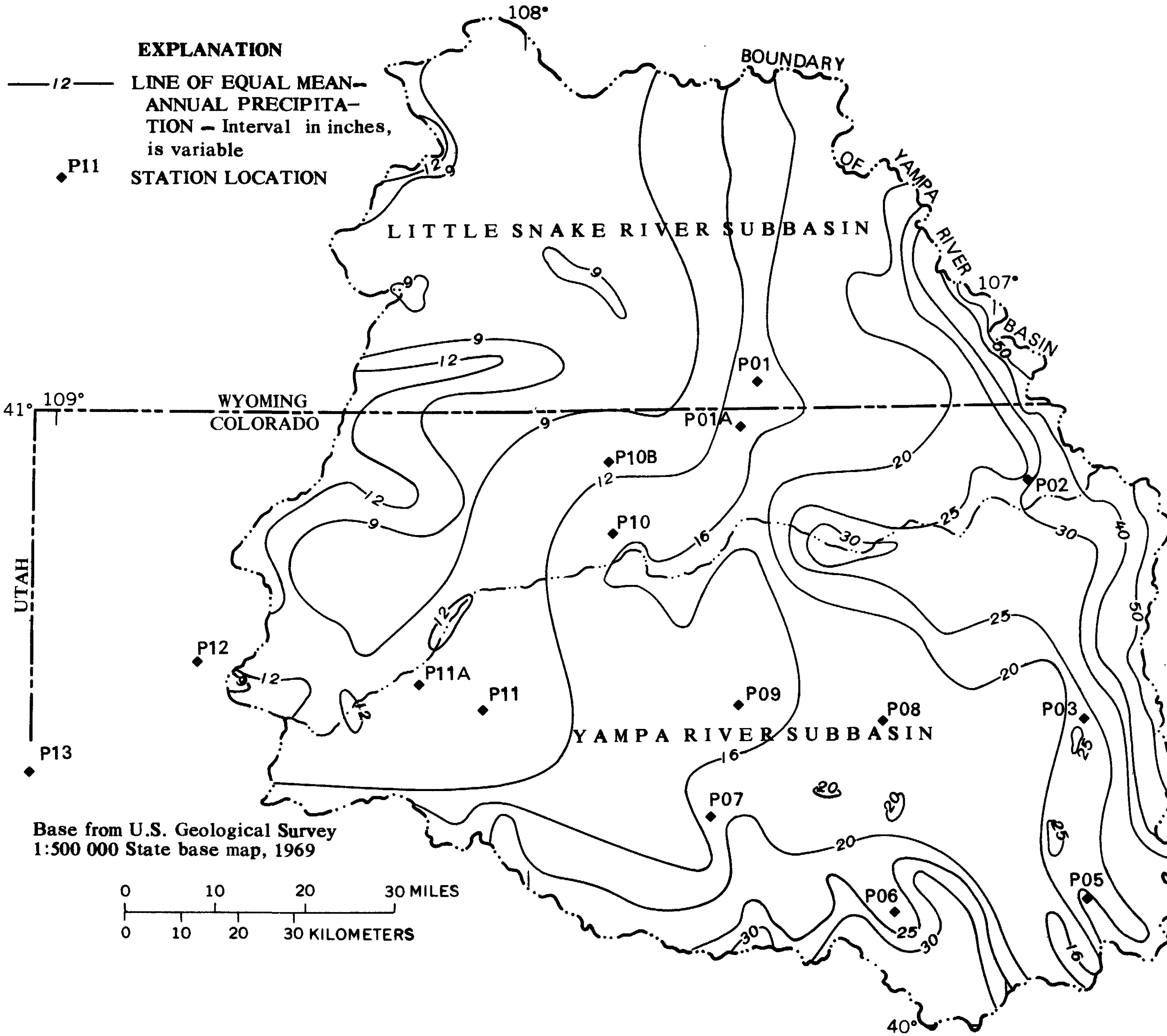


Figure 10.--Seasonal distribution of monthly mean air temperatures at Craig, Hayden, and Steamboat Springs, Colo.



STATION LOCATIONS

Number	Station name
P01	Dixon
P01A	Willow Creek 4 SE
P02	Columbine
P03	Steamboat Springs
P04	Rabbit Ears Pass
P05	Yampa
P06	Pyramid
P07	Hamilton
P08	Hayden
P09	Craig
P10	Great Divide 8 SE
P10B	Ferndale Ranch
P11	Maybell
P11A	Sunbeam 7 SW
P12	Greystone
P13	Dinosaur National Monument

Figure 11.--Mean-annual precipitation and location of measurement stations.

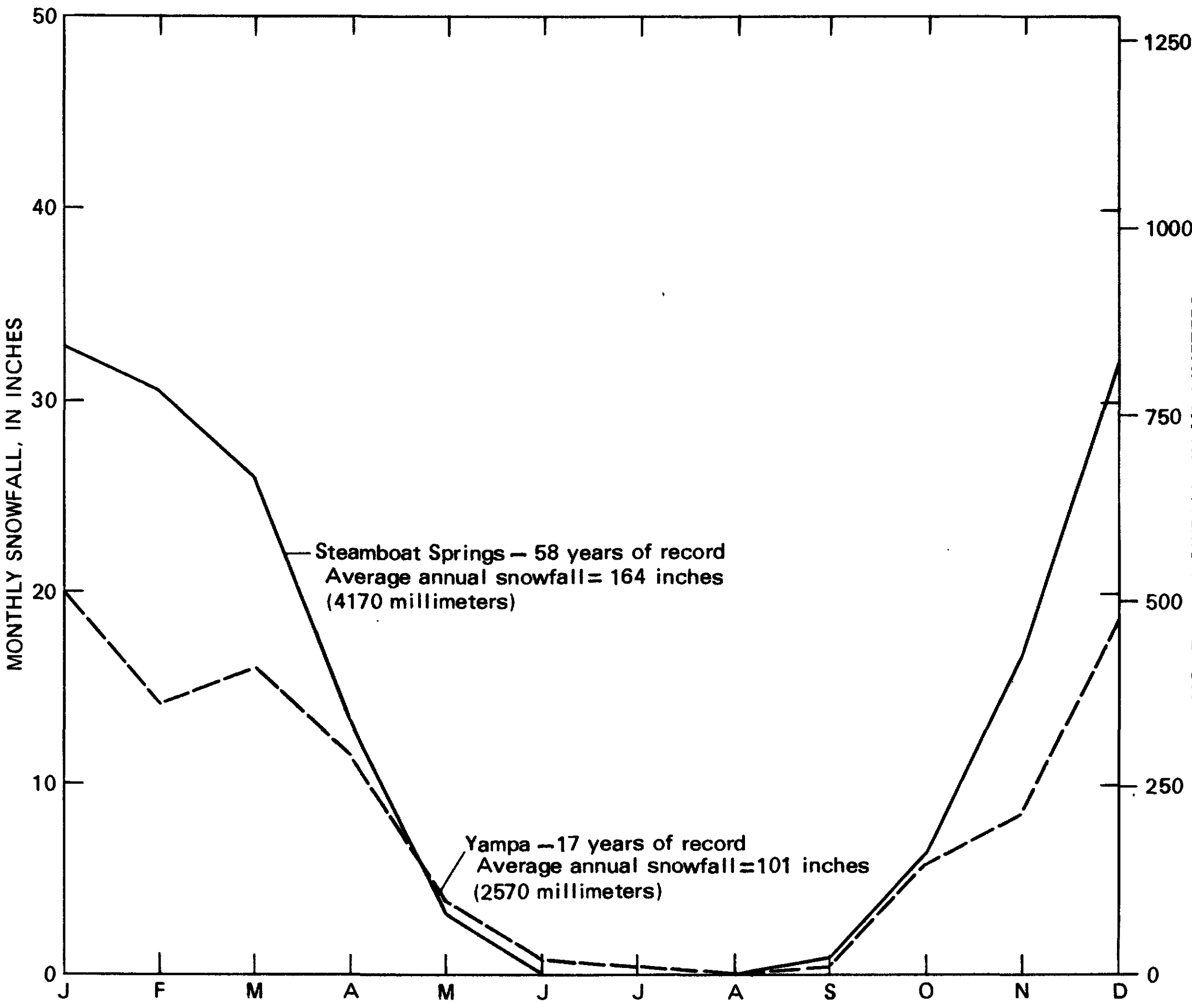


Figure 12.--Seasonal distribution of monthly mean snowfall, Steamboat Springs and Yampa, Colo.

Seasonal variations of monthly total precipitation (rain and snow) are indicated in figure 13 for six stations with long-term records in the basin. Steamboat Springs receives nearly one-half of its precipitation as snow during December through April; whereas, Craig receives more than one-third of its annual average precipitation in the form of snow during the same period. Winter snow accumulation serves as the principal source of streamflow.

More than one-third of the total precipitation at Craig occurs during the peak growing season (July and August); whereas, Steamboat Springs receives little more than one-fifth of its total amount during the same period. Summer precipitation throughout the basin generally takes the form of showers which contribute little to the overall water availability. In the mountainous areas, summer precipitation occurs typically as thundershowers, with only localized areas receiving significant amounts. At lower altitudes, summer showers frequently occur as thunderstorms. Evaporation losses from existing small ponds and reservoirs range from 17 to 20 inches (430 to 510 mm) per year, with the higher values applicable in the western part of the basin.

Surface Water

The Yampa River basin consists of two principal subbasins, the Little Snake River subbasin and the Yampa River subbasin (fig. 1). Using more than 50 years of daily-streamflow records, the long-term estimated average annual flow from the entire basin is slightly more than 1.5 million acre-ft (1.8 billion m^3). The Yampa River subbasin contributes about 1.1 million acre-ft (1.4 billion m^3) and the Little Snake River subbasin contributes about 0.4 million acre-ft (0.5 billion m^3) (updated from Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). These average flow estimates are based on long-term periods of streamflow records for two active stream-gaging stations: Yampa River at Maybell, Colo. (1917-77 water years), and the Little Snake River near Lily, Colo. (1922-77 water years) (fig. 14).

Most of the streamflow from the two subbasins results from snowmelt runoff in the spring. On the average, about 65 percent of the annual flow occurs in the months of May and June. Major tributaries of the Yampa and the Little Snake Rivers originate in the Park Range along the Continental Divide (figs. 1 and 3). The headwaters of the Yampa River are at an altitude of about 9,800 ft (2,990 m), while the headwaters of the Little Snake River are at an altitude of about 9,100 ft (2,770 m). The drainage areas of the two subbasins are approximately equal--3,410 mi^2 (8,830 km^2) for the Yampa River and 3,730 mi^2 (9,660 km^2) for the Little Snake River. As shown by the average flow values stated above, the average annual streamflow for the Little Snake River is about one-third that for the Yampa River; this difference for nearly equivalent drainage areas is due largely to greater total precipitation amounts (fig. 11), resulting in greater runoff from the Yampa River subbasin.

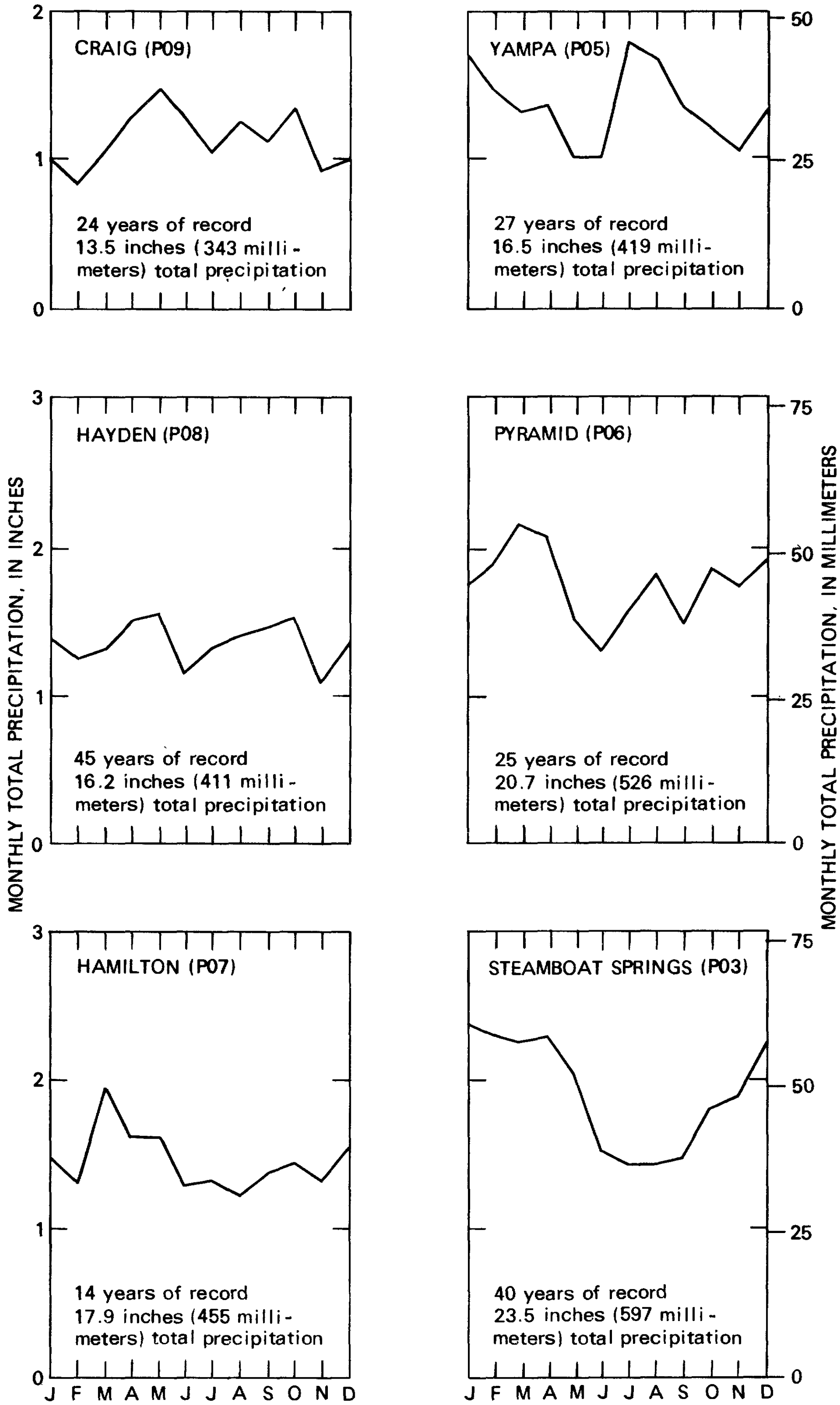


Figure 13.--Seasonal distribution of monthly total precipitation.

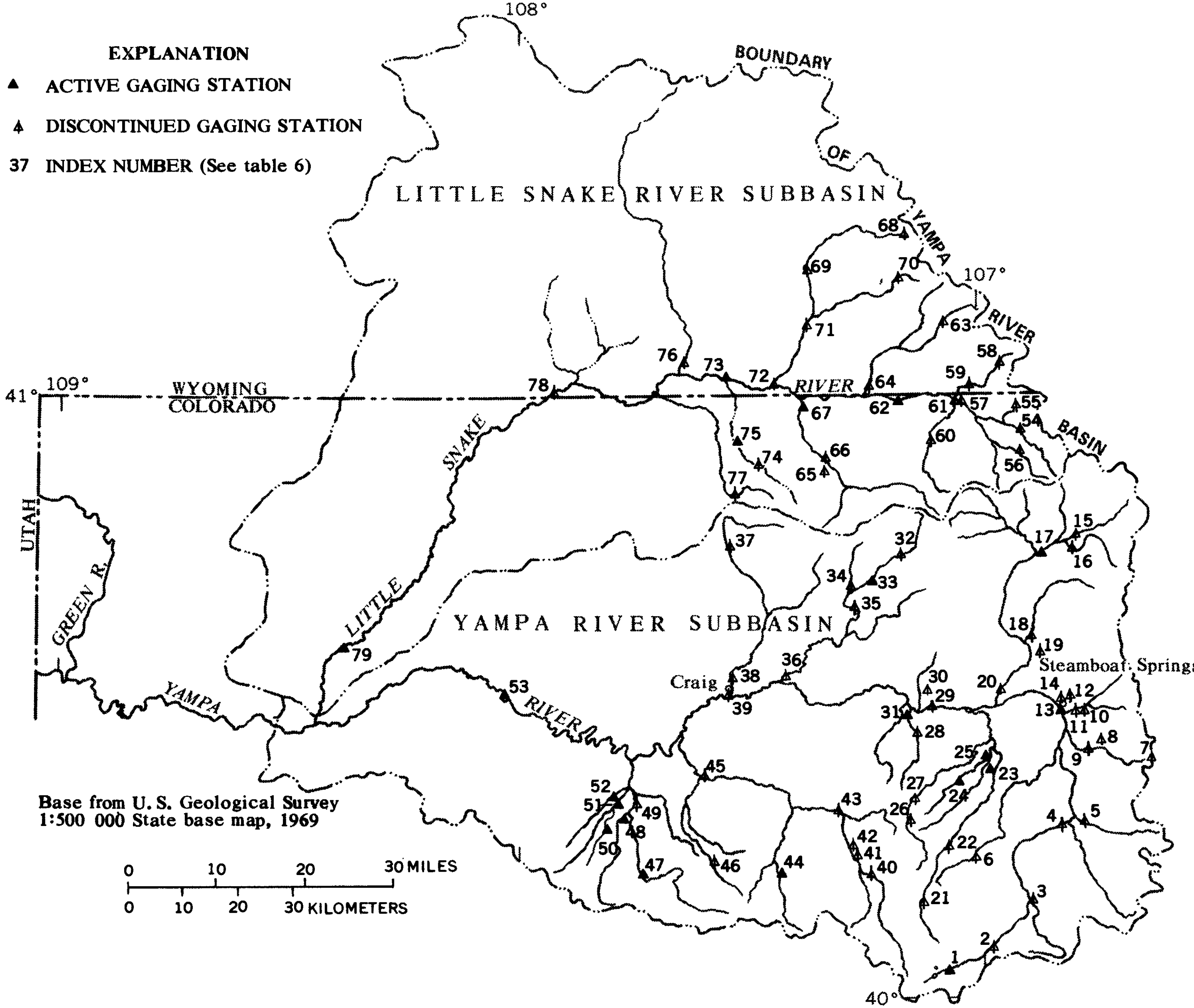


Figure 14.--Location of surface-water gaging stations, Yampa River basin.

The larger reservoirs (storage capacity more than 100 acre-ft or 120 thousand m^3) and lakes in the basin are listed in table 5. The reservoirs individually have relatively small storage capacities, the aggregate total exceeding 54,000 acre-ft (67 million m^3). Because the mean outflow of surface water from the basin is approximately 1.5 million acre-ft (1.8 billion m^3), which is 28 times the total existing aggregate storage, the existing reservoirs and lakes have had little effect on changing the seasonal high-flow pattern of flow of the basin. However, with the addition of the many proposed larger reservoirs (see p. 105), pronounced changes in downstream-flow characteristics may occur, depending on the water uses, timing of reservoir releases, and interaction of reservoir operations.

Table 5.--*Existing reservoirs and capacities Yampa River basin, 1977*

[Use: I, irrigation; P, fishery; R, recreation; O, other]

Name	Stream	Use	Storage capacity[1] (acre-ft)	Location
Steamboat Lake (Upper Willow Creek Reservoir).	Willow Creek	P,R,I	23,060	NWNE32-10N-85W
Stillwater Reservoir--------	Bear River	P,R,I	6,390	NWSE26- 1N-87W
Pearl Lake (Lester Creek Reservoir).	Lester Creek	P,O	5,660	NESW 2- 9N-85W
Elkhead Creek Reservoir----	Elkhead Creek	R,P	5,390	SWSE16- 7N-89W
Three reservoirs (capacity of each between 1,000 and 1,200 acre-ft).	---	---	3,350	----
Twenty-four reservoirs (capacities of each between 100 and 1,000 acre-ft).	---	---	10,210	----
Total existing reservoir capacity----------			54,060	

[1]Based upon water-rights data, Colorado State Engineer's Office.

In the Yampa River basin, the U.S. Geological Survey has operated a network of 79 streamflow-gaging stations (fig. 14) for varying time periods, beginning in 1901; however, only 20 stations in the basin were operated during the 1977 water year. The period of record and availability of data in computer storage for each station is summarized in table 6. Currently (1978), the aggregate number of complete water years of daily streamflow records for the basin available in U.S. Geological Survey computer files is 853 years for 54 stations (table 6), giving an approximate average available record of nearly 16 years per station. Approximately 124 additional station years of complete record have been collected at 34 stations but are not

Table 6.--*Available stream-discharge records, Yampa River basin*

Code[1]	Map location	Station number	Station name	State	Water temperature (in degrees Celsius)[2]	Drainage area (square miles)	Number years record	Daily values file period	Surface-water matrix number[3]
Y-76	1	09236000	Bear River near Toponas	CO	T	23.0	24	1953-65, 1967-77	10
	2	09236500	Yampa River near Yampa	CO		39.9			
	3	09237000	Yampa River at Yampa	CO		52.0			
	4	09237500	Yampa River near Oak Creek	CO	T	227	21	1940-44, 1957-72	7
	5	09237800	Service Creek near Oak Creek	CO	T	38.2	8	1966-73	29
Y-70	6	09238000	Oak Creek near Oak Creek	CO		14.0			
Y-65	7	09238300	North Fork Walton Creek near Rabbit Ears Pass	CO	T	.71	3	1973-75	
	8	09238350	Fishhook Creek near Rabbit Ears Pass	CO	T	6.45	3	1973-75	
	9	09238500	Walton Creek near Steamboat Springs	CO	T	42.4	8	1966-73	30
	10	09238900	Fish Creek at upper station, near Steamboat Springs	CO	T	25.8	6	1967-72	
	11	09239000	Fish Creek near Steamboat Springs	CO		26.0			
	12	09239400	Spring Creek near Steamboat Springs	CO	T	6.96	7	1966-72	33
Y-64	13	09239500	Yampa River at Steamboat Springs	CO	T	604	70	1905-06, 1910-77	1
	14	09240000	Soda Creek at Steamboat Springs	CO		47.0			
	15	09240500	Elk River at Hinman Park	CO		61.0	7	1912-18	
	16	09240800	South Fork Elk River near Clark	CO	T	33.7	7	1967-73	
Y-59	17	09241000	Elk River at Clark	CO	T	206	59	1911-22, 1931-77	3
	18	09241500	Big Creek near Steamboat Springs	CO		41.0			
	19	09242000	Mad Creek near Steamboat Springs	CO		40.0			
Y-58	20	09242500	Elk River near Trull	CO		415	20	1905-06, 1910-27	14
Y-57	21	09243000	Trout Creek near Phippsburg	CO		16.0			
	22	09243500	Trout Creek at Pinnacle	CO		27.0			
Y-55	23	09243700	Middle Creek near Oak Creek	CO		23.5	2	1976-77	
Y-54	24	09243800	Foidel Creek near Oak Creek	CO		8.61	2	1976-77	
Y-53	25	09243900	Foidel Creek at mouth, near Oak Creek	CO		17.5	2	1976-77	
	26	09244000	Fish Creek at Dunkley	CO		29.0			
Y-52	27	09244100	Fish Creek near Milner	CO	T	34.5	18	1956-73	17
Y-48	28	09244300	Grassy Creek near Mount Harris	CO	T	25.8	8	1959-66	
	29	09244400	Yampa River near Hayden	CO	T	1,430	7	1966-72	[4]31
	30	09244405	Gibraltar Canal near Hayden	CO	T		3	1971-73	

Table 6.--*Available stream-discharge records, Yampa River basin*--Continued

Code[1]	Map location	Station number	Station name	State	Water temperature (in degrees Celsius)[2]	Drainage area (square miles)	Number years record	Daily values file period	Surface-water matrix number[3]
Y-47	31	09244410	Yampa River below diversion, near Hayden	CO	T	1,430	7	1971-77	31
	32	09244500	Elkhead Creek near Clark	CO	T	45.4	16	1944, 1959-73	19
Y-43	33	09245000	Elkhead Creek near Elkhead	CO	T	64.2	24	1954-77	11
Y-42B	34	09245500	North Fork Elkhead Creek near Elkhead	CO	T	21.0	15	1959-73	21
	35	09246000	Elkhead Creek near Hayden	CO		97.4			
Y-42	36	09246500	Elkhead Creek near Craig	CO		249	9	1910-18	23
	37	09246900	Fortification Creek near Craig	CO		34.3			
	38	09247000	Fortification Creek at Craig	CO		258	13	1910-18, 1944-47	22
Y-39	39	09247500	Yampa River at Craig	CO		1,730			[5]36
	40	09248000	East Fork Williams Fork near Pyramid	CO		68.0			
	41	09248500	East Fork Williams Fork near Willow Creek	CO		96.0			
	42	09248600	East Fork Williams Fork above Willow Creek	CO	T	108	16	1957-72	20
Y-37	43	09249000	East Fork Williams Fork near Pagoda	CO	T	150	18	1954-71	18
Y-35	44	09249200	South Fork Williams Fork near Pagoda	CO	T	46.7	12	1966-77	24
	45	09249500	Williams Fork at Hamilton	CO		341	20	1905-06, 1910-27	15
	46	09249700	Morapos Creek near Hamilton	CO		13.7	2	1966-67	
Y-28	47	09250000	Milk Creek near Thornburgh	CO	T	65.0	25	1953-77	12
Y-27	48	09250400	Good Springs Creek at Axial	CO		35.0	3	1975-77	
	49	09250500	Milk Creek near Axial	CO		135			
Y-24	50	09250510	Taylor Creek at mouth, near Axial	CO		7.22	2	1976-77	
Y-23	51	09250600	Wilson Creek near Axial	CO		22.0	3	1975-77	
Y-22	52	09250610	Jubb Creek near Axial	CO		7.53	2	1976-77	
Y-17	53	09251000	Yampa River near Maybell	CO	T	3,410	61	1917-77	2
	54	09251200	Middle Fork Little Snake River near Columbine	CO		26.7			
	55	09251300	Whiskey Creek near Columbine	CO		13.3			
	56	09251400	King Solomon Creek near Columbine	CO		15.0			
	57	09251500	Middle Fork Little Snake River near Battle Creek	CO		120	10	1913-22	25
	58	09251800	North Fork Little Snake River near Encampment	WY	T	9.64	9	1957-65	26

Table 6.--*Available stream-discharge records, Yampa River basin*--Continued

Code[1]	Map location	Station number	Station name	State	Water temperature (in degrees Celsius)[2]	Drainage area (square miles)	Number years record	Daily values file period	Surface-water matrix number[3]
	59	09251900	North Fork Little Snake River near Slater	CO	T	29.3	7	1957-63	34
	60	09252000	South Fork Little Snake River at Flemings	CO					
	61	09252500	South Fork Little Snake River near Battle Creek	CO		46.0	8	1913-20	27
Y-12	62	09253000	Little Snake River near Slater	CO	T	285	32	1943-47, 1951-77	8
	63	09253400	Battle Creek near Encampment	WY	T	12.8	7	1957-63	35
Y-11A	64	09253500	Battle Creek near Slater	CO		83.5			
	65	09254000	Roaring Fork of Slater Fork near Baxter Ranch near Slater	CO					
	66	09254500	Slater Fork at Baxter Ranch near Slater	CO		80.0	8	1913-20	28
Y-11	67	09255000	Slater Fork near Slater	CO	T	161	46	1932-77	6
	68	09255400	East Fork Savery Creek near Encampment	WY		7.91	2	1957-58	
Y-10A	69	09255500	Savery Creek at upper station near Savery	WY	T	200	20	1941, 1953-71	16
	70	09255900	Big Sandstone Creek near Savery	WY		10.3	2	1957-58	
Y-10	71	09256000	Savery Creek near Savery	WY	T	330	29	1942-46, 1948-71	9
Y-9	72	09256500	Savery Creek at Savery	WY		354	4	1919-22	
Y-8	73	09257000	Little Snake River near Dixon	WY	T	988	[6]46	[6]1911-23, 1939-71	5
	74	09257500	Willow Creek near Baggs	WY		5.00			
Y-7	75	09258000	Willow Creek near Dixon	WY	T	24.0	24	1954-77	13
Y-5	76	09259000	Muddy Creek near Baggs	WY		1,178			
	77	09259500	Fourmile Creek near Baggs	WY		4.00			
Y-2	78	09259700	Little Snake River near Baggs	WY	T	3,020	7	1962-68	32
Y-1	79	09260000	Little Snake River near Lily	CO	T	3,730	56	1922-77	4

[1]Y code designation is for those surface-water gaging stations included in a basinwide water-quality reconnaissance (Steele and others, 1976a, table 2).

[2]T=those station locations having intermittent temperature measurements.

[3]Surface-water matrix number-order designation of those station records used in the surface-water correlation-matrix analysis (A. W. Burns, written commun., 1976).

[4]1966-70 water-year records for 09244400 adjusted and merged with 09244410 for surface-water matrix and temperature analysis.

[5]Data records have been published but have not been entered into the computer file.

[6]Since 1971, records published only for 6-month period from April through September.

included in the computer files. The periods of record during which the streamflow data were collected in the Yampa River basin vary considerably since 1902; however, the most common time base is from 1950 to 1973.

Records for 36 of the 54 stations in the computer file plus one additional record (table 6) were utilized to generate a streamflow matrix at 36 flow points in the Yampa River system for a 67-year period (1910-76 water years). The records for the Yampa River near Hayden (station 09244400) for the 1966-70 water years were adjusted to take into account an upstream diversion and to be compatible with the records for station 09244410 (table 6). The combined records were then used in modeling studies of reservoirs and stream salinity (Steele and others, 1977; D. B. Adams, D. P. Bauer, R. H. Dale, and T. D. Steele, written commun., 1978).

The year-to-year variability of flows from the Yampa River basin, based upon records at the two downstream gaging stations for the two subbasins (index numbers 53 and 79, fig. 14), is depicted in figure 15. Due to the relatively undeveloped state of the stream system, historical annual flows have varied widely, from 448 thousand acre-ft (552 million m^3) in 1977 to more than 2.9 million acre-ft (nearly 3.6 billion m^3) in 1929.

The areal variation of selected streamflow characteristics is indicated in table 7 for 19 selected main-stem and tributary sites in the Yampa River basin. These sites were selected at various geographic locations to represent a range of climatic conditions. Several locations include effects of irrigation on the streamflow characteristics. Streams in the eastern part of the basin draining high-altitude areas yield relatively high flows per unit area (table 7).

The mean annual flow per unit of drainage area (table 7) varies considerably among the given locations. The largest values occur at the higher altitude stations in the Yampa River subbasin indicated by the first through third, and fifth entries in table 7. These areas receive the largest precipitation amounts occurring in the Yampa River basin (fig. 11). The smaller values of unit-area flows occur generally in streams of the Little Snake River subbasin and of the lower parts of the Yampa River subbasin. Station 09244300, Grassy Creek near Mount Harris, has the smallest mean annual flow per unit area, 0.05 $(ft^3/s)/mi^2$ [5.47×10^{-4} $(m^3/s)/km^2$] (table 7); however, little irrigation takes place that would affect flows in this drainage area. The smaller flow value per unit area could be the result of a very permeable soil type in this drainage area. The 7-day, 10-year ($Q_{7,10}$) recurrence-interval flow characteristics (table 7) varied considerably for the 19 stations. These values were computed using annual series data for the period of record available at each site (table 6). Flow-measurement sites that were located in drainage areas less than 10 mi^2 (26 km^2) had a fairly consistent correlation of $Q_{7,10}$ values with drainage area (Tuthill, 1975).

Monthly mean flows are shown for 19 selected stream-gaging stations in table 8. The seasonal variation of flows is fairly consistent at the 19 locations with the largest streamflow amounts occurring from April through June of each year; this pattern in seasonal flows is due primarily to the

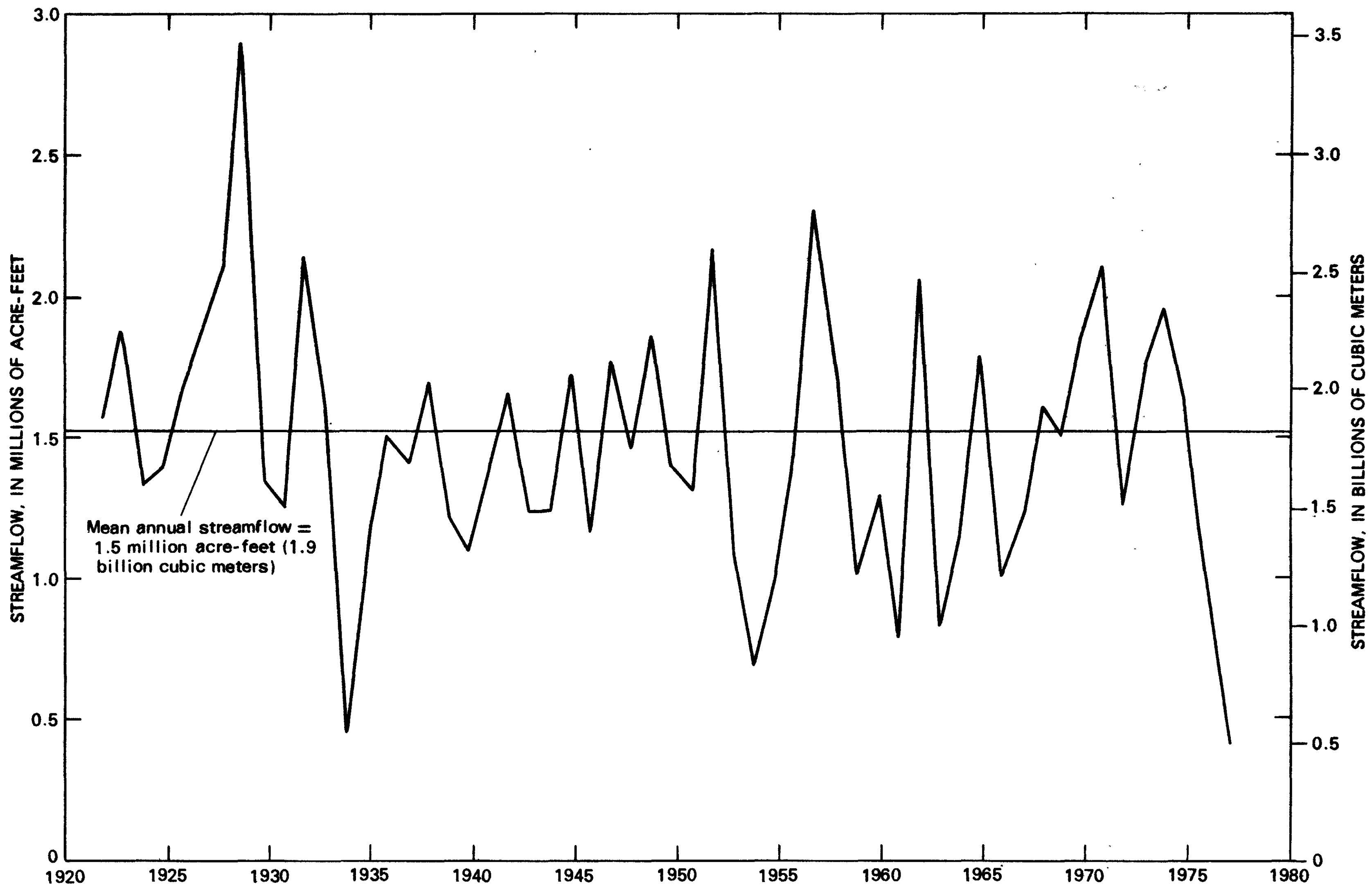


Figure 15.--Annual streamflows from the Yampa River basin, 1922–77 (streamflows depict sum of flows at stations 09251000 and 09260000).

Table 7.--*Streamflow characteristics at selected stream-gaging stations, Yampa River basin*

[Based upon available records through the 1976 water year]

Map code[1]	Station number	Station name	Mean annual flow per square mile (cubic feet per second per square mile)	7-day 10-year low flow (cubic feet per second)	1-day 50-year high flow (cubic feet per second)
5	09237800	Service Creek near Oak Creek, Colo	1.18	2.37	810
8	09238500	Walton Creek near Steamboat Springs, Colo	1.90	6.03	1,280
12	09239400	Spring Creek near Steamboat Springs, Colo	1.36	.09	124
13	09239500	Yampa River at Steamboat Springs, Colo	.77	29.9	5,540
17	09241000	Elk River at Clark, Colo	1.64	27.8	4,060
27	09244100	Fish Creek near Milner, Colo	.37	.63	174
28	09244300	Grassy Creek near Mount Harris, Colo	.05	0	128
32	09244500	Elkhead Creek near Clark, Colo	.75	.70	675
33	09245000	Elkhead Creek near Elkhead, Colo	.82	.12	1,220
42	09248600	East Fork of Williams Fork above Willow Creek, Colo	1.00	17.1	1,390
43	09249000	East Fork of Williams Fork near Pagoda, Colo	.75	17.4	1,490
44	09249200	South Fork of Williams Fork near Pagoda, Colo	.95	.5	829
53	09251000	Yampa River near Maybell, Colo	.46	39.0	16,500
62	09253000	Little Snake River near Slater, Colo	.79	11.2	3,450
67	09255000	Slater Fork near Slater, Colo	.46	.64	1,190
69	09255500	Savery Creek at upper station, near Savery, Wyo	.23	1.21	1,080
75	09258000	Willow Creek near Dixon, Wyo	.40	.28	192
79	09260000	Little Snake River near Lily, Colo	.15	.26	8,850

[1]See figure 14.

Table 8.--*Mean monthly flows at selected stream-gaging stations, Yampa River basin*

[Based upon available records through the 1976 water year]

Map code[1]	Station number	Mean monthly flow for period of record, in cubic feet per second											
		October	November	December	January	February	March	April	May	June	July	August	September
5	09237800	6.70	5.33	4.56	4.12	4.01	6.11	37.2	228	208	25.2	6.76	5.10
8	09238500	17.0	13.0	11.6	10.7	10.2	11.8	35.4	281	474	72.1	16.7	12.7
12	09239400	1.11	1.18	1.07	1.00	1.03	2.18	12.4	44.8	42.7	4.46	.65	.43
13	09239500	136	125	104	101	103	172	679	1,770	1,840	344	149	106
17	09241000	83.5	70.0	64.2	58.4	58.8	75.0	295	1,230	1,430	462	135	80.8
27	09244100	4.44	4.84	4.66	4.66	5.10	7.92	28.0	59.8	22.5	4.81	2.91	2.95
28	09244300	.28	.59	.30	.03	.16	1.87	12.6	15.7	3.14	.90	.34	.14
32	09244500	4.45	4.46	3.65	3.19	3.19	4.88	60.6	225	77.4	10.7	3.64	3.25
33	09245000	5.40	5.82	5.32	4.87	5.21	10.0	116	346	105	13.1	4.07	3.61
42	09248600	39.7	32.9	29.0	26.2	25.5	28.8	90.0	382	408	128	55.0	41.4
43	09249000	41.2	35.9	31.3	28.7	26.9	31.8	114	422	403	123	51.7	39.2
44	09249200	7.34	6.51	5.56	5.96	5.99	9.18	49.6	257	159	14.2	4.68	4.17
53	09251000	346	346	301	273	321	675	2,640	6,290	5,510	1,330	378	242
62	09253000	35.2	33.4	31.1	30.3	32.3	46.9	274	1,080	939	140	37.0	27.0
67	09255000	17.0	16.9	15.9	15.9	17.2	25.3	110	367	244	32.2	8.70	9.88
69	09255500	15.0	16.9	14.9	13.9	17.4	33.2	130	175	86.7	16.8	9.69	10.2
75	09258000	2.64	2.35	2.26	2.29	2.58	4.83	17.5	30.4	34.5	9.32	3.33	2.36
79	09260000	108	114	94.5	85.1	111	376	1,140	2,620	1,860	259	65.1	54.7

[1]See figure 14.

spring-snowmelt runoff. Minimum flows occur principally from August through February. The summertime flows from July to October generally include a large component of ground-water discharge to the streams (Iorns and others, 1965). The seasonal distributions of monthly mean discharges are shown on figure 16 for 6 of the 19 selected locations. The dominant seasonal pattern exemplifies the high volumes of snowmelt runoff from April through June, with from 72 to 87 percent of the total annual runoff occurring during this 3-month period at these selected stations.

Flow-duration curves (fig. 17) were constructed using streamflow records through the 1976 water year for main-stem stations along the Yampa and the Little Snake Rivers. Significant irrigation use of water from the Little Snake River may explain much of the steeper gradient of the flow-duration curves in a downstream direction with smaller high-frequency flows indicating downstream losses (fig. 17*B*). The effects of irrigation are not as apparent for downstream flows of the Yampa River (fig. 17*A*).

The U.S. Geological Survey conducted streamflow data-evaluation studies for Colorado (Livingston, 1970) and Wyoming (Wahl, 1970). Accuracy goals, defined in these reports, were established for regionalizing various flow characteristics (such as low flow, flood peaks, flood volume, mean flow, and flow variability), using basin characteristics as independent variables. The statewide regression results indicated that the present methods of describing basin characteristics would not provide estimates of streamflow characteristics for Colorado or Wyoming within the assumed accuracy goals for principal or minor streams. The largest standard errors occurred in predicting low-flow characteristics. Livingston (1970) indicated that statewide regression methods generally should not be used for estimating low flows in Colorado. Low-flow characteristics in Colorado and Wyoming are affected greatly by highly variable geologic conditions occurring throughout each State.

A low-flow regional analysis of records for several Yampa River tributary streams was conducted by Tuthill (1975). Fifteen subbasins in the Yampa River basin having little or no effects from irrigation or regulation were selected for this analysis. In an attempt to regionalize the low-flow estimates from the 15 subbasins in the Yampa River basin, a multiple-regression relationship involving various basin characteristics as independent variables was used. These characteristics included precipitation, climate, contributing area, altitude, relief, land use, soil permeability, geology, and channel dimensions. The regional-regression analysis determined that the contributing area (assumed as the entire drainage area in this study) and percentage of alluvium (geologic parameter representing the ratio of the area underlain by alluvium to the total subbasin drainage area) were the most significant parameters in the regression relationship.

Low-flow characteristics with standard errors of estimate of 40 to 95 percent were obtained (Tuthill, 1975). These were substantially lower than the 90- to 150—percent error range obtained by Livingston (1970) in Colorado and the 270- to 340—percent error range obtained

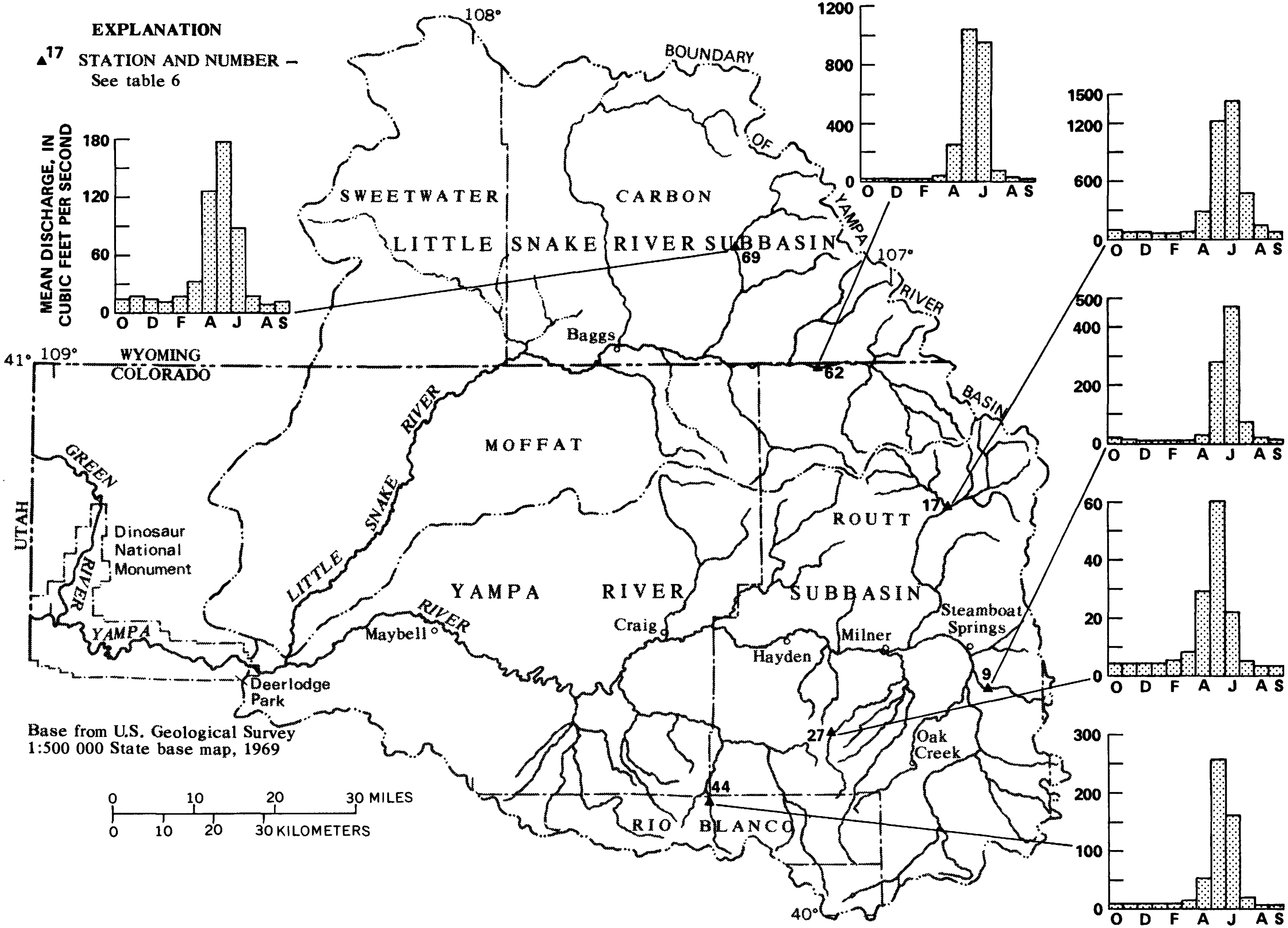
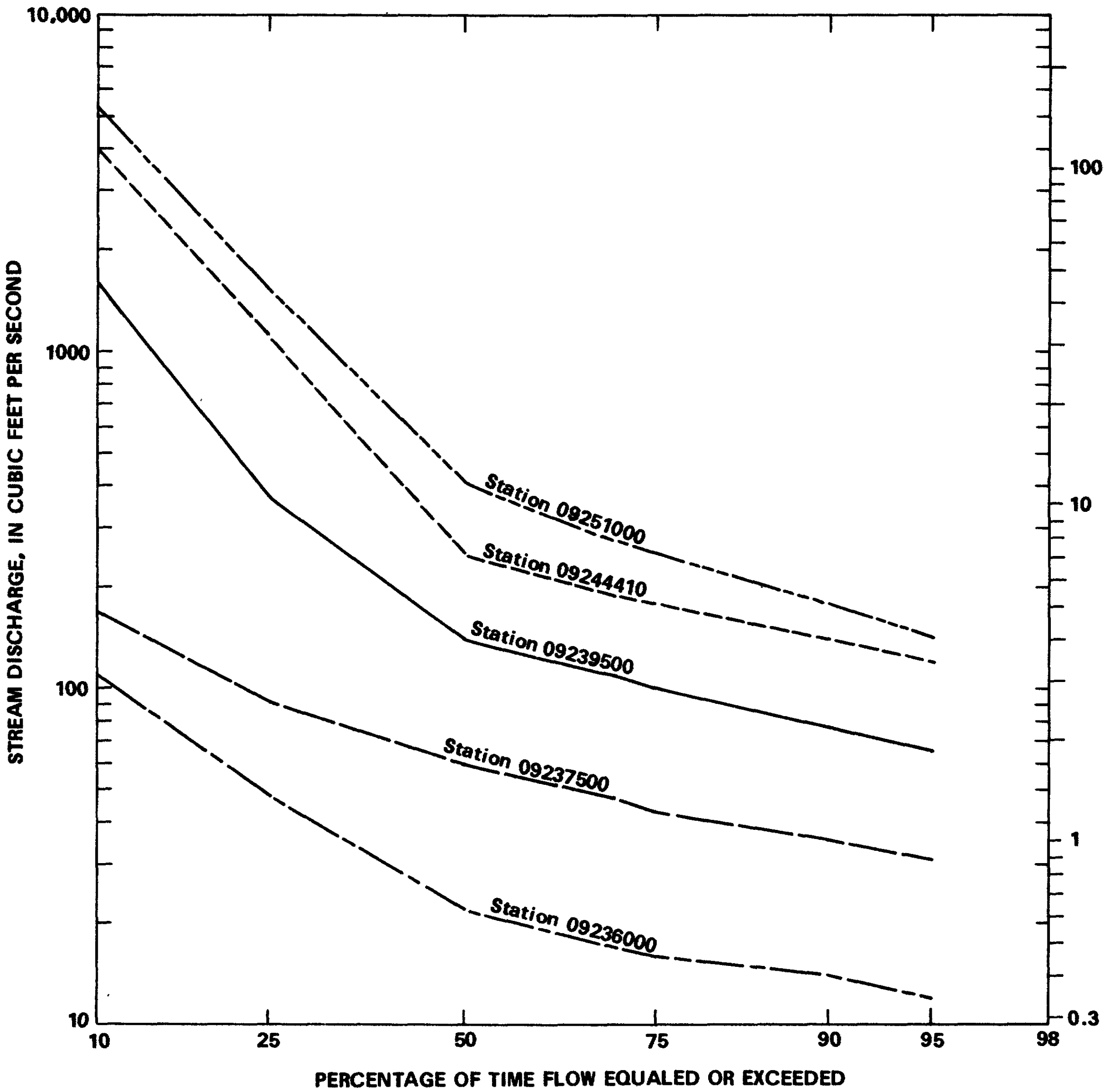
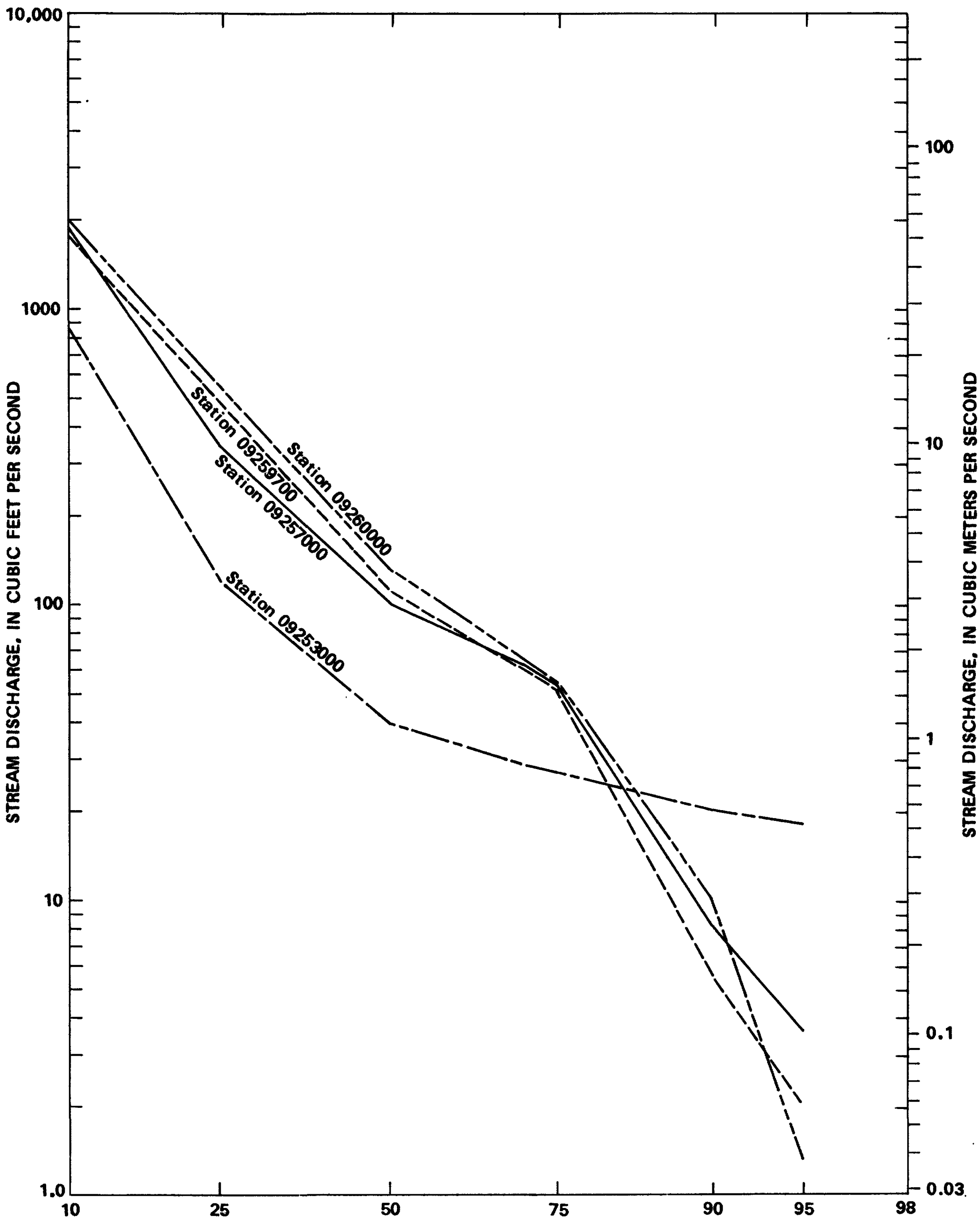


Figure 16.--Seasonal variation of monthly stream discharge at selected locations, Yampa River basin.



A. Yampa River, five stations.

Figure 17.--Flow-duration curves for selected streamflow records.



B. Little Snake River, four stations.

Figure 17.--Flow--duration curves for selected streamflow records--Continued.

by Wahl (1970) in Wyoming. However, Tuthill's study had the advantage of being conducted in a smaller region than the statewide-data evaluations cited above. The Tuthill study also included two geology-basin characteristics as part of the regression analysis. The characteristics were not included in the Colorado or Wyoming analysis. The geology-basin characteristics included: the percent alluvium in the basin, and the percent good aquifers in the basin. The percent alluvium in the basin was found to be significant on the basis of 5-percent inclusion probability for the regression analysis. For localized areas, low-flow and perhaps other flow characteristics may be estimated with sufficient accuracy, using this regionalization technique.

Stream Quality

Two approaches were used to assess ambient stream quality in the Yampa River basin. The first was to evaluate information gathered by past and ongoing data-collection programs. The second was to design reconnaissance and quarterly sampling programs that would complement these prior data. Evaluations of historic data on stream temperature, sediment, and major inorganic constituents are presented below. Results of the basinwide reconnaissance, which also are presented below, are based on 85 stream sites visited throughout the Yampa River basin during the last week of August and the first week of September 1975. The areal locations of these sites are shown on figure 18. Detailed station descriptions are listed in Steele, Bauer, Wentz, and Warner (1976a, table 2, p. 11-12). On-site measurements of streamflow, temperature, pH, dissolved oxygen, and specific conductance were obtained at 82 of these sites: stations Y-3, Y-5, and Y-38A (fig. 18) were dry at the time of the reconnaissance. Laboratory analyses of other physical, chemical, and biological variables were performed as discussed in the following individual sections of this report. The data from the basinwide reconnaissance have been published by Giles and Brogden (1978). Also, during September 23-24, 1975, an intensive 24-hour sampling of selected main-stem, tributary, and effluent-discharge sites along the Yampa River between Steamboat Springs and Hayden was conducted (Steele and others, 1976a, table 3). Various physical, chemical, and biological variables also were analyzed for samples collected as part of this study.

Selected results of statistical or modeling analyses of the above data are included in the following discussion. Some of the information summarized here is discussed by Wentz and Steele (1976) and by Bauer, Steele, and Anderson (1978). Results of the quarterly sampling program, which extended from December 1975 through September 1976 (Steele and others, 1976a, table 2), will be incorporated in an expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978). Previous basinwide water-quality investigations have been conducted in the Yampa River basin (McCall-Ellingson and Morrill, Inc., 1974; Wyoming Department of Environmental Quality, 1976) in fulfillment of section 303(e) of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500).

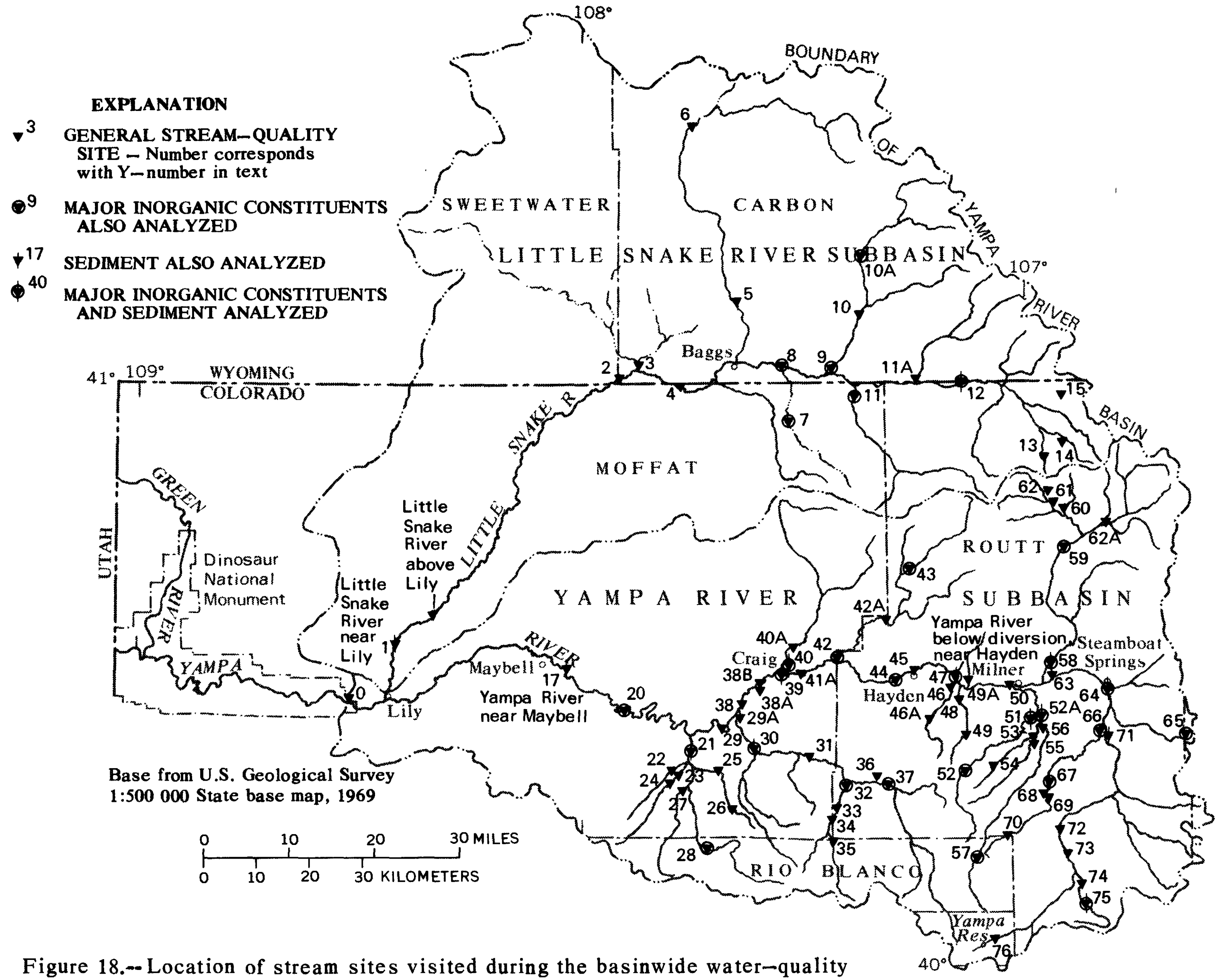


Figure 18.--Location of stream sites visited during the basinwide water-quality reconnaissance, August-September 1975.

Stream Temperature

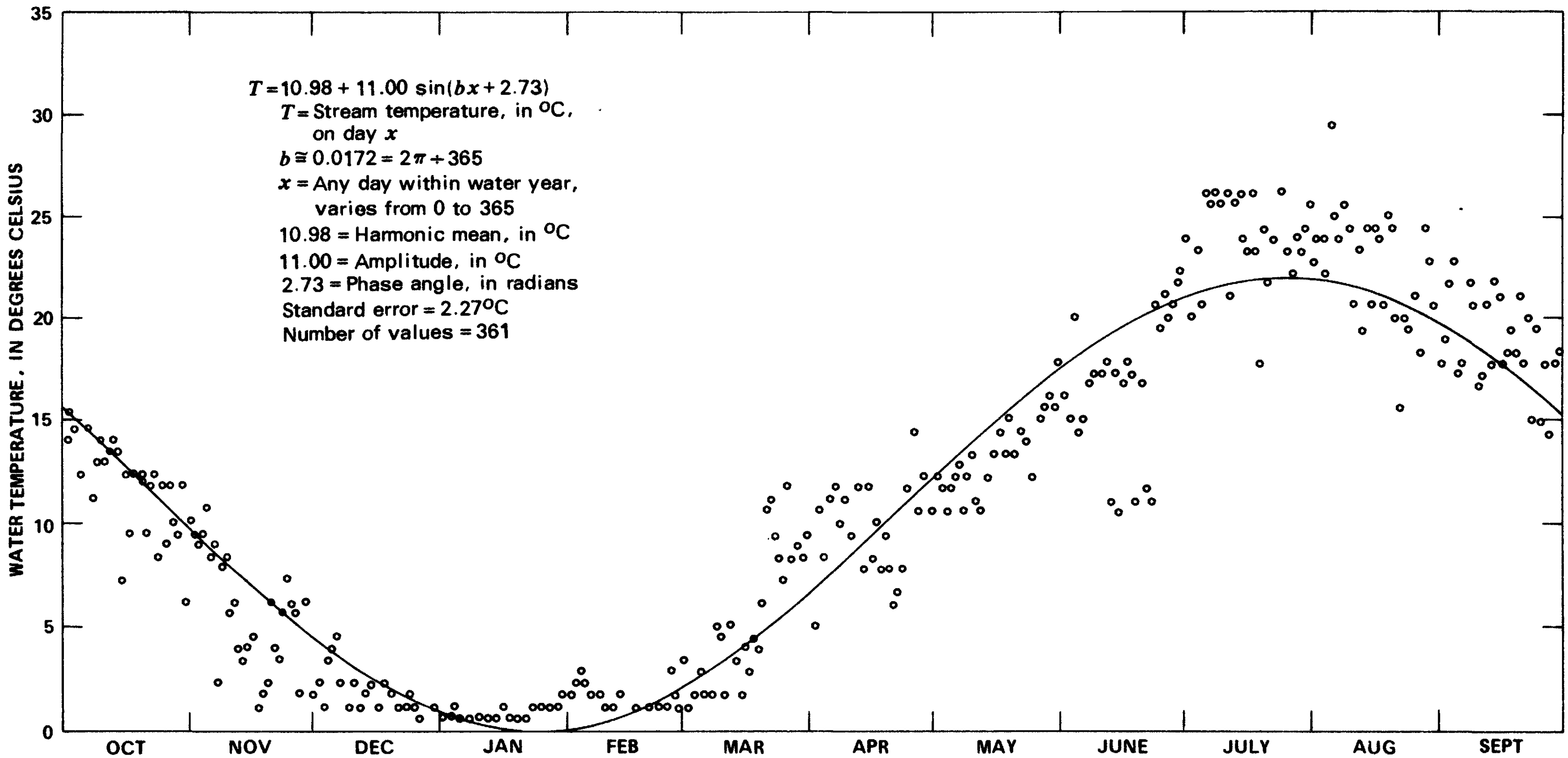
Daily stream-temperature records are available for station 09251000, Yampa River near Maybell, Colo., 1951-73 water years, and station 09259950, Little Snake River above Lily, Colo., 1951-69 water years (fig. 18). Annual stream-temperature variations at these sites were characterized using a harmonic-analysis procedure originally developed by Ward (1963) and subsequently modified and documented in the form of a computer program by Steele (1974). Seasonal temperature patterns thus developed are shown in figures 19*A* and 19*B* for the 1963 water year at these two locations. Similar seasonal variations persist from year to year. A trend-analysis technique described by Steele, Gilroy, and Hawkinson (1974) indicated no significant time trends in stream-temperature characteristics at either the Yampa River near Maybell or the Little Snake River above Lily for the indicated periods of record.

The combination of harmonic and trend analysis can aid in detecting and characterizing stream-temperature changes resulting from dam construction on large streams. Specific historic examples are not available in the Yampa River basin; however, Flaming Gorge Reservoir to the west of the basin may be used as an example. Using daily water-temperature data collected at the U.S. Geological Survey's streamflow gage on the Green River near Greendale, Utah (station 09234500), a significant shift in the seasonal stream-temperature pattern between the 1962 and 1963 water years was attributed to the filling of Flaming Gorge Reservoir just upstream from the gage site (fig. 20). The time trends in the harmonic coefficients characterizing stream temperature for this site have been reported by Steele, Gilroy, and Hawkinson (1974) and were described qualitatively by Bolke and Waddell (1975).

In addition to the above daily stream temperatures, data collected intermittently are available for 34 U.S. Geological Survey gaging stations in the Yampa River basin (table 6). Stream temperatures were measured in conjunction with discharge measurements approximately every 4 to 6 weeks during 1960-75. Twenty-one of these stations were included in the August-September 1975 basinwide reconnaissance (see table 6, and Steele and others, 1976a, table 2).

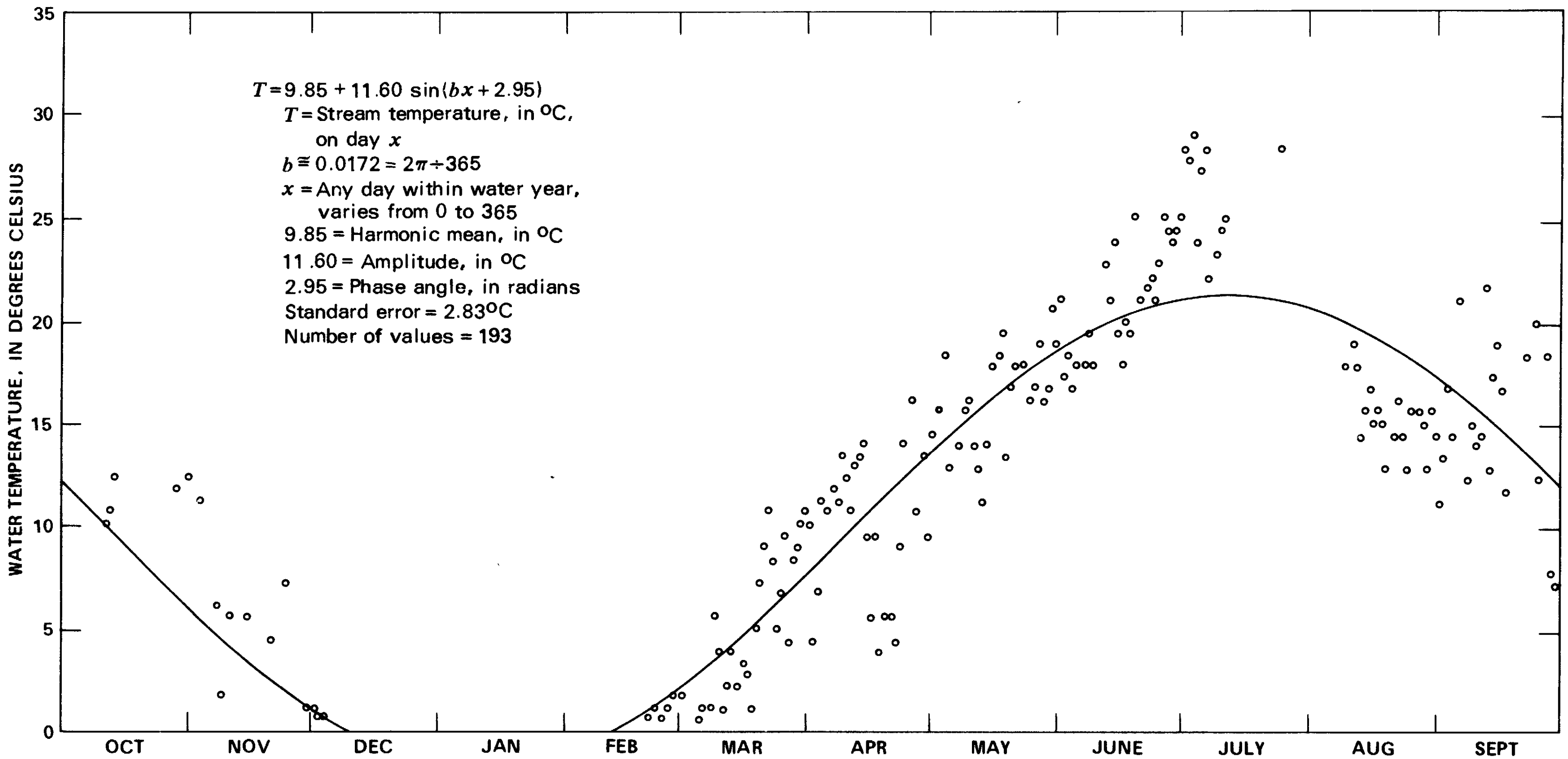
Because of the lack of time trends in stream-temperature coefficients for the Yampa River near Maybell or the Little Snake River above Lily, the harmonic-analysis procedure was applied to the entire period of record for each of the intermittent-measurement sites. Seasonal stream-temperature patterns for selected main-stem sites are depicted in figure 21. Note that, in general, the harmonic-mean coefficients increased in a downstream direction. More detailed results of this analysis are given in the expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978).

Stream-temperature coefficients were correlated with selected basin characteristics to determine if regional patterns were discernible. Graphs of the three harmonic coefficients for stream temperature versus altitude for the 34 sites are shown in figure 22. A general inverse correlation between altitude and harmonic-mean coefficient is observed, although the scatter is



A. **Yampa River near Maybell, Colo.**

Figure 19.--Seasonal temperature patterns, 1963 water year (from Wentz and Steele, 1976).



B. **Little Snake River above Lily, Colo.**

Figure 19.--Seasonal temperature patterns, 1963 water year (from Wentz and Steele, 1976)—Continued.

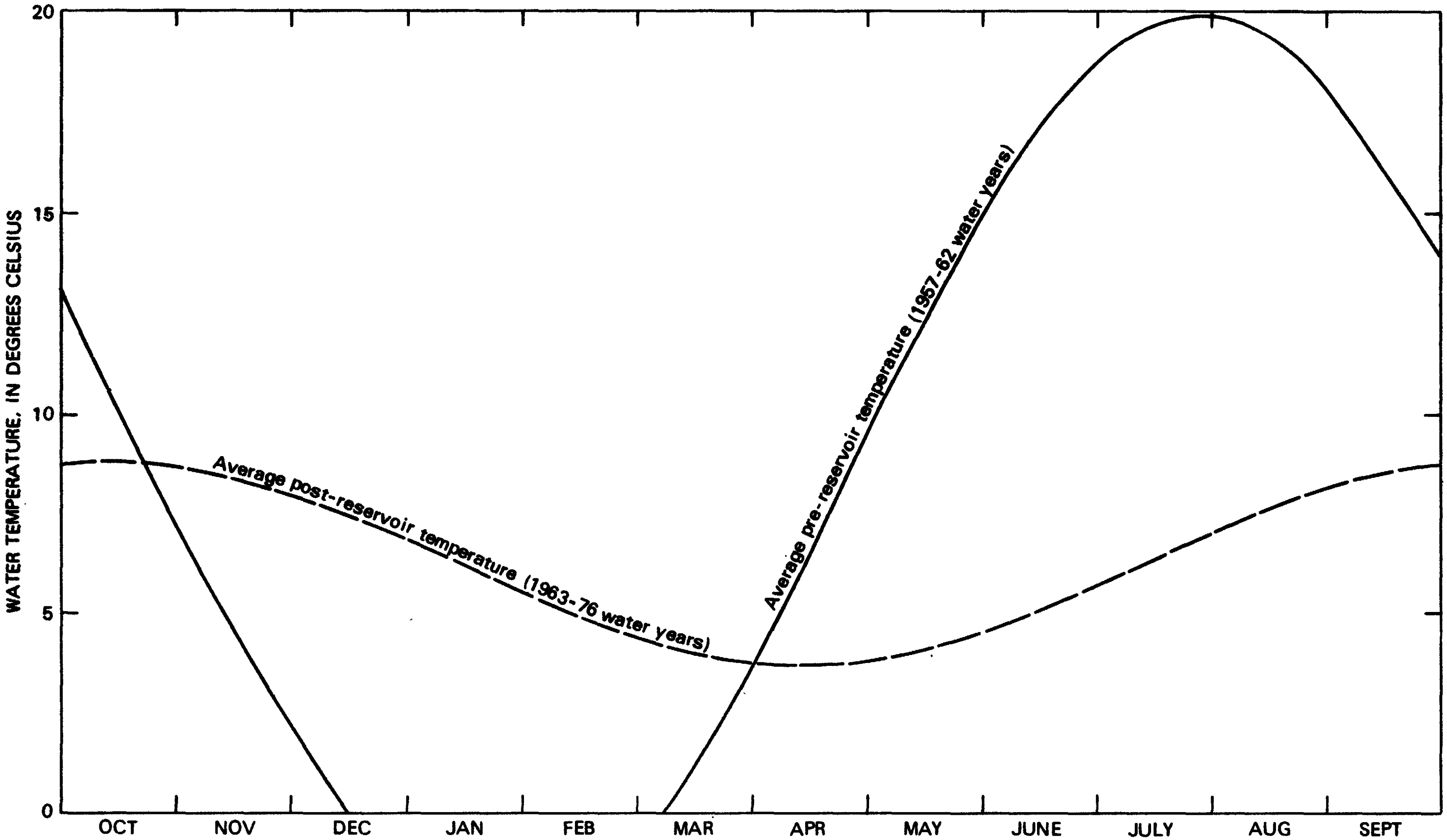


Figure 20.--Change in seasonal stream-temperature pattern due to reservoir construction, Green River near Greendale, Utah.

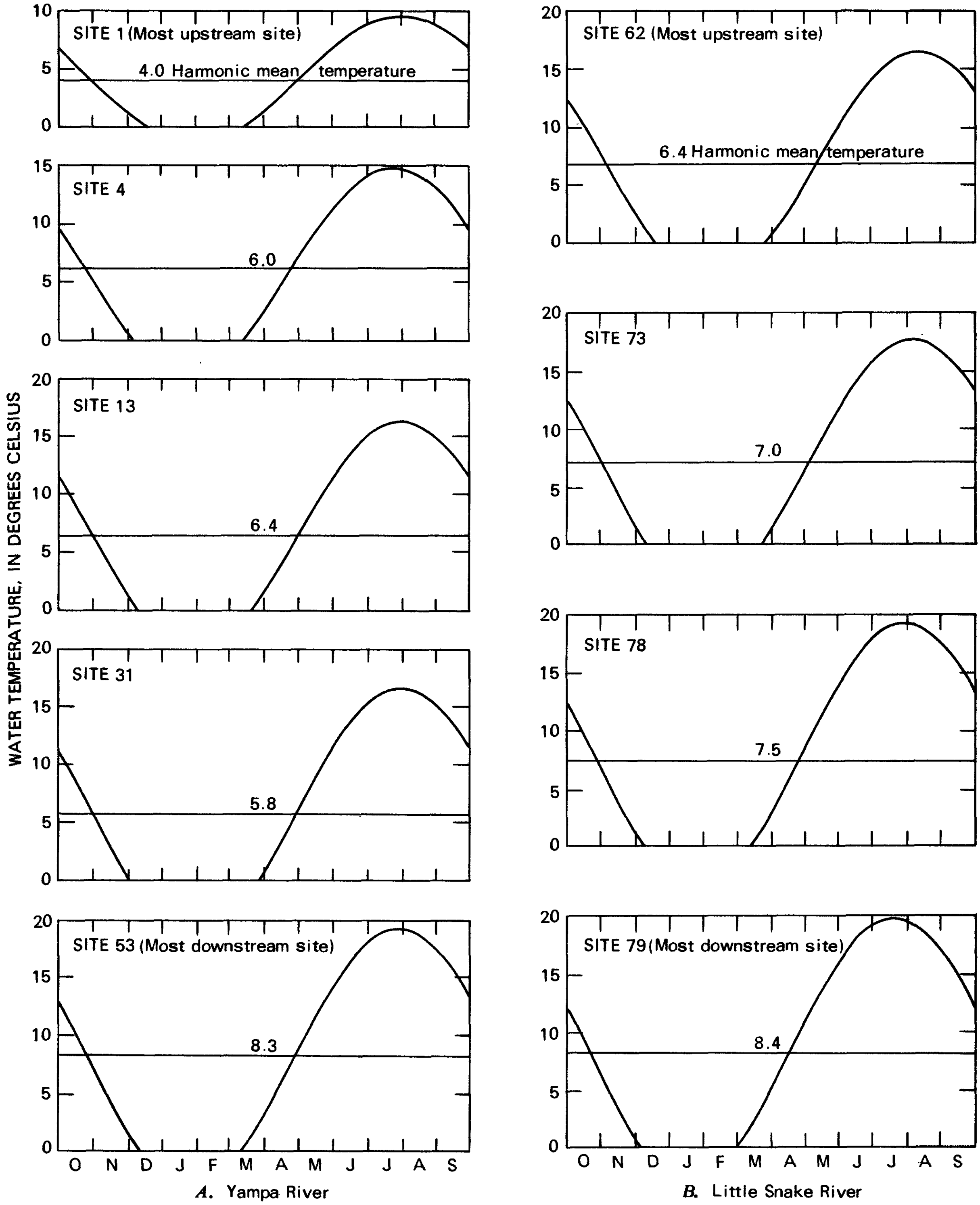


Figure 21.--Changes in seasonal stream-temperature patterns from upstream to downstream in the Yampa River basin. (See figure 14 for site locations.)

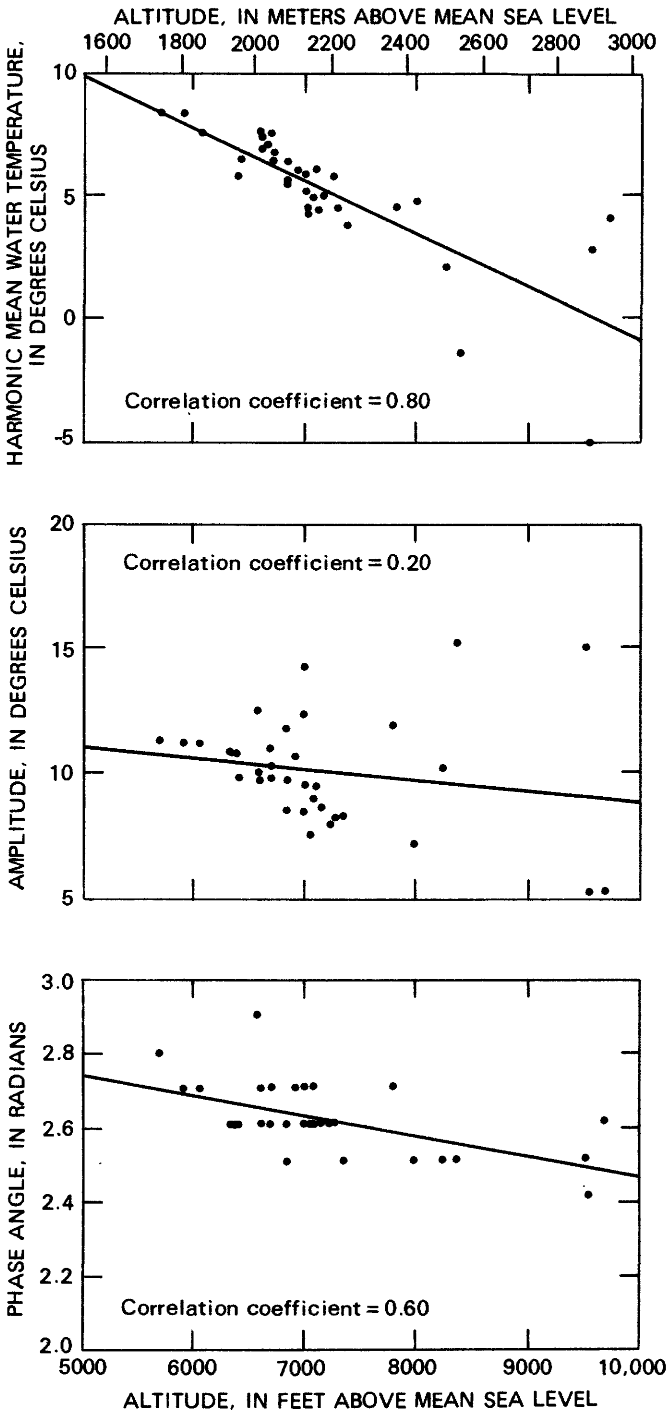


Figure 22.--Relationships between stream- temperature harmonic- analysis coefficients and altitude for streams in the Yampa River basin, 1960- 75.

greater at higher altitudes. Little or no correlation is observed between amplitude or phase angle and altitude; hence, these coefficients might be assumed constant. Estimating stream-temperature characteristics from a known physical parameter--altitude--enables one to document changes resulting from man's activities at previously unmeasured sites. Similar regional analyses have been reported for other areas of the United States (Steele and Dyar, 1974; Shampine, 1977; and Lowham, 1978).

Mountain streams typically undergo diel variations in temperature during the summer. Because of this and the fact that the sites visited during the basinwide reconnaissance were sampled randomly during daylight hours of most days, it is very difficult to draw any concrete conclusions regarding stream temperatures measured as part of the basinwide reconnaissance. The upper temperature limit to protect cold-water biota is 20°C (Colorado Department of Health, 1977). Nine of 82 measurements (11 percent) made during the reconnaissance exceeded this limit. All cases of noncompliance to the stream standard appear to be due to natural causes. None of the temperatures measured during the 2-week reconnaissance exceeded the upper limit of 30°C (Colorado Department of Health, 1977) for warm-water biota.

Suspended Sediment

Iorns, Hembree, and Oakland (1965) made estimates of fluvial-sediment discharge in the Yampa River basin for two downstream sites and two intermediate sites in the basin. Their analysis was based on daily records at the Yampa River near Maybell, Colo. (station 09251000), for 1951-57 water years, and on data collected intermittently at 10 other sites in the basin during 1952-53 and 1957-58. A basic assumption of the analysis was that no trend in suspended-sediment concentrations occurred in the basin from 1914 to 1957. The suspended-sediment load of the Yampa River basin was estimated at slightly more than 1.8 million tons (1.6 million t) per year.

Since completion of the study by Iorns, Hembree, and Oakland (1965), additional daily records have been collected for the Yampa River near Maybell, Colo. (station 09251000), adding 1958 to the previously available 1951-57 water years. Also, daily data have been collected for the Little Snake River near Lily, Colo. (station 09260000), for 1958-64 water years. Revised estimates for suspended-sediment discharge of these two sites are given in another report (Andrews, 1978). Based on analysis of these records, the estimated mean annual suspended-sediment load from the basin is about 2.0 million tons (1.8 million t), which is 11 percent higher than that estimated by Iorns, Hembree, and Oakland (1965). The difference may be accounted for largely by the inclusion of bedload estimates in Andrews (1978) computations. Either estimate represents about 2 percent of the computed sediment load of the Colorado River at Lees Ferry, Ariz., the Compact point of the Upper Colorado River Basin (Iorns and others, 1965, p. 36). Historical records indicate that 90 percent of the annual sediment load of the Yampa River near Maybell is discharged during the period of snowmelt runoff (April through June); whereas, only about 60 percent of the annual sediment load of the Little Snake River above Lily is discharged during this period. The smaller sediment-runoff percentage associated with the spring-runoff period for the Little Snake River reflects effects of occasional rainstorms in late summer (August and September) that intermittently contribute a substantial part of the annual sediment load from easily eroded surficial material.

Average-annual discharge-weighted suspended-sediment concentrations for the two downstream sites (fig. 18) are as follows: (1) 270 mg/L for the Yampa River near Maybell; and (2) 2,890 mg/L for the Little Snake River near Lily. Again, these sediment concentrations are 38 percent greater for the Yampa River and 61 percent greater for the Little Snake River than those estimated by Iorns, Hembree, and Oakland (1965). Although the average-annual suspended-sediment concentration in the Little Snake River is an order of magnitude greater than in the Yampa River, the total sediment load from the Yampa River subbasin is about 3 to 4 times greater, due to the relatively lower flow from the Little Snake River subbasin. This ratio of sediment loads for the two subbasins is comparable to the value of 3½ times reported by Iorns, Hembree, and Oakland (1965, p. 215).

Suspended-sediment samples were collected at 14 sites during the basinwide reconnaissance in August-September 1975 (fig. 18). Concentrations ranged from 0 mg/L at site Y-52A to 133 mg/L at site Y-21. Nine of the 14 concentrations were 13 mg/L or less, and all but 1 were 52 mg/L or less. Supplemental sediment samples were collected at selected sites throughout the basin during 1976 and 1977. Information derived from these additional data and a regional appraisal of ambient sediment conditions are discussed by Andrews (1977, 1978).

Major Inorganic Constituents

Long-term water-quality data on major inorganic constituents and specific conductance are available for the following stations (fig. 18): (1) 09251000, Yampa River near Maybell, Colo., 1951 water year to present; (2) 09259950, Little Snake River above Lily, Colo., 1951-69 water years; and (3) 09260000, Little Snake River near Lily, Colo., 1970 water year to present. The latter two stations represent a minor change in location of virtually the same sampling site, and herein will be considered together as the Little Snake River near Lily, Colo. Until 1969, laboratory analyses were made on approximately 36 daily composited samples per year collected by local observers. Since 1969, laboratory analyses have been performed on individual monthly samples. In addition to the above long-term site-specific data, Iorns, Hembree, Phoenix, and Oakland (1964) summarized reconnaissance data on major inorganic constituents collected during 1944-58. A total of 102 samples were collected at 35 sites located throughout the Yampa River basin in the study by Iorns, Hembree, Phoenix, and Oakland (1964).

Concentrations of the major inorganic constituents commonly are correlated with specific conductance. For purposes of this analysis, linear, bivariate, least-squares regression equations were developed for major inorganic constituents versus specific conductance using both the site-specific and regional data. These equations then were applied to the long-term daily specific-conductance records available for the stations on the Yampa and the Little Snake Rivers. A computer program documented by Steele (1973) was used for estimating daily chemical loads and concentrations and monthly and annual discharge-weighted and time-weighted values. Most of the results reported are in terms of annual means. More detailed results will be given in the expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978).

Regional regression relationships developed from the data of Iorns, Hembree, Phoenix, and Oakland (1964) are summarized in table 9A. Additional relationships were developed from the long-term data (1951-75 water years) for the Yampa River near Maybell and the Little Snake River near Lily (D. A. Wentz and T. D. Steele, written commun., 1978). Simulation results for annual concentrations of dissolved solids were almost identical using regional or site-specific equations (Wentz and Steele, 1976, fig. 5*A*). A comparison of observed and simulated annual mean discharge-weighted concentrations of dissolved solids in the Yampa River near Maybell, Colo., utilizing both regional and site-specific regression equations (D. A. Wentz and T. D. Steele, written commun., 1978) is given in figure 23. These results are quite similar through 1970. The greater deviations since 1970 are attributed largely to changing from composited to monthly analyses for determining annual mean concentrations.

Time-trend analyses were conducted using the actual specific-conductance data for the Yampa River near Maybell and the Little Snake River near Lily sites as a function of stream discharge, adjusting for streamflow effects. The above procedure is documented by Steele, Gilroy, and Hawkinson (1974). Data from 1951 through 1972 for the Yampa River and from 1951 through 1969 for the Little Snake River were analyzed. A long-term increase in specific conductance of 14 percent was observed for the Yampa River site (Steele and others, 1974, table 9, p. 67); however, no change was observed for the Little Snake River site. The trend in increasing specific conductance for the Yampa River is attributed to increasing use of surface water for agricultural and municipal purposes. Using a shorter period of record (1951-63 water years), no significant changes at either of these two sites were reported in a study by Blackman, Rouse, Schillinger, and Shafer (1973, table III).

Major inorganic constituents were determined at 29 sites during the August-September 1975 reconnaissance (fig. 18). These data were used to check the regional regression relationships developed previously from historic data. The results of this analysis are summarized in table 9B. Data from sites Y-21 and Y-40 were deleted because of suspected contamination, possibly from irrigation return flow. Data from site Y-65 were deleted because the specific conductance was not known precisely enough. Graphic depiction of the equations indicates that the regression relationships calculated from data obtained at the 26 remaining sites compare quite closely with those calculated from historic data (table 9A).

Table 9A.--*Regional regression relationships for major inorganic constituents in streams of the Yampa River basin, as computed from historic data*

[Predicted variable, in milligrams per liter=a+b×(specific conductance, in micromhos per centimeter at 25°C); data from Iorns, Hembree, Phoenix, and Oakland (1964)]

Predicted variable	Intercept (a)	Slope (b)	Standard error of estimate of predicted variable	Correlation coefficient (r)	Number of data pairs[1]	Range of specific conductance[2] (micromhos per centimeter at 25°C) Minimum	Maximum
Calcium	7.06	0.0860	7.27	0.90	62	20	831
Magnesium	-2.43	.0465	3.73	.91	62	20	831
Sodium	-1.16	.0426	2.35	.92	14	59	219
Potassium	.197	.00758	.24	.97	3	116	308
Sodium and potassium	-4.93	.0741	8.52	.86	57	20	831
Total hardness	7.84	.404	21.1	.96	62	20	831
Bicarbonate	14.6	.406	22.2	.95	96	17	831
Sulfate	-13.0	.182	13.4	.92	87	17	831
Chloride	-1.98	.0277	8.50	.51	73	17	229
Calculated dissolved solids	4.48	.586	5.81	.99	5	59	308
Measured dissolved solids	7.35	.628	10.0	.99	35	39	831
Nitrate-N[3]	[4].104	-------	[5].0927	----	57	20	831
Silica[3]	[4]11.3	-------	[5]4.64	----	55	20	831

[1]Data for 96 samples collected at 34 sites were used in this analysis.

[2]Range of specific-conductance values for analyses used to determine the regression equation. Due to scatter in some of the data, application of the equation at the lower end of the specific-conductance range may result in negative estimates for the predicted variable.

[3]The alternative model, predicted value = mean value, is given because of low values of r.

[4]Mean.

[5]Standard deviation.

Table 9B.--*Regional regression relationships for major inorganic constituents in streams of the Yampa River basin, as computed from data collected during the basinwide reconnaissance, August-September 1975*

[Predicted variable, in milligrams per liter=a+b×(specific conductance, in micromhos per centimeter at 25°C), where specific conductance ranges from 65 to 950 micromhos per centimeter for 26 determinations]

Predicted variable	Intercept (a)	Slope (b)	Standard error of estimate of predicted variable	Correlation coefficient (r)
Calcium----------------------	4.36	0.0962	8.63	0.94
Magnesium[1]-------------------	-7.25	.0632	5.97	.94
Sodium-----------------------	-.0758	.0415	7.49	.81
Potassium--------------------	.830	.00370	.554	.86
Total hardness---------------	-18.8	.502	25.8	.98
Bicarbonate------------------	28.8	.348	29.3	.95
Sulfate[1]---------------------	-45.5	.283	26.3	.94
Chloride[2]--------------------	1.79	.00501	2.57	.44
	[3](3.82)	(------)	[4](2.80)	(---)
Calculated dissolved solids--	-16.0	.659	17.9	.99
Fluoride[2]--------------------	.102	.000241	.0687	.66
	[3](.200)	(-------)	[4](.0894)	(---)
Silica[5]----------------------	[3]10.6	-------	[4]5.36	---

[1]Due to scatter in some of the data, application of the equation at the lower end of the specific-conductance range may result in negative estimates for the predicted variable.

[2]The alternative model, predicted value = mean value, is given in parentheses because of low values of r.

[3]Mean.

[4]Standard deviation.

[5]The alternative model, predicted value = mean value, is given because of an extremely low value of r.

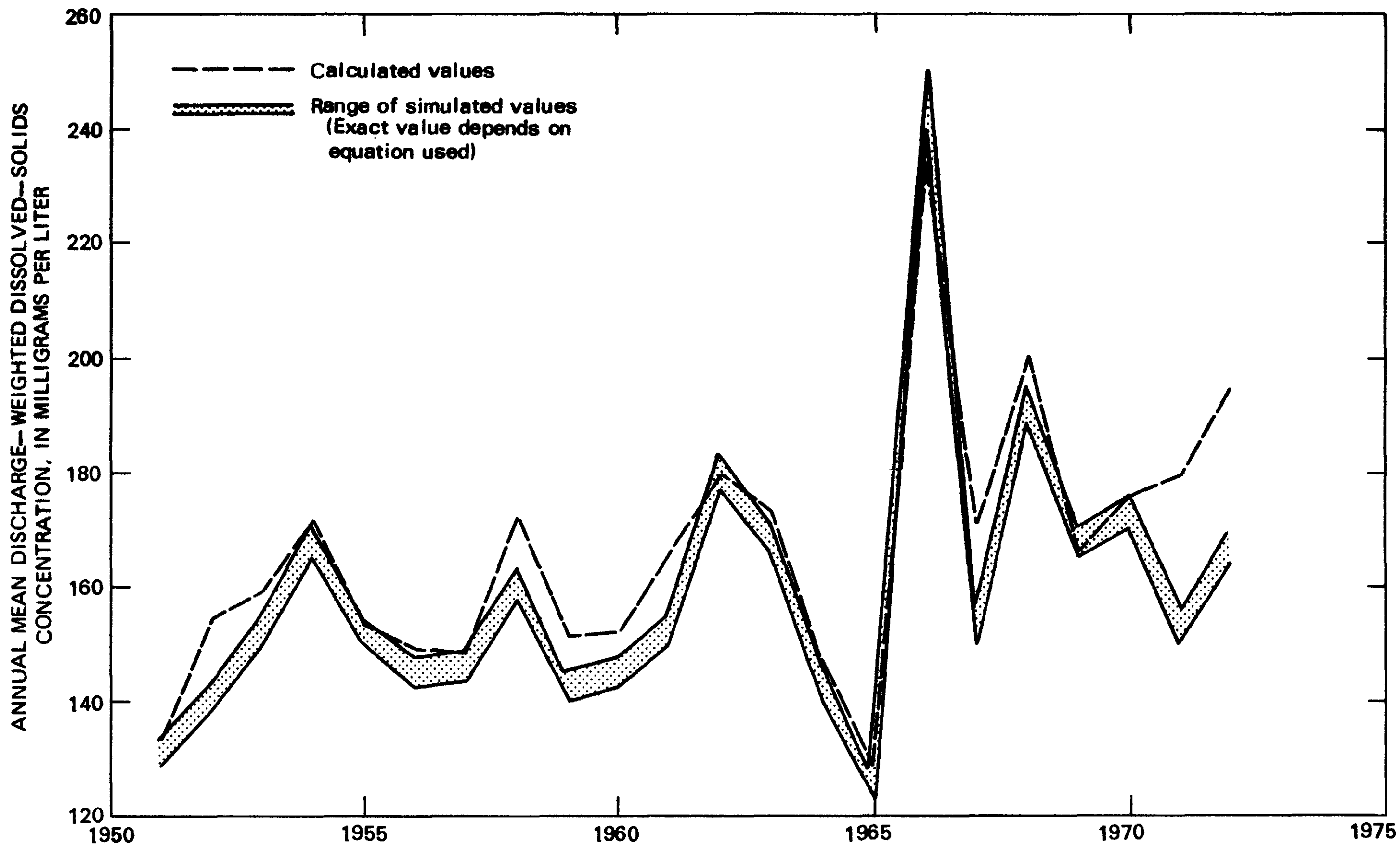


Figure 23.--Calculated and simulated annual mean discharge–weighted dissolved–solids concentrations, Yampa River near Maybell, Colo., 1951–72.

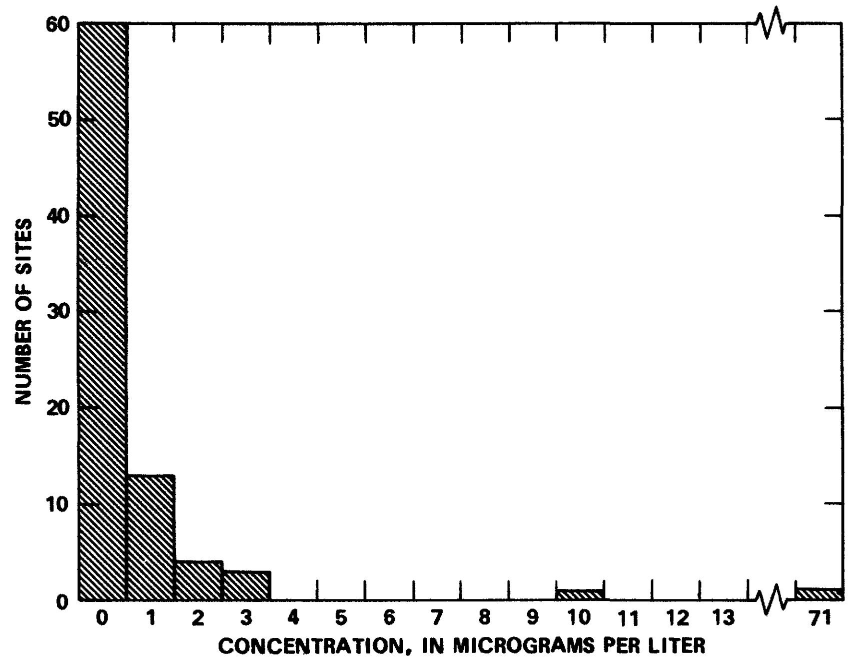
Trace Elements and pH

Water samples were collected at 82 reconnaissance sites (fig. 18) for determination of total (unfiltered samples) and dissolved (samples filtered using a 0.45-micrometer membrane filter) cadmium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, vanadium (dissolved only), and zinc. Forty-eight samples of stream-bottom sediments also were obtained. Bed materials were too large at the other sites. The fraction of the stream-bottom sediments whose nominal particle diameter was less than 208 micrometers was extracted in hot hydrochloric acid: antimony, arsenic, chromium, copper, iron, lead, mercury, and nickel were determined on the extract. Selected results of trace-element and pH determinations are discussed in this report; a more detailed discussion is presented in the expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978).

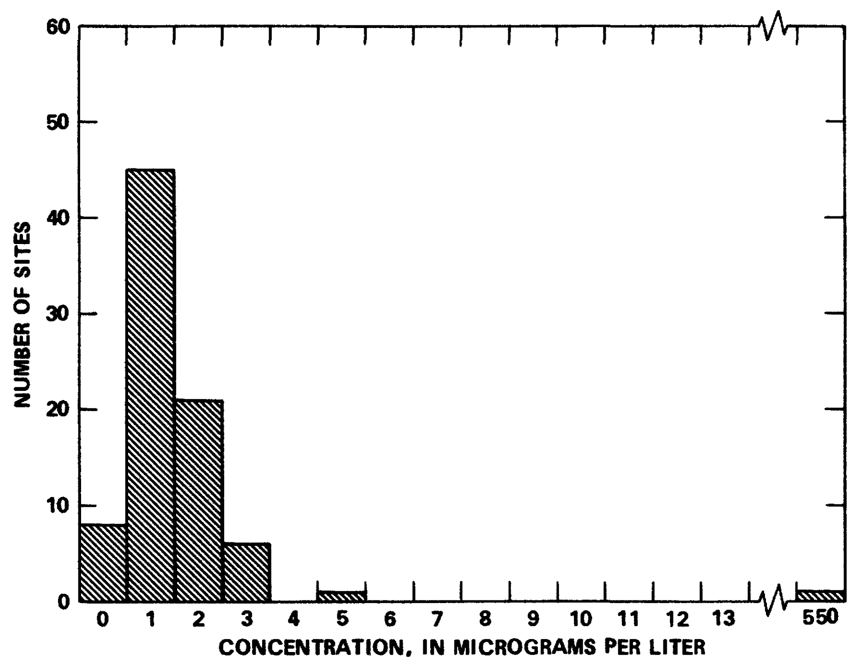
Frequency distributions of dissolved and total trace elements in water were generally positively skewed as shown in figure 24*A*. Possible exceptions were total zinc and dissolved copper (fig. 24*B*), which are somewhat more symmetrical. Stream sites with degraded water quality with respect to dissolved and total trace elements were determined by analyzing the various frequency distributions and statistically separating the outliers--indicating anomalous conditions--from the background distributions representative of ambient conditions. For example, the concentrations of 71 µg/L (micrograms per liter) total selenium in figure 24*A* and 550 µg/L dissolved copper in figure 24*B* are outliers. The outlier analysis technique is described in detail in the expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978).

Only data from sites Y-26, Y-46, Y-54, and Y-68 indicate upstream sources of water-quality degradation (2-6 outliers each) (fig. 25). However, many of the outliers are from one of four constituent distributions: dissolved iron, total iron, dissolved manganese, and total manganese. Moreover, many of the ambient concentrations from these four distributions exceed the proposed water-supply standards, aquatic-life standards, and agricultural standards (Colorado Department of Health, 1977), indicating a separate technique might be applied to these data. Deleting iron and manganese from the outlier analysis, data from sites Y-26, Y-46, and Y-68, with three outliers each, still indicate upstream sources of water-quality degradation. Detailed discussion of probable causes of these degraded conditions is given in the expanded technical report (D. A. Wentz and T. D. Steele, written commun., 1978). Sites where excessive concentrations of iron and manganese were measured also have been delineated in this expanded report.

A number of stream sites in the Yampa River basin were found where proposed water-supply standards, aquatic-life standards, and agricultural standards for trace elements and pH (Colorado Department of Health, 1977) were exceeded during August-September 1975 (table 10). These comparisons were made as general indicators of conditions during low flows in the basin for the constituents considered. It should be recognized that substantial



A. Total Selenium



B. Dissolved Copper

Figure 24.--Frequency distributions of selected trace elements in streams of the Yampa River basin, August–September, 1975 (from Wentz and Steele, 1976).

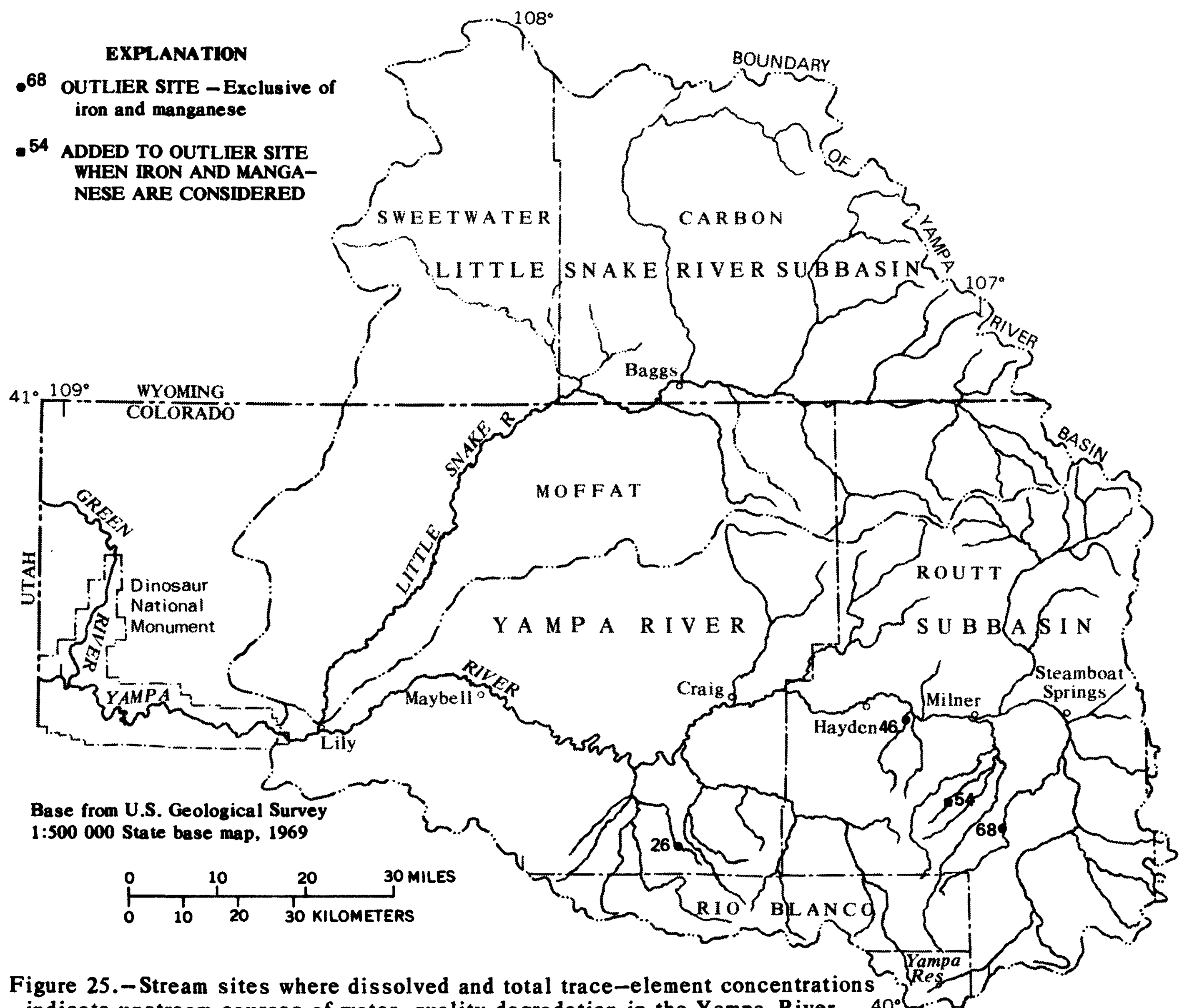


Figure 25.—Stream sites where dissolved and total trace-element concentrations indicate upstream sources of water-quality degradation in the Yampa River basin, August–September 1975. (See text for explanation.)

Table 10.--*Summary of trace-element concentrations and pH values in streams relative to proposed water-supply, aquatic-life, and agricultural standards, Yampa River basin, August-September 1975*

[Range of values shown for pH; all values expressed as micrograms per liter, unless otherwise specified]

Water-quality parameter	Water-supply standard[1]	Number of sites where standard was exceeded		Aquatic-life standard[1]	Number of sites where standard was exceeded		Agri-culture standard[1]	Number of sites where standard was exceeded	
		Dissolved	Total		Dissolved	Total		Dissolved	Total
Cadmium	10	0	0	0.4	0	[2]2	10	0	0
Copper	1,000	0	0	10	1	3	200	1	1
Iron	300	3	33	1,000	2	13	---	-	-
Lead	50	0	[3]1	4	1	[3]1	100	0	0
Manganese	50	12	23	2,000	0	0	200	7	8
Mercury	2	0	0	.05	7	18	10	0	0
Nickel	----------	--	--	50	0	0	100	0	0
pH (standard units)	$5.0 \le pH \le 9.0$	3	--	$6.5 \le pH \le 9.0$	3	--	---	-	-
Selenium	10	1	1	50	1	1	50	1	1
Zinc	5,000	0	0	50	[4]0	[4]0	200	0	0

[1]Colorado Department of Health (1977).

[2]The lower limit of detection for total cadmium is 10 µg/L (micrograms per liter), and 80 values were reported as less than 10 µg/L. Two values of 10 µg/L were reported; these are the only values that definitely exceeded the aquatic-life standard of 0.4 µg/L.

[3]The lower limit of detection for total lead is 100 µg/L, and 80 values were reported as less than 100 µg/L. One value of 100 µg/L was reported; this is the only value that definitely exceeded the drinking-water and aquatic-life standards of 50 and 4 µg/L, respectively.

[4]It is suspected that one site (Y-46) had total and dissolved zinc concentrations that exceeded the 50-µg/L limit for aquatic life; however, analytical problems prevented confirmation.

year-to-year variations may occur during late-summer low flows for several constituents and that there is nothing sacred about the proposed standards used in the comparison. Ambient concentrations of iron, manganese, and mercury at several sites in the basin pose problems relative to statewide water-quality standards. A detailed discussion of these sites is given by D. A. Wentz and T. D. Steele (written commun., 1978).

For a pH range of between 3 and 9, pH values and trace-element concentrations are negatively correlated (Moran and Wentz, 1974; Wentz, 1974), because many trace elements are more soluble in acid waters. Of the pH's measured during the August-September 1975 reconnaissance, only the value of 2.1 at site Y-46 (fig. 18) could be considered anomalously low. It is believed to be associated with nonrecurring discharge of water from cooling towers at the Hayden Powerplant (Stratton and Lee, 1975). This pH was the only value less than the lower limit of 6.5 recommended for aquatic life by the Colorado Department of Health (1977). All other values were 7.2 or greater. Values of pH at sites Y-12 and Y-52A were greater than the recommended upper limit of 9.0 for aquatic life (Colorado Department of Health, 1977). As pH may often undergo a daily fluctuation similar to water temperature (fig. 26), it is possible that the pH values could have differed significantly, depending upon the time of day that measurements were made. However, this documented diel variation may not be as pronounced at other locations or at this same location during other periods.

Because stream-bottom sediments are exposed to varying conditions over an extended period of time, an assessment of the trace-element concentrations associated with stream-bottom sediments potentially provides information not obtainable from concentrations of trace elements in water. The sediments act as integrators; they reflect at least some type of average of conditions during the period of exposure. Under certain circumstances, the stream-bottom sediments may reflect the extreme conditions. The underlying assumptions in this analysis are that the trace elements in question exist in the particulate phase, and that bottom-sediment transport rates are substantially less than average stream velocities.

Stream-bottom sediment samples were collected at 48 sites in the Yampa River basin during August-September 1975. The exact fraction of the trace elements associated with the stream-bottom sediments which is extracted by the analytical procedure used in this study (see p. 72) is not known; however, at a minimum, adsorbed and chemically precipitated elements should be released. Organically bound elements and those that are present as part of the internal structure of the inorganic fraction probably are not freed by the extraction technique employed.

Trace-element frequency distributions in stream-bottom sediments were analyzed using the same techniques used for trace-element distributions in water. Generally speaking, the distributions were approximately symmetrical. For example, the iron distribution shown in figure 27*A* also is typical of antimony, arsenic, copper, and mercury. On the other hand, the positively skewed chromium distribution (fig. 27*B*) is additionally representative of only lead, and perhaps nickel.

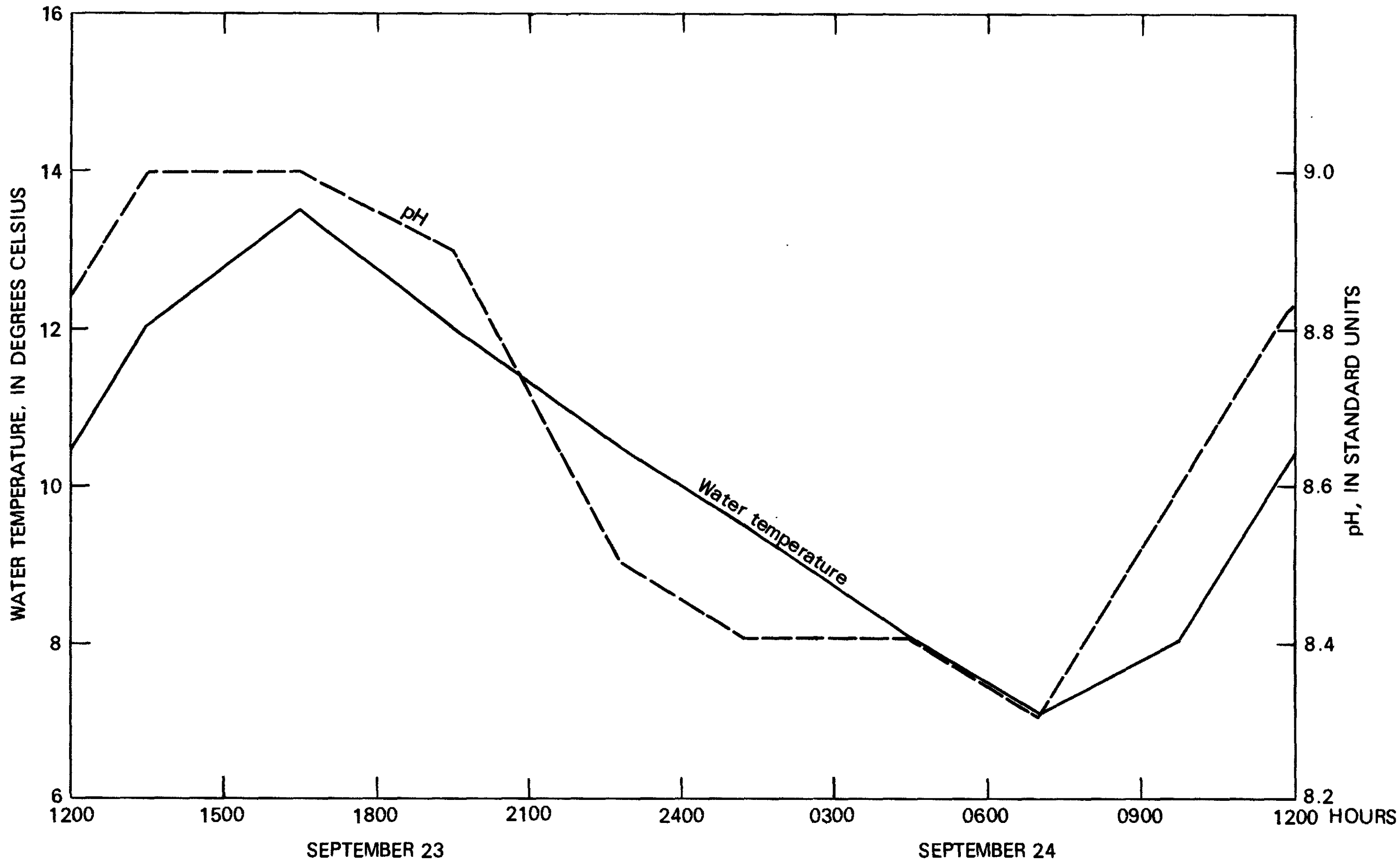
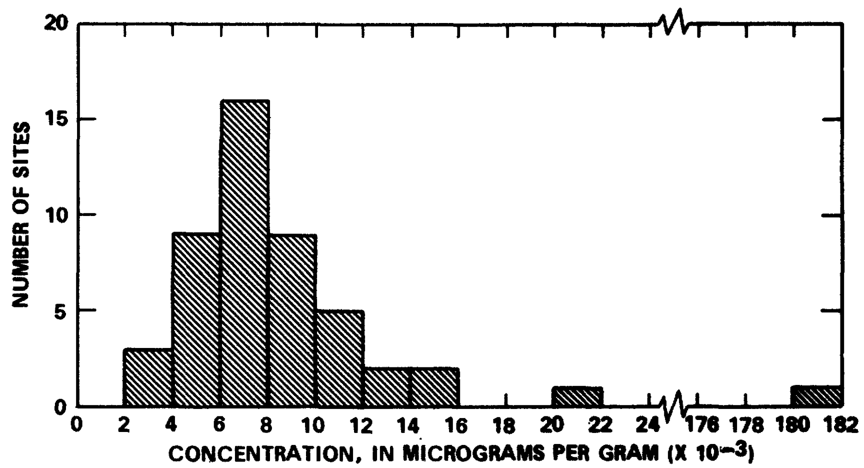
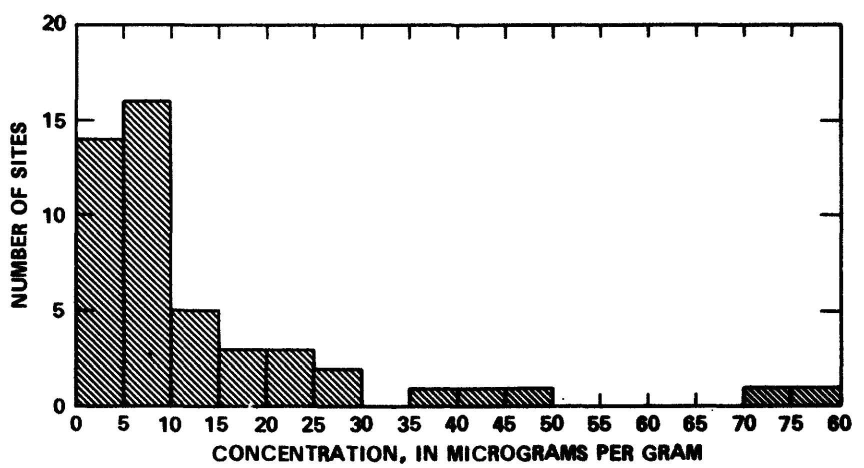


Figure 26.--Diel variation of water temperature and pH, Yampa River at Steamboat Springs, Colo. (site Y-64), September 23-24, 1975.



A. Iron



B. Chromium

Figure 27.—Frequency distributions of selected trace elements in stream–bottom sediments of the Yampa River basin, August–September, 1975 (from Wentz and Steele, 1976).

Data determined by the outlier analysis to be indicative of upstream sources of water-quality degradation were collected at site Y-46 (one outlier) and Y-68 (three outliers). Water-quality data at these sites also indicated upstream sources of water-quality degradation (p. 72).

One potential problem area not indicated by the outlier analysis is in the vicinity of sites Y-38 and Y-39 (fig. 18). Both sites are on the Yampa River downstream from Craig; and, although data from neither site are considered outliers, these two sites contain the two largest concentrations of chromium in their bottom sediments (the two largest values in fig. 27*B*). Site Y-38B is located between sites Y-38 and Y-39; and, although the chromium concentration, 41 μg/g (micrograms per gram) (fig. 27*B*), is less than that at sites Y-38 and Y-39, the concentration is larger than the concentrations at most of the sites. The chromium concentrations in the sediments at sites Y-40 and Y-41A (upstream from Craig) are equal to or less than the median value of 5 to 10 μg/g.

Nutrients, Dissolved Oxygen, and Aquatic Biology

Dissolved and total nitrogen, phosphorus, and organic carbon were determined for the water samples collected during August-September 1975. An outlier analysis of the data indicates that sites Y-26, Y-46, and Y-54 are located downstream from sources that contribute significant nitrogen or phosphorus to the streams. Water at site Y-26 contained 3.0 mg/L dissolved nitrite plus nitrate as nitrogen. Water at site Y-46 contained 0.17 mg/L dissolved phosphorus. Water at site Y-54, a site designed to evaluate the relative effects of coal mining along Foidel Creek, contained 0.46 mg/L total phosphorus, most of which was in the suspended phase.

Dissolved oxygen was measured at all sites that contained flowing water during the August-September 1975 reconnaissance. One measurement had to be discarded. Three of the measurements (sites Y-42A, Y-48, and Y-54) were below the lower allowable limit of 6 mg/L for cold-water biota (Colorado Department of Health, 1977); whereas, only two measurements (sites Y-42A and Y-54) were less than the lower limit of 5 mg/L believed to be applicable to warm-water biota according to the current standard (see fig. 18 for locations). The value of 3.6 mg/L at site Y-54 can be explained by the lack of reaeration at this site; there was no continuous surface flow at this site during the basinwide reconnaissance. The dissolved-oxygen concentration at site Y-42A was 4.7 mg/L, and at site Y-48 it was 5.9 mg/L.

The solubility of oxygen in water decreases with increasing altitude and with increasing water temperature. Thus, it theoretically is possible for the saturation value of dissolved oxygen to be less than the 6 mg/L limit cited above. During the August-September 1975 reconnaissance, this did not occur; the lowest saturation value for dissolved oxygen was 6.6 mg/L at sites Y-1 and Y-32. The percent saturation of dissolved oxygen ranged from 44 to 162; 57 of 81 values were greater than 100 percent of saturation. The minimum percent saturation occurred at site Y-54, which also was the site of the minimum dissolved-oxygen concentration.

A Surber sampler (Greeson and others, 1977a, p. 172-173) was used to collect samples of the aquatic macroinvertebrate communities at 72 stream sites in the Yampa River basin during August-September 1975. Ekman-dredge samples (Greeson and others, 1977a, p. 148) were collected at eight sites that were unsuitable for use of the Surber sampler. Periphyton populations were sampled using plastic strips tied to a stake in the stream bottom (Greeson and others, 1977a, p. 129-130). These strips were recovered approximately 5 weeks later at 62 of 74 sites.

As part of the analysis performed on the benthic macroinvertebrate samples, diversity indices were computed using the formula given by Slack, Averett, Greeson, and Lipscomb (1973):

$$\bar{d} = -\sum_{i=1}^{t} \left(\frac{n_i}{n}\right) \log_2 \left(\frac{n_i}{n}\right),$$

where $\bar{d}$ is the diversity per individual, n is the total number of individuals, n_i is the number of individuals in each taxon, and t is the number of taxa. The calculations were made at the genus level. When plotted in the form of a histogram (fig. 28), the distribution of $\bar{d}$ is seen to be negatively skewed with most values in the range from 2.0 to 4.0.

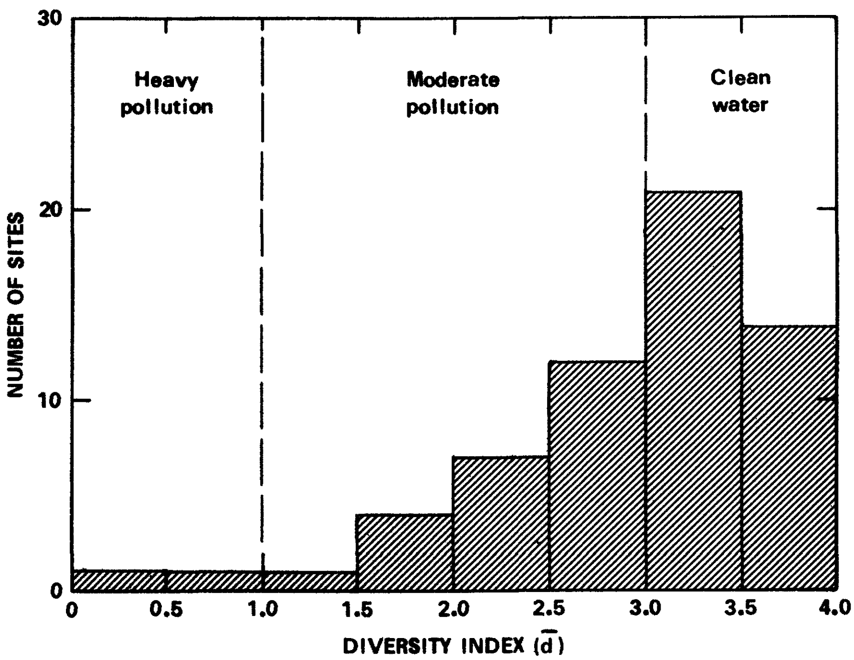


Figure 28.—Frequency distribution of diversity indices of benthic macroinvertebrates in streams of the Yampa River basin, August-September 1975 (the classifications heavy pollution, moderate pollution, and clean water are after Wilhm and Dorris, 1968).

According to Wilhm and Dorris (1968), values of $\bar{d}$ "* * * less than 1 have been obtained in areas of heavy pollution, values from 1 to 3 in areas of moderate pollution, and values exceeding 3 in clean water areas." However, these descriptions of the range of diversity indices are not felt to apply to curved conditions in the Yampa River basin. Fifty-seven percent of the $\bar{d}$ values calculated as part of the basinwide reconnaissance were greater than 3. Only two values of $\bar{d}$ were less than 1--at sites Y-24 and Y-76. The low values at both sites are felt to result from natural environmental stress, rather than from any kind of pollution (D. A. Wentz and T. D. Steele, written commun., 1978).

Ambient Stream Quality

Based on the preceding analysis of data collected during the August-September 1975 basinwide reconnaissance, the maximum likely ambient concentrations of selected chemical constituents in streams of the Yampa River basin have been determined. Application of the procedure in this context was first used by Wentz (1974) for detecting impacts of metal mining on Colorado streams. The maximum likely limit for ambient concentration for a given constituent is defined herein as the mean plus twice the standard deviation ($\bar{x}$+2s) for data obtained at sites determined from the outlier analysis to be unaffected by upstream water-quality degradation. This includes all sites except Y-21, Y-26, Y-46, Y-54, and Y-68. A summary of these maximum concentrations of constituents, so determined, is given in table 11. These values are revisions of those originally presented by Wentz and Steele (1976).

Waste-Load Assimilative Capacity of the Yampa River

An extensive 24-hour data-collection effort was conducted during September 23-24, 1975, on a reach of the Yampa River from Steamboat Springs to Hayden, Colo. These data were collected during low-flow conditions to evaluate the waste-load assimilative capacity of this reach of the stream. An overview of the data-collection and modeling results is presented below. Details of the model-simulation analysis and findings of the several waste-load alternatives are described by Bauer, Steele, and Anderson (1978). This study updates previous waste-load allocation studies for the Yampa River reported by Misbach (1972) and McCall-Ellingson and Morrill, Inc. (1974).

The study reach is 38 mi (61 km) in length and drains an area primarily consisting of forested mountains on the western slope of the southern Rocky Mountains. The 1975 permanent population in the Steamboat Springs area was approximately 5,000 people; however, the permanent population is expected to double by 1985. This growth will be due to a combination of impending development of coal resources and increased recreational use. A substantial seasonal variation in population in the Steamboat Springs area occurs each year because of summer and winter recreational activities. Because of this variation, two population indexes (peak-day and permanent population) were used for the analysis of waste-load assimilative capacity. The peak-day population is defined as the maximum daily population for a given year, and

Table 11.--*Maximum likely ambient concentrations of chemical constituents in streams of the Yampa River basin, August-September 1975*

[Modified from Wentz and Steele, 1976]

Constituent	Number of analyses	Concentration ($\bar{x}+2s$)
Specific conductance, micromhos per centimeter at 25°C	77	1,700
Dissolved solids, mg/L (milligrams per liter)	28	660
Total hardness, mg/L as calcium carbonate	28	440
Calcium, mg/L	28	97
Magnesium, mg/L	28	51
Potassium, mg/L	28	4.5
Sodium, mg/L	28	85
Bicarbonate, mg/L	28	360
Chloride, mg/L	28	21
Fluoride, mg/L	28	.42
Sulfate, mg/L	30	250
Silica, mg/L	28	21
Dissolved organic carbon, mg/L	75	21
Dissolved plus suspended organic carbon, mg/L	75	22
Dissolved Kjeldahl nitrogen, mg/L as N	75	.49
Total Kjeldahl nitrogen, mg/L as N	75	.69
Dissolved nitrite plus nitrate, mg/L as N	75	.21
Total nitrite plus nitrate, mg/L as N	75	.21
Dissolved phosphorus, mg/L as P	75	.067
Total phosphorus, mg/L as P	75	.13
Dissolved cadmium, µg/L (micrograms per liter)	77	0
Total cadmium, µg/L	77	([1])
Dissolved cobalt, µg/L	77	.56
Total cobalt, µg/L	76	62
Dissolved copper, µg/L	77	3.0
Total copper, µg/L	75	18
Dissolved iron, µg/L	77	160
Total iron, µg/L	77	1,900
Dissolved lead, µg/L	77	1.4
Total lead, µg/L	76	([2])
Dissolved manganese, µg/L	77	220
Total manganese, µg/L	76	310
Dissolved mercury, µg/L	77	.067
Total mercury, µg/L	77	.10
Dissolved nickel, µg/L	77	4.4

Table 11.--*Maximum likely ambient concentrations of chemical constituents in streams of the Yampa River basin, August-September 1975*--Continued

Constituent	Number of analyses	Concentration ($\bar{x}$+2s)
Total nickel, µg/L	76	50
Dissolved selenium, µg/L	77	2.6
Total selenium, µg/L	77	3.0
Dissolved vanadium, µg/L	77	2.7
Dissolved zinc, µg/L	77	14
Total zinc, µg/L	76	33
Bottom antimony, µg/g (micrograms per gram)	43	7.0
Bottom arsenic, µg/g	43	13
Bottom chromium, µg/g	43	50
Bottom copper, µg/g	43	19
Bottom iron, µg/g	43	15,000
Bottom lead, µg/g	43	270
Bottom mercury, µg/g	43	.072
Bottom nickel, µg/g	43	17

[1]All values were <10 µg/L.
[2]All values were <100 µg/L.

permanent population is defined as the average number of year-round residents in the Steamboat Springs area.

During the 24-hour data-collection effort, samples were collected at approximately 3-hour intervals at 33 sites along the study reach. A total of 6 wastewater-effluent, 16 main-stem, and 11 tributary sites were sampled (fig. 29). At all sites, field determinations were made for stream discharge, dissolved oxygen (DO), water temperature, specific conductance, fecal-coliform and total-coliform bacteria, and pH. In addition, water samples were collected for laboratory analysis of biochemical oxygen demand (BOD) and selected forms of nitrogen and phosphorus.

Based upon data collected during the 24-hour sampling period, profiles of the mean values of DO concentrations, stream temperature, and 5-day BOD are shown in figure 30. The mean DO concentrations in the study reach were within 5 percent of saturation, with the mean concentration exceeding 8 mg/L at each location. Mean DO concentrations in the reach were larger just upstream and downstream from the Steamboat Springs wastewater-treatment plant. These large concentrations may be due, in part, to the large number of algae and submerged vascular plants at the sites (Eddy, 1975). The BOD peaks observed at main-stem sites YM-1 and YM-3 probably reflect the effects of discharges of wastewater-treatment plants just upstream (sites YE-1 and YE-3, fig. 30). The BOD peak in the vicinity of site YM-8 is not readily explainable. One possible cause is irrigation return flow in this area of the study reach.

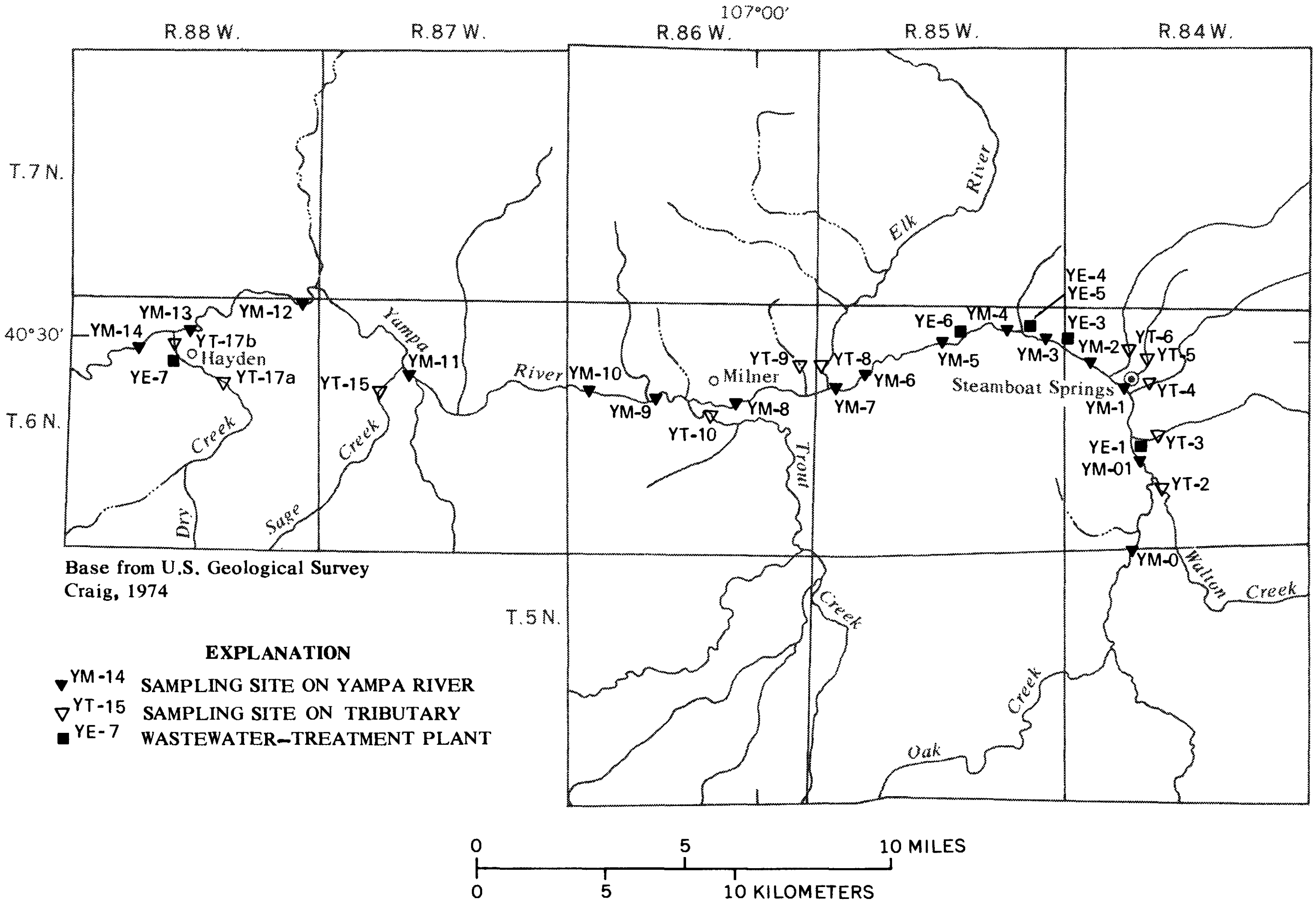


Figure 29.--Location of sampling sites for analysis of waste–load assimilative capacity of Yampa River, September 23–24, 1975 (from Bauer and others, 1978).

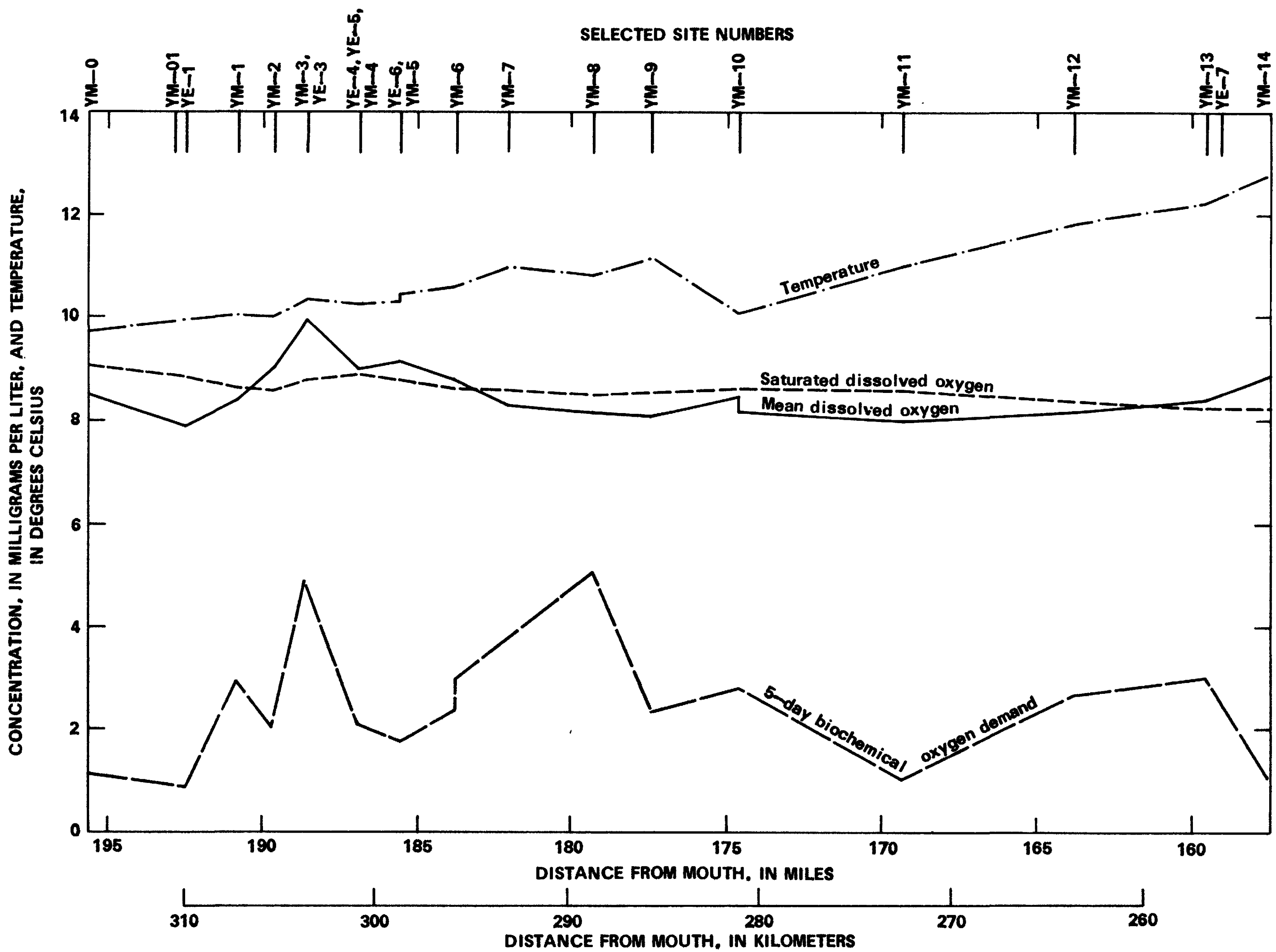


Figure 30.--Mean water temperature and concentrations of selected water-quality constituents in Yampa River, September 23-24, 1975 (from Bauer and others, 1978).

Stream temperatures during the 24-hour sampling period averaged about 10° to 11°C from Steamboat Springs to Sage Creek. Downstream from Sage Creek, the stream temperature in the Yampa River increased to approximately 13°C (fig. 30). The discharge from Sage Creek, which was receiving thermal-heated effluent from the Hayden Powerplant, had an average temperature of 16°C and contributed to the increased temperature in the Yampa River downstream from Sage Creek. The slope of the Yampa River decreases from Sage Creek to Hayden (fig. 29). As a result, the mean river velocity decreases, creating larger pools in this part of the study reach. This results in a longer residence time per unit length of stream and allows the water in the stream to approach its equilibrium temperature more quickly for a given length of stream reach.

The diel variations of pH and water temperature for one of the sampling sites were depicted previously in figure 26. Diel variations observed for other water-quality variables during the 24-hour sampling period are discussed by Bauer, Steele, and Anderson (1978).

The streamflows of the Yampa River during the field data-collection effort were nearly four times higher than the estimated minimum mean 7-day low flow and 10-year recurrence interval (Q7,10). For the Yampa River at Steamboat Springs, the measured average flow at the time of collection of the calibration data was 111 ft^3/s (3.14 m^3/s); whereas, the estimated Q7,10 flow is nearly 30 ft^3/s (0.85 m^3/s) (table 7, p. 52). For the simulation phase of the analysis of the waste-load assimilative capacity, the streamflows and water-quality conditions were adjusted to a Q7,10 discharge level, and the corresponding subreach traveltimes and rate coefficients were modified accordingly (Bauer and others, 1978). Possible augmentation of flow from the proposed Yamcolo Reservoir upstream from Steamboat Springs (see p. 106) also was evaluated. Detailed results of this analysis are discussed by Bauer, Steele, and Anderson (1978).

Two models were used in the calibration phase of the analysis--the U.S. Geological Survey model (Bauer and Jennings, 1975) and a modified Pioneer-I steady-state water-quality model (Waddel and others, 1973). The purpose of this comparison was to show differences in the computational algorithms used in the models for the same model-parameter values. Modeling comparisons included the following water-quality variables: Total-nitrogen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, carbonaceous BOD (CBOD), DO, and fecal-coliform-bacteria concentrations (Bauer and others, 1978).

For the simulation phase of the report, the U.S. Geological Survey model was used. This choice was made because of previous experience, the ease with which it can be used, and the form of the required data. Several major factors were considered in the model simulations--for example, existing stream-reach classifications, suggested standards for effluent from a proposed regional wastewater-treatment plant, and Steamboat Springs area population projections. The stream reach has been classified by the State of Colorado as a cold-water-fishery secondary-body-contact type B1 (Colorado Department of Health, 1974). With this classification, there are various water-quality requirements.

A regional wastewater-treatment plant is proposed in the Steamboat Springs area (U.S. Environmental Protection Agency, 1977). There are four alternative proposals for the location of the plant and type of treatment to be used. Two alternative proposals involve extended aeration and advanced wastewater treatment. The other two alternative proposals involve mixed advanced wastewater treatment and include land treatment during a part of each year. The analysis of waste-load assimilative capacity only considered alternatives which included extended aeration and advanced wastewater treatment. The land treatment of the other alternatives can produce nonpoint surface runoff which the study framework has no means to evaluate. Suggested effluent standards for various time designations (1978, 1983, and 1985) were considered.

The modeling analysis of waste-load assimilative capacity of the Yampa River from Steamboat Springs to Hayden indicated that nonionized ammonia-nitrogen concentrations possibly may exceed proposed stream standards on peak-population days (fig. 31). Based upon this analysis, concentrations of dissolved oxygen, fecal-coliform bacteria, total nitrogen, and nitrate nitrogen would not exceed current or proposed stream standards for the projected waste loadings (Bauer and others, 1978). The computed concentrations were based on population projections for 2010 and inflow to the proposed regional wastewater-treatment plant at Steamboat Springs of 134 gal (0.507 m^3) per capita per day. Both December and September streamflow conditions and population projections were considered. For December, a peak-day population of approximately 26,000 people was used and, for September, a permanent population of approximately 11,500 was used. Effects of interim population of the area and of uncertainty in per-capita plant-inflow loadings on total and nonionized ammonia nitrogen are indicated in tables 12A and 12B (Bauer and others, 1978). The model-simulated concentrations of nonionized ammonia nitrogen consistently indicated that the proposed Colorado standard using peak-day population projections might be exceeded (table 12B). Critical-period streamflow conditions in the study reach were assumed for both the December and September conditions to equal the 7-day low flow with 10-year recurrence interval (28 ft^3/s or 0.79 m^3/s). This index flow is computed from a standardized computerized procedure from annual flow series (April 1 through March 31) from the period of record. A 20-ft^3/s (0.57-m^3/s) flow augmentation from the proposed Yamcolo Reservoir also was considered. A permissible increase in waste load of approximately 25 percent was indicated by the modeling analysis for this amount of flow augmentation. The different treatment-plant effluent concentrations assumed for September and December (fig. 31) reflect the relatively larger plant loadings in December and the proposed effluent standards considered by the State of Colorado. The estimated peak in nonionized ammonia concentration occurred at site YM-6. An average pH value of 8.5 at this site measured during the collection of calibration in September 23-24, 1975 (Bauer and others, 1978), was used in this computation.

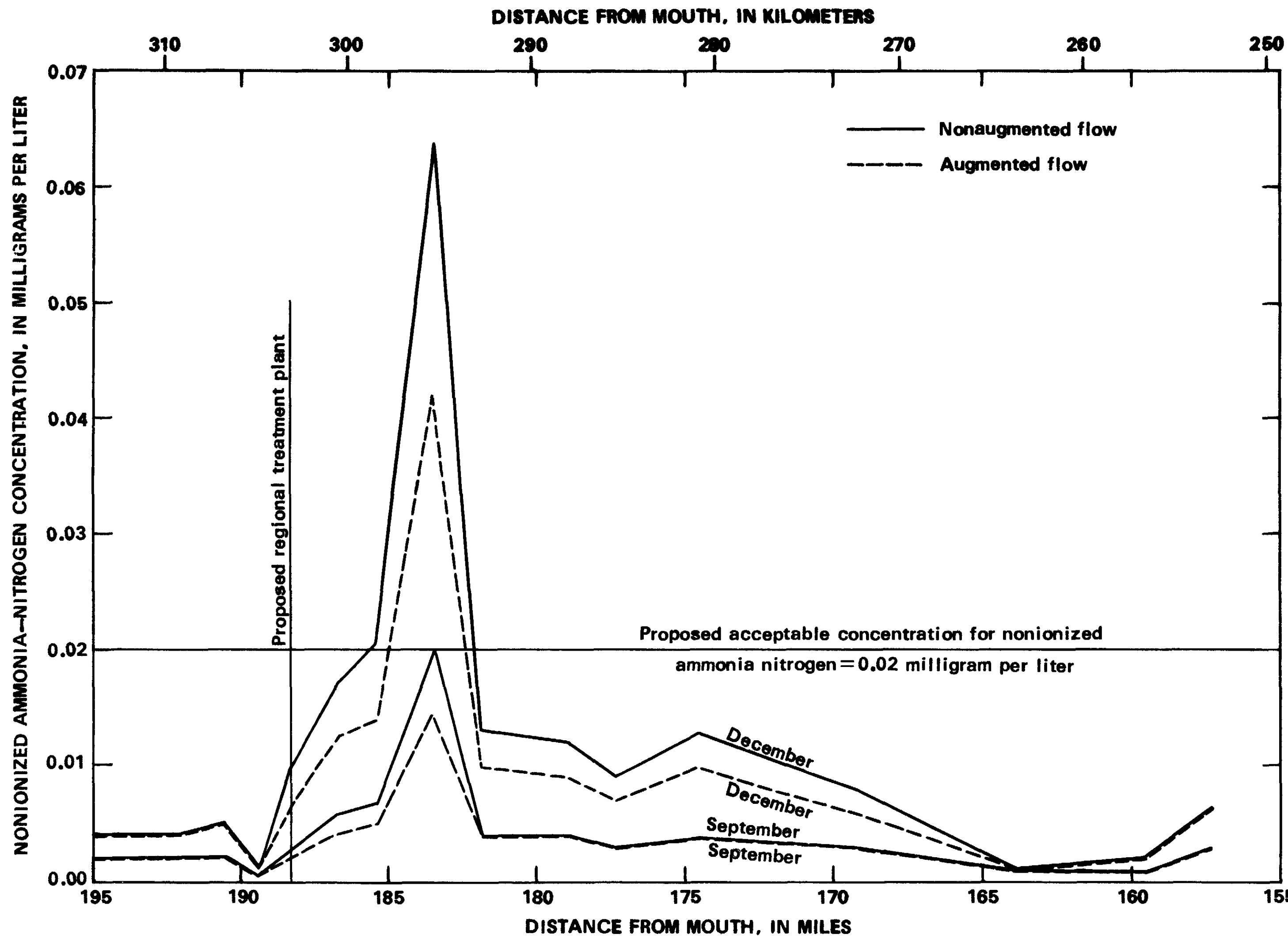


Figure 31.--Computed concentrations of nonionized ammonia nitrogen using 1978 standards for effluent, Yampa River, assuming 9 milligrams per liter (December) and 2.8 milligrams per liter (September) of ammonia nitrogen in effluent from wastewater–treatment plant (from Bauer and others, 1978).

Table 12.--*Maximum computed ammonia-nitrogen and nonionized ammonia-nitrogen concentrations for the Yampa River, Steamboat Springs to Hayden, Colo.*

[From Bauer, Steele, and Anderson, 1978]

Year	Projected permanent population	Effluent (gallons per capita)	Maximum concentration, in milligrams per liter	
			Ammonia nitrogen	Nonionized ammonia nitrogen
	A. Permanent populations and 1978 effluent standards			
1990	8,200	100	0.15	0.015
1995	9,000	100	.16	.016
2000	9,600	100	.18	.017
2005	9,750	100	.18	.017
2010	10,000	100	.19	.018
1990	8,200	125	.19	.018
1995	9,000	125	.19	.018
2000	9,600	125	.21	.020
2005	9,750	125	.21	.020
2010	10,000	125	.21	.020
1990	8,200	150	.21	.020
1995	9,000	150	.22	.021
2000	9,600	150	.23	.022
2005	9,750	150	.23	.022
2010	10,000	150	.24	.023
	B. Peak-day populations and 1978 effluent standards			
1990	17,000	100	0.81	0.036
1995	20,500	100	.94	.042
2000	23,000	100	1.04	.047
2005	24,500	100	1.09	.049
2010	26,000	100	1.11	.050
1990	17,500	125	.99	.044
1995	20,500	125	1.14	.051
2000	23,000	125	1.23	.055
2005	24,500	125	1.30	.058
2010	26,000	125	1.33	.059
1990	17,500	150	1.16	.052
1995	20,500	150	1.33	.059
2000	23,000	150	1.44	.064
2005	24,500	150	1.53	.068
2010	26,000	150	1.55	.070

A concurrent assessment of periphyton and macroinvertebrates was conducted for the 16 main-stem locations by the U.S. Environmental Protection Agency and U.S. Geological Survey (Eddy, 1975). A possible relation between the benthic-invertebrate diversity index and several nutrient concentrations was compared with the mean diversity data and resulted in relatively high negative correlation coefficients, r= -0.7 for ammonia nitrogen and -0.6 for orthophosphate. Periphyton data collected at the 16 main-stem locations indicated low correlation with the nutrient concentrations observed in the stream reach.

Ground Water

Ground water occurs in all of the sedimentary rocks underlying the Yampa River basin. The hydrologic characteristics of each of these geologic units are summarized in table 13.

Most ground-water use in the basin is for domestic and stock-watering purposes. Ground water provides less than 1 percent of the water used on irrigated lands in the basin (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). The public-water supply for the town of Baggs, Wyo., as well as for a few other small towns in the western part of the basin, is provided by ground-water sources. Industrial use of ground water is very limited to date but does include several oil-well, coal-mining, and railroad operations.

Most wells in the basin yield generally less than 25 gal/min (1.6×10^{-3} m^3/s). Favorably located wells penetrating the entire formation where the sandstones are thickest and (or) fractured probably would have yields considerably greater.

The Mancos Shale, the Lewis Shale, and the Lance Formation contain ground water but are relatively impermeable. This effectively prevents the movement of water through these geologic units, and they can be considered as aquicludes.

Ground water in the Mesaverde Group (Williams Fork and Iles Formations) in most of the basin is confined by the Mancos and Lewis Shales and by the Lance Formation (Brogden and Giles, 1977). Along the outcrop areas of the Mesaverde Group, water-table conditions exist.

Water in the Browns Park, Fort Union, and Wasatch Formations is generally under water-table conditions. The lacustrine deposits of the Green River Formation may result in more than one aquifer in sections of the Wasatch Formation.

Recharge to the ground water occurs as infiltration of precipitation and snowmelt and as seepage losses from streams. Recharge to the deep aquifers occurs only in the outcrop areas.

Table 13.--*Hydrologic characteristics of geologic units*

[Adapted from Boettcher (1972) and Brogden and Giles (1977)]

Geologic unit	Hydrologic properties	Water quality	Sources of recharge and discharge
Alluvium	Of the alluvial deposits, river-channel deposits are the most important source of water. Probably more wells tap the river-channel deposits than any other geologic unit. Where saturated, yield water freely to wells, as much as several hundred gallons per minute	Dissolved-solids concentration varies over a wide range depending on the source of recharge. Dissolved-solids concentration generally less than 1,000 mg/L	For river-channel deposits, recharge occurs primarily as seepage losses from streams. For all other alluvial deposits, local infiltration of precipitation and snowmelt are main sources of recharge. Discharge is to streams and by wells.
Browns Park Formation	Probably the best aquifer within the study area. Yields water freely to wells. Favorably located wells might yield as much as 300 gal/min	Generally this water has a dissolved-solids concentration less than 1,000 mg/L. In the area south of Steamboat Springs, dissolved-solids concentration generally less than 500 mg/L	Recharge to the Browns Park is from direct infiltration of precipitation and snowmelt. Discharge from the Browns Park occurs mainly as discharge to streams. In some areas, ground water is discharged to the underlying bedrock aquifer, such as south of Steamboat Springs where the Browns Park overlies the upturned Iles Formation. Increasing pumpage by wells from some areas of the Browns Park Formation also may be an important source of discharge.
Green River and Wasatch Formations	Well yields from Green River Formation are reported by Welder and McGreevey (1966) to be as much as 200 gal/min in the western part of Washakie Basin. Elsewhere, wells tapping the Green River Formation have smaller yields. Ground-water possibilities of the Wasatch Formation are generally better than that of the Green River Formation. Many domestic and stock wells tap ground-water sources within the Wasatch. Most wells yield less than 15 gal/min,	Dissolved-solids concentration normally in range of 500 to 1,500 mg/L but may be locally much greater	Direct infiltration of precipitation and snowmelt accounts for most of recharge to the ground water for the Green River, Wasatch, and Fort Union Formations. In addition, stream losses from the Little Snake River may be a major source of recharge to the Wasatch and Fort Union Formations. The Little Snake River downstream from Baggs flows mainly through the Wasatch and Fort Union Formations. In this reach, the water table is mainly below the stream level and,

Table 13.--*Hydrologic characteristics of geologic units*--Continued

Geologic unit	Hydrologic properties	Water quality	Sources of recharge and discharge
Green River and Wasatch Formations	but yields as much as 250 gal/min have been reported. Favorably located wells might yield as much as 500 gal/min		therefore, stream losses to the ground water should occur. Discharge from the Green River, Wasatch, and Fort Union Formations probably is due mainly to evapotranspiration.
Fort Union Formation	Reported well yields from the Fort Union are as much as 300 gal/min. Favorably located wells might yield as much as 500 gal/min	Dissolved-solids concentration is typically in range of 400 to 700 mg/L near Craig to 800 to 3,000 mg/L in the Wyoming part of the basin	
Lance Formation	Ground-water potential largely unknown but probably small. Shale layers should prevent most movement of ground water. Sandstone beds may provide up to 5 gal/min of water to favorably located wells	Two analyses indicate dissolved-solids concentrations of about 500 mg/L	Small amounts of recharge occur in the Lance Formation and Lewis Shale in the outcrop areas from direct infiltration of precipitation and snowmelt and from seepage losses from streams. No recharge occurs as the result of deep infiltration. Sources of discharge from Lance or Lewis are unknown.
Lewis Shale	Well yields generally less than 5 gal/min. Few wells in study area obtain water from the formation	In the vicinity of Craig and Hayden, dissolved-solids concentrations are generally less than 1,000 mg/L. Elsewhere, dissolved-solids concentrations are more than 1,000 mg/L	
Mesaverde Group	Well yields generally less than 100 gal/min, but favorably located wells may yield as much as 200 gal/min. The sandstones of the Williams Fork Formation, with the exception of the Twentymile Sandstone Member, generally are less continuous and, hence, less significant as aquifers than those of the underlying Iles	Dissolved-solids concentration ranges from about 300 to 1,500 mg/L but is normally less than 1,000 mg/L	Recharge areas are in the Williams Fork Mountains in the southeastern part of the basin and in the outcrop areas along the eastern margin of the basin at the base of the Park Range. Recharge is from direct infiltration of precipitation and snowmelt in these areas. The Yampa River flows across the Mesaverde just west of Milner and

Table 13.--*Hydrologic characteristics of geologic units*--Continued

Geologic unit	Hydrologic properties	Water quality	Sources of recharge and discharge
Mesaverde Group	Formation. In Wyoming, the Almond and Ericson Formations are much more important aquifers than the Rock Springs and Blair Formations		again southwest of Craig. Possible seepage losses from the Yampa River in these reaches may be a major source of recharge. Additional recharge to the Mesaverde occurs in the Rock Springs uplift and near the Rawlins uplift. However, this additional recharge is probably minimal, as there are relatively small amounts of precipitation recorded in these areas. No recharge occurs as the result of deep infiltration in the central part of the basin. Discharge points from the Mesaverde are largely unknown. Discharge may result from ground-water underflow into the Green River basin or from upward movement of the ground water through the Lewis Shale and Lance Formation into the overlying Wasatch and Fort Union Formations.
Mancos Shale	Well yields generally less than 5 gal/min. Locally used for stock watering. The shales are relatively impermeable to water movement	Generally this water is highly mineralized with a dissolved-solids concentration greater than 1,000 mg/L	Small amounts of recharge occur in outcrop areas from direct infiltration of precipitation and snowmelt and from seepage losses from streams. No recharge occurs as the result of deep infiltration in the central part of the basin. Discharge points are not known.
Lower Cretaceous through Cambrian rocks	These rocks are generally deeply buried in most of the basin, and, therefore, are of little practical importance and, thus, largely ignored. The Leadville or Madison Limestone in other parts of Colorado and Wyoming has yielded as much as 3,000 gal/min to wells from caverns and solution cavities	Unknown	Unknown.

Table 13.--*Hydrologic characteristics of geologic units*--Continued

Geologic unit	Hydrologic properties	Water quality	Sources of recharge and discharge
Basement complex	For hydrologic purposes, the basement complex is considered to be nonwater-bearing. These rocks are nearly impermeable except where fractured or weathered.		

Ground-water losses from the basin occur as evapotranspiration, ground-water underflow, and discharge into streams. Discharge to wells is generally small relative to the above losses; therefore, the current ground-water regime is virtually in steady-state conditions. Discharge also may occur as a result of upward movement of the water from the deep confined aquifers into overlying formations.

The interactive relationship between the ground- and surface-water systems depends, for the most part, on the geologic structure of the bedrock strata in the basin. In reaches where streams flow over exposed sandstone beds, such as occurs in the Mesaverde Group, Browns Park, Wasatch, and Fort Union Formations, or through unconsolidated alluvial deposits, the degree of hydrologic connection is great and the ground- and surface-water systems interact to varying degrees with each other. In other reaches where streams flow over exposed shale layers, such as occurs in the Mancos and Lewis Shales and in the Lance Formation, the degree of hydrologic connection is small and the ground- and surface-water systems have little influence on each other.

Boettcher (1972) estimated the ground-water contribution to streamflow at three sites in the Yampa River basin. The average ground-water contribution was 26 percent of total streamflow for the Yampa River at Steamboat Springs (station 09239500, map code 13), 25 percent for Fish Creek near Milner (station 09244100, map code 27), and 15 percent for the Little Snake River near Slater (station 09253000, map code 62) (fig. 14). During high flow, the ground-water contribution is a much smaller percentage of the streamflow and during low flow it probably accounts for nearly 100 percent of the streamflow at locations not affected appreciably by irrigation return flows. For the most part, the streams upstream from these three sites f[illegible] through the Browns Park Formation or unconsolidated alluvial deposits, where significant interaction occurs between the ground- and surface-water systems.

Ground-water resources in the basin have been relatively undeveloped. In the past, sufficient surface-water supplies have been available to meet most needs and, therefore, there has been no reason to extensively develop the ground-water resources of the basin. However, present unimpounded surface-water supplies are inadequate to meet the projected water demands that will accompany the planned development of the mineral resources in the basin.

The extent to which increased ground-water utilization can be used to offset these future water demands in the basin is dependent upon the availability of sufficient quantities of ground water of acceptable chemical quality for the intended uses. Guidelines would be useful to assure that additional ground-water development would require appropriate spacing of wells and would specify volume limitations so that potential adverse impacts on nearby surface-water bodies would be minimal.

Few quantitative data are available on the geohydrology of the basin. No estimates have been made on the amount of ground water in storage or of recharge and discharge to the various geologic formations. Few data have been gathered on ground-water levels, permeability, and storage-coefficient values or on ground-water quality of the geologic formations. However, a reconnaissance study of aquifers in the Steamboat Springs-Craig area of the Yampa River valley (fig. 1) recently was completed (Brogden and Giles, 1977). Based upon the findings of this study and on known geologic, hydrologic, and climatic conditions, certain qualitative inferences can be made.

The quantity of ground water stored in sedimentary deposits, which may be as much as 25,000 ft (7,600 m) thick in the central part of the basin, is relatively large. The Browns Park, Green River, Wasatch, and Fort Union Formations and the Mesaverde Group are potentially major sources of ground water in the basin. Though the Lance Formation and the Lewis and Mancos Shales contain substantial amounts of ground water, the relative impermeability of these formations preclude their use as possible major sources. The alluvial deposits are not considered as potential major sources of ground water because, in general, these deposits are not thick, are limited in areal extent, and derive their water from streamflow.

The Green River, Wasatch, and Fort Union Formations are considered to be relatively major sources of ground water in the more arid parts of the basin because of their permeability and thickness. Properly located wells might yield from 300 to 500 gal/min (0.02 to 0.03 m^3/s). Recharge to the aquifers is probably small because of the small precipitation and the large rate of evaporation in these areas. Large withdrawals of water would probably result in mining of ground water.

In those areas where the Browns Park Formation is the thickest, large-scale ground-water development may be possible. Properly located wells might yield as much as 300 gal/min (0.02 m^3/s). In areas where this formation is relatively thin and of small areal extent, extensive ground-water development may be limited.

The Mesaverde Group is generally deeply buried in most of the basin; thus, extensive ground-water development seems unlikely in the near future. Recharge to the Mesaverde Group may be large from potential stream losses from the Yampa River in the several reaches where the Yampa flows over this group. Properly located wells might yield a maximum of about 200 gal/min (0.01 m^3/s). Ground-water development from the Mesaverde Group in the outcrop areas probably would result in large water-level declines because of the lack of an adequate recharge source. Moreover, excessive pumping possibly might induce greater infiltration losses in several subreaches of the Yampa River.

No extensive ground-water development is possible from the Lance Formation or the Lewis and Mancos Shales. A regional potentiometric surface probably does not exist in these formations. In general, ground water does not move laterally any appreciable distance from the area of recharge before being discharged at a spring or seep. The potential for ground-water development of these deeper geologic units is largely unknown but probably limited.

Ground-Water Quality

The quality of the ground water is highly variable throughout the basin. In general, ground water in the younger formations near the surface is of better quality than ground water in the older formations that are deeply buried.

The relationship between lithology and the chemical constituents in ground water is complex. In general, the cations (mainly calcium, magnesium, sodium, and potassium) and dissolved silica are derived directly from the solution of minerals in rocks; whereas, the anions (mainly bicarbonate, carbonate, chloride, sulfate, and nitrate) are derived from nonlithologic sources. The dominant cations found in ground water are calcium and sodium ions. These are commonly derived from weathering of igneous rocks, such as granite, which comprise the bordering mountains and form the basement complex beneath the basin. Another source of sodium ions is from cation-exchange reactions in ground water contacting either marine sandstones or marine shales which have been saturated in the past with sea water. The solution of limestone, dolomite, and gypsum also contributes calcium ions as well as some magnesium ions in localized areas.

The dominant anions found in the ground water are bicarbonate and sulfate ions. Sulfate ions are found in ground water that has been in contact with gypsum, organic materials, or coals. Bicarbonate and carbonate ions are commonly derived from the carbon dioxide which is dissolved by naturally circulating water. The chloride ion is not found in ground water in the basin to any appreciable degree. This is unexpected, in that fine-grained marine shales, such as those that occur in the basin, normally retain some of the chloride ions found in sea water for very long periods as sodium chloride.

Using data collected by the U.S. Geological Survey, areal patterns by geologic units in ground-water chemical quality are shown on figure 32. The area within each stiff diagram is representative of the dissolved-solids concentration of the water.

The chemical character of water from the alluvial aquifers is influenced by surface water in the stream channels that is in contact with the alluvium, by the underflow of water from sedimentary aquifers, and by the type of material that was eroded and deposited as alluvium. Dissolved-solids concentration of water in the alluvium is generally less than 1,000 mg/L, and this water normally is suitable for agricultural, municipal, or most industrial uses.

Water from the Browns Park Formation is predominantly a calcium bicarbonate type. Precipitated calcium carbonate works as a cementing agent and partly cements the sandstone and conglomerate aquifer of the Browns Park Formation. Dissolution of this precipitate also may occur, which may account for the predominantly calcium bicarbonate type water found in this geologic unit. Dissolved-solids concentration of water in the Browns Park Formation

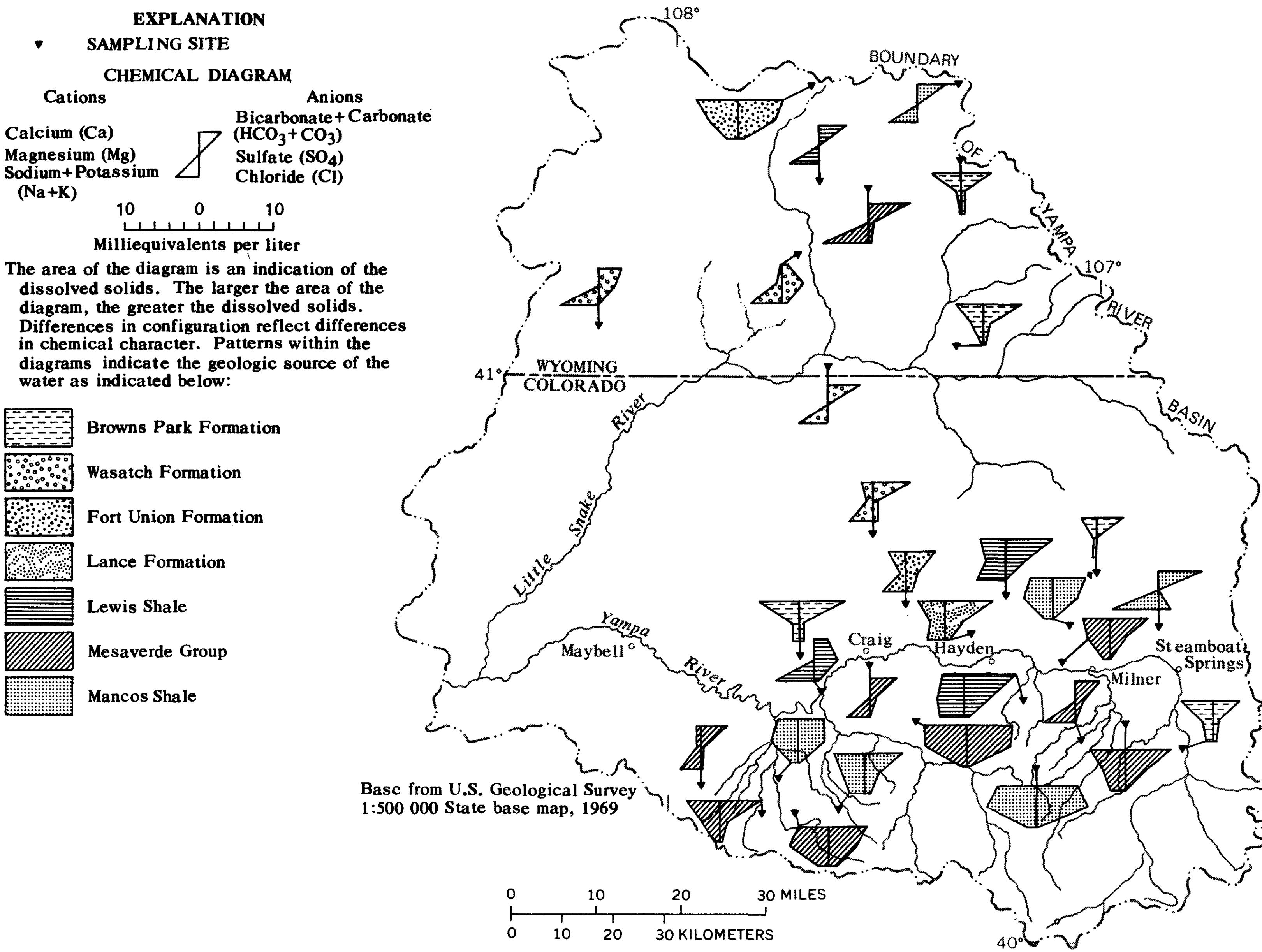


Figure 32.--Areal distribution of ground-water chemical quality.

generally is less than 1,000 mg/L, which makes the water suitable for most agricultural uses, such as irrigation of crops and stock watering, as well as for municipal or industrial supplies.

Water from the Wasatch and Fort Union Formations is predominantly a sodium or calcium bicarbonate type. Sulfate type water also is found where the water has been in contact with gypsum or coals that are present in these formations. Dissolved-solids concentration of water in these geologic units commonly ranges from 500 to 1,500 mg/L but locally may be as much as 3,000 mg/L. Hence, water from this source is suitable for most agricultural uses but may be unsuitable for municipal or certain industrial uses. These formations are sources of water in the more arid parts of the basin where the soils are poorly weathered and not well drained. These factors probably would limit the use of water from the Wasatch and Fort Union Formations for irrigation more than would the dissolved-solids concentration of the water.

Water from the Lance Formation and the Lewis and Mancos Shales is predominantly a calcium or sodium bicarbonate type water. Also common in the Lewis and Mancos Shales are sulfate type waters which probably are produced from the reduction of organic materials that are common in black shales. Calcium and magnesium type waters are found in the Mancos Shale as the result of the solution of some limestone and dolomite beds that do occur in this formation. Dissolved-solids concentration of water in these three formations is generally more than 1,000 mg/L and frequently much greater. Well yields in the Lance Formation and the Mancos and Lewis Shales are too small for most water uses except for stock watering.

Water from the Mesaverde Group is generally either a sodium bicarbonate type or a calcium magnesium, bicarbonate sulfate type, the latter probably resulting from upward water flow from the Mancos Shale into the Mesaverde Group. Coals in the Mesaverde Group contain few sulfur coals, and sulfate type water resulting from reduction of sulfur-containing minerals, such as pyrite and gypsum usually associated with coals, is not often found in the Mesaverde Group. Dissolved-solids concentration of water from the Mesaverde Group ranges from 300 to 1,500 mg/L but generally is less than 1,000 mg/L. Ground water from this group normally is suitable for most agricultural, industrial, and municipal uses.

Ground-water quality in the rocks of lower Cretaceous through Precambrian ages is largely unknown but assumed poor. These rocks are generally too deeply buried to be of practical importance.

Water-quality requirements for industrial uses normally are not as stringent as those for public-water supplies, recreational, stock, or agricultural uses. In many instances, the quantity requirement may be a greater hindrance to ground-water development than the chemical-quality restrictions. Possible relevant industrial uses include cooling in coal-conversion plants, source of hydrogen for coal gasification, or slurry pipelines. The relatively small quantities of water needed for drinking purposes at industrial sites in the basin generally are available.

Water Law and Legal Compacts

Water availablilty in the Yampa River basin for any given use is controlled largely by the water-rights doctrines of Colorado and Wyoming. Also, the availability of water is influenced by interstate and regional compacts dictated for the Upper Colorado River Basin and the Colorado River basin in its entirety. An excellent treatise on the legal ramifications of energy development in the Colorado River basin is provided by Weatherford and Jacoby (1975).

A brief discussion of the pertinent legal and institutional factors which determine water availability in the Yampa River basin is given in this report. A more complete discussion of water law and other institutional aspects affecting water availability and use in the Colorado part of the Yampa River basin is found in a report by Knudsen and Danielson (1977). This report is the result of a study by the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer, that was funded by the U.S. Geological Survey. Other aspects of water law in Colorado are discussed by Peak (1977).

Both Colorado and Wyoming authorize diversions of water for beneficial uses within the appropriated doctrine of water rights (U.S. Department of the Interior, 1974). However, the means of obtaining water rights in each State differs. Water rights are issued in terms of flow-diversion rates, in cubic feet per second, or reservoir-storage capacity, in acre-feet. Differences in water-law procedures in the two States in the Yampa River basin are highlighted below.

Water Law in Colorado

In Colorado, two types of water decrees are made--conditional and absolute decrees. Conditional decrees are authorized as a result of proposed plans, particularly for reservoir projects. These decrees have no time limits as far as conversion to absolute decrees. When projects have been completed and all of the prerequisites have been fulfilled, absolute water-right decrees are issued. In Colorado, water rights generally can be transferred from the land to which they originally applied. Water rights are administered by the Colorado State Engineer's Office as established by court decrees (U.S. Bureau of Reclamation, 1974b). Court procedures have no safeguard to prevent granting of new water rights except for advisory litigative process. As a result, most streams in Colorado have been over-appropriated by prior decrees (Weatherford and Jacoby, 1975). Nonetheless, a party holding a junior adjudicated water right with a current priority date may be able to utilize this right during periods when senior rights are not being used in their entirety. The expansion of water-based outdoor recreation in Colorado and increasing development of the State's energy resources point toward increasing demands on available water supplies, resulting in more intense conflicts over water (Peak, 1977).

The Colorado part of the Yampa River basin is in Water Division 6 under the jurisdiction of the Colorado State Engineer's Office. Five former water districts within Water Division 6 are included in the basin (fig. 33). More than 2,200 adjudicated or pending water rights for these former water districts in Water Division 6 are included in the Water Rights Data File of the Colorado State Engineer's Office (Knudsen and Danielson, 1977). These water rights are ordered according to adjudication date and more than 1,400 rankings are given for Water Division 6. Appropriation dates for water rights in Colorado began in May 1879. The water-data file is current through May 1972.

As a case study, the water rights for Walton Creek and its tributaries in Routt County (former Water District 58) were analyzed (fig. 34). This case study exemplifies the complexity of the water-rights situation and indicates the various types of water uses, diversions, and transbasin exports that take place in the Yampa River basin. In the case study, 39 water-rights decrees involved 98 entries. The majority of the decrees consist of single entries, but several decrees have multiple entries and 1 decree has 16 entries. The major consumptive use of water in this area is for irrigation; however, additional supplies are provided for domestic, municipal, and stock uses. Also, an interbasin diversion from the Yampa River basin into the South Platte River drainage is included in one of the decrees. No adjudicated water rights since May 30, 1972, were included in the water-rights tabulation provided from the State Engineer's Office.

With respect to ground-water development, a recent law requires a State well permit for all newly drilled wells. Well-permit data available in the water-data bank for the Yampa River basin include an estimated one-half of the total wells existing and currently being used (W. I. Knudsen, Jr., oral commun., 1975). Further discussion of the water rights involving well-permit data is given by Knudsen and Danielson (1977).

Water Law in Wyoming

Wyoming issues water-right permits and recognizes the priority system of water allocation. As in Colorado, issuing of water rights is under the administration of the State Engineer's Office with each water right being adjudicated by the Board of Control. That part of the Little Snake River basin in Wyoming lies within Wyoming's Water Division 1 (fig. 33). Any application to the State Engineer's Office fulfilling the stipulated requirements is approved unless denial can be justified by public interests. If water rights are requested for proposed projects, completion dates are stated; however, extensions for completion of construction of storage projects may be granted by the State Engineer's Office. After the water right specified in the permit is put to "beneficial use" (Trelease, 1965) and all the required notices are filed, the Wyoming Board of Control issues a Certificate of Appropriation which serves as evidence of an adjudicated water right. A water right is considered attached to the land; however, through actions of the Board of Control, certain rights may be transferred and the

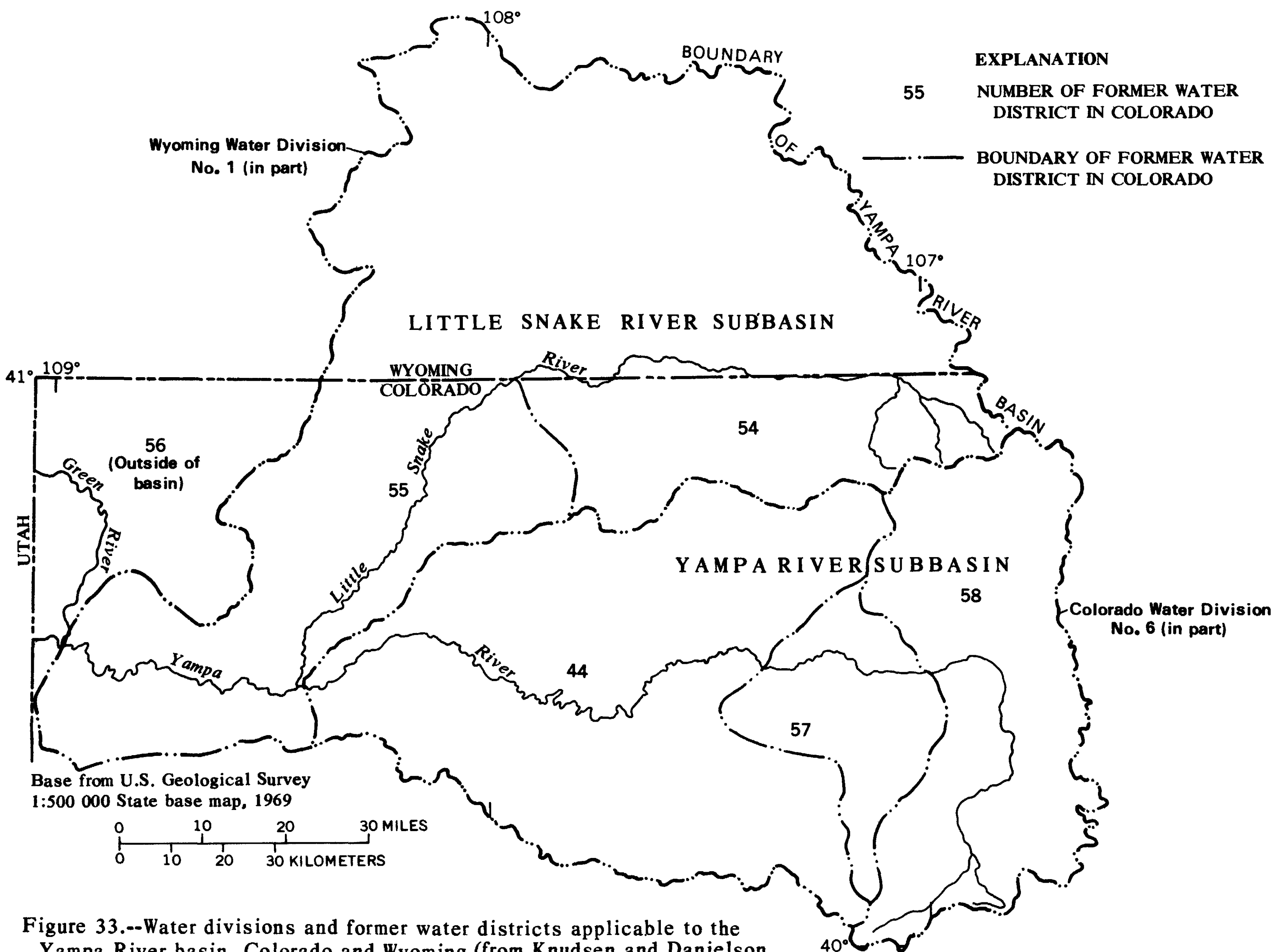


Figure 33.--Water divisions and former water districts applicable to the Yampa River basin, Colorado and Wyoming (from Knudsen and Danielson, 1977).

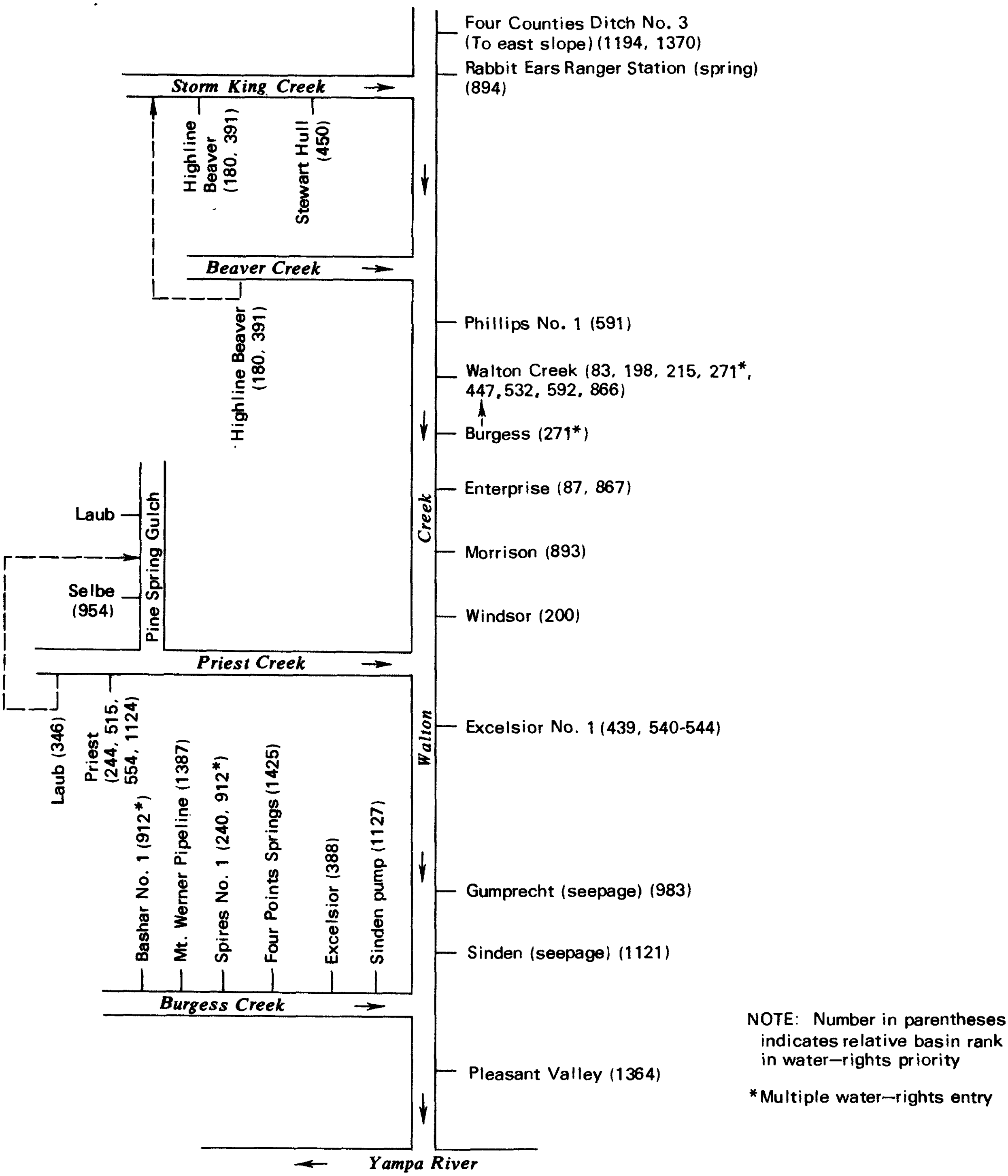


Figure 34.--Flow diagram of water rights and diversions of Walton Creek and tributary streams, Colorado Water Division 6, former Water District 58.

place, purpose, and methods of use may be modified. Numerous outstanding water-right permits for proposed projects have not been completed and, as a result, certificates indicating adjudication of these rights have not been issued.

The waters of the Little Snake River downstream from its confluence with Savery Creek were divided between Wyoming and Colorado on a basis of priority of appropriation for existing development; the unused waters were divided equally between the two States (Wyoming State Engineer's Office, 1970).

Adjudicated water rights for Wyoming are published in a tabulation dated 1965 with supplements in 1967, 1970, and 1972. Territorial rights were decreed from 1875 to 1890, including rights in that part of the Little Snake River subbasin located in Wyoming and included in the Yampa River basin. Appropriations of State water rights began in 1894. Primary uses of adjudicated surface waters are for irrigation; secondary uses are for stock reservoirs, domestic supplies, mining, fish, and municipal supplies. Three hundred and seventy-three entries for adjudicated water rights for the Little Snake River in Wyoming are included in the tabulations described above; however, several decrees have multiple entries and 72 entries involve territorial decrees.

An estimated 29,600 acres (12,000 ha) have been irrigated in the Little Snake River subbasin in Wyoming (Wyoming State Engineer's Office, 1970). Of this acreage, 4,000 acres (1,600 ha) used unadjudicated water rights in 1963, the last year when data were available for this compilation.

Legal Compacts

Two major legal compacts directly influencing water availability in the Yampa River basin are the Colorado River Compact of 1922 and the Upper Colorado River Basin Compact of 1948 (Upper Colorado River Commission, 1965-77). In recent years, rigorous legal enforcement of the water-quantity stipulations of these compacts has been overshadowed by an equal or greater concern about deterioration of water quality resulting from increased consumption or changing uses of water in the basin (Weatherford and Jacoby, 1975; Radosevich and others, 1973).

The 1922 compact divided the Colorado River basin in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming into an upper basin and a lower basin using Lees Ferry, Ariz., near the Arizona-Utah border as the dividing or compact point. As stipulated in this compact, flow in the Colorado River past Lees Ferry is to be 75 million acre-ft (92.5 billion m^3) during each 10-year period. A major concern created by the 1922 compact was that the apportionment of the basin's water was based on an optimistic value for long-term water availability (Stockton, 1975). The U.S. Bureau of Reclamation has suggested that 5.8 million acre-ft (7.15 billion m^3) rather than 7.5 million acre-ft (9.25 billion m^3) be considered as the average annual amount of water available for transport out of the upper basin (U.S. Department of the Interior, 1974).

The 1948 compact apportioned the water among Arizona, Colorado, New Mexico, Utah, and Wyoming in the Upper Colorado River Basin. An Upper Colorado River Commission was created to administer the 1948 compact. The commission's responsibilities include resolving water-allocation disputes among member States.

The 1948 compact contains provisions concerning maintenance of flows in certain interstate streams in the Upper Colorado River Basin. Specifically, for the mutual benefit of Colorado and Utah, flows of the Yampa River at the Maybell station (which effectively measures streamflow from the Yampa River subbasin, fig. 14) must be maintained at a minimum level of 5 million acre-ft (6.2 billion m^3) for any given 10-year period. This flow volume stipulated by the compact is approximately one-half of the recorded flows determined from long-term records at this site (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969).

Proposed Water-Development Projects

Since promotion of irrigation lands in the West in the early 1900's, potential reservoir sites in major basins have been designated for irrigation, municipal, and industrial uses or for generation of hydropower (Wooley, 1930). Currently, a number of reservoirs are being proposed for the Yampa River basin. The proposed reservoirs with designed storage capacities exceeding 2,000 acre-ft (2.5 million m^3) are listed in table 14. The approximate total storage of all proposed reservoirs is 2.2 million acre-ft (2.7 billion m^3), which is nearly 1½ times the annual surface-water flow from the basin. However, a few of the proposed reservoirs compete for the same site. The Colorado Water Conservation Board holds the conditional water-rights decrees on several of the reservoirs in the basin; numerous others are being proposed by the U.S. Bureau of Reclamation (1974a) or local water-conservancy districts.

As indicated by the U.S. Department of the Interior (1976a), the more active proposed projects include the Yamcolo, Juniper-Cross Mountain, and Savery-Pot Hook projects. The Yamcolo Reservoir is being proposed by the Upper Yampa Water Conservancy District (Western Engineers, Inc., 1975). Plans for the Juniper and Cross Mountain Reservoirs have been filed by the Colorado River Water Conservation District (1975). The Savery-Pot Hook project is proposed by the U.S. Bureau of Reclamation (1974a). Funding currently is being sought for the Juniper and Yamcolo projects; whereas, initial authorized Federal funds available for the Savery-Pot Hook project (U.S. Department of the Interior, 1976b) have been withheld pending further evaluation of the project's feasiblity.

In addition to the planned water uses listed for proposed reservoirs in table 14, two projects are proposed for diversion of surface water from the Yampa River basin to the White River basin for anticipated oil-shale development (U.S. Bureau of Reclamation, 1974a). These proposals are included in several alternative plans for obtaining water for the oil-shale development. The first proposal is to divert 75,000 acre-ft (92 million m^3)

Table 14.--*Proposed major surface-water impoundments*

Project codes

CRWCD, Colorado River Water Conservation District
CU, Colorado-Ute Association
GN, Great Northern Project (CRWCD)
HM, Hayden-Mesa Project (CRWCD)
JC, Juniper-Cross Mountain Project
JEL, J. E. Lutrell
LY, Lower Yampa Project (CRWCD)
OCP, Oak Creek Power Company
PM, Pittsburg & Midway Coal Company
PSC, Public Service Company of Colorado
PVI, Pleasant Valley Investment Corporation
SP, Savery-Pot Hook Project (USBR)
T, Toponas Project (CRWCD)
UI, Utah International, Inc.
USBR, U.S. Bureau of Reclamation
UY, Upper Yampa Projects (CRWCD)
VTW, Vidler Tunnel Water Project (Sheephorn Project)
W, Wessels Project (CRWCD)
YGC, Yampa-Green Corporation
YJ, Yellow Jacket Project (USBR)

Project purposes

D, Domestic; I, Irrigation; M, Municipal; N, Industrial; O, Other; P, Power; R, Recreation; S, Stock supply; X, Export (transbasin diversions)

Reservoir	River or creek	Total capacity (acre-feet)[1]	Project	Project purpose	Remarks
		Carbon County, Wyoming			
Savery----------	Savery---------	(19,000)	SP	I	Alternative to Sandstone site (U.S. Department of Interior, 1976b).
Sandstone--------	Savery---------	15,500	SP	I	
		Moffat County, Colorado			
Pot Hook---------	Slater---------	60,000	SP	I	Water-rights application of 73,580 acre-feet.
Juniper----------	Yampa----------	1,079,990	LY,JC	I,P	Original water right 844,290 acre-feet plus enlargement of 235,700 acre-feet.
Cross Mountain---	Yampa----------	142,000	LY,JC	I,P	
Jubb------------	Jubb-----------	2,250	LY	I	Application for water rights not found.
Thornburg--------	Milk-----------	36,000	YJ	I	Water-rights application of 31,810 acre-feet.
Craig-----------	Yampa----------	44,490	UI	N,D	
Rampart----------	Fortification---	12,330	LY,GN	I	

Routt County, Colorado

California Park--	Elkhead---------	36,540	LY,GN	I	
Hayden (Mesa)----	Sage-----------	8,620	CU	I,D	
Trout-----------	Trout----------	23,340	PM	I,N,D	
Childress--------	Trout----------	24,160	OCP	M,N,D	
Upper Middle-----	Middle---------	102,200	OCP	P,N	Water-rights application of 17,000 acre-feet.
Lower Middle-----	Middle---------	25,150	OCP	P,N	
Twenty Mile------	Fish-----------	15,300	JEL	I	
Dunckley---------	Fish-----------	57,090	UY,HM	I,D,S	
Hinman Park------	Elk------------	44,040	PSC	P	
Big Creek--------	Big------------	6,900	(2)	(2)	
Grouse Mountain--	Willow---------	79,260	(2)	(2)	
Pleasant Valley--	Yampa----------	(43,220)	CRWCD	I	
Woodchuck--------	Yampa----------	(40,000)	CRWCD	I	
Lake Catamount---	Yampa----------	7,400	PVI	R,M	
Yampa------------	Yampa----------	(151,120)	OCP	P	Water-rights conditional decrees; not included in Oak Creek Water & Power Project.
Blacktail--------	Yampa----------	229,250	YGC	P	
Lower Green------	Green----------	99,600	YGC	(2)	Water-rights application of 45,000 acre-feet.
Main Green-------	Green----------	(103,230)	YGC	(2)	Water-rights conditional decrees; not included in Oak Creek Water & Power Project.
Yampa------------	Yampa----------	(32,500)	VTW	X	Overlapping sites, Blacktail Reservoir.
Morrison---------	Morrison--------	(12,500)	VTW	X	
Service----------	Service--------	(22,000)	YGC	(2)	Water-rights conditional decrees; not included in Oak Creek Water & Power Project.
Wren-------------	Fish-----------	2,160	(2)	I,R,D	
Allen Basin------	Middle Hunt-----	2,250	(2)	I,D	
Bear-------------	Yampa----------	11,610	UY,W	I	
Yamcolo----------	Bear-----------	9,000	UY,T	I,N,D	Water-rights application of 6,530 acre-feet.
Total------------------------		2,176,430 acre-feet			

[1]Capacities in parentheses indicate reservoirs competing for the same sites.
[2]Information not available.

per year from the Juniper Reservoir on the main-stem Yampa River into the Piceance Creek and Yellow Creek basins. Both creeks are tributaries to the White River. A second plan is to modify the Savery-Pot Hook project to provide 57,000 acre-ft (70 million m^3) per year of water to the White River basin. These plans would include modifying the size of the Pot Hook Reservoir to provide the necessary water.

One additional consideration to those presented in the U.S. Bureau of Reclamation report (1974a) is the "Four Counties Water-Users' Division" with a proposed water diversion of 50,000 acre-ft (62 million m^3) from the Yampa River subbasin across the Continental Divide to the North Platte River. An adaptation of this proposal involves a diversion of 59,000 acre-ft (73 million m^3) annually from the Little Snake River subbasin in the Huston Park area to Cheyenne via the North Platte River. The proposed Vidler Tunnel Water Project would divert water at a rate of 1,756 ft^3/s (49.7 m^3/s) from the western slope to the city of Golden (Rifle Telegram, Feb. 18, 1976). Much of this water would come from Water Division 6.

Water Use

At the present time (1978), the majority of water use in the Yampa River basin involves surface-water diversions for irrigated croplands. Other uses of water include withdrawals for municipal water supplies, stock ponds, cooling water for the Hayden Powerplant, losses through riparian vegetation and phreatophytes (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969, tables 21 and 28), and transbasin diversions. Withdrawals from aquifers in the basin constitute a minor part of the current total water use in the basin.

In assessing water use in a region, one must differentiate between water withdrawal and water consumption. A water withdrawal is a diversion or physical act of taking water from a stream or aquifer. Water consumption is that part of the withdrawn water that is not returned to a water source after it is put to beneficial use. In adjudicating a water right, consideration is given to how much of the water withdrawn is returned to the water source for subsequent use by others (W. I. Knudsen, Jr., written commun., 1977).

For that part of the Yampa River basin in Colorado, total surface-water withdrawal during 1976, the latest year for which a compilation is available, was nearly 415,000 acre-ft (512 million m^3), of which nearly 399,000 acre-ft (492 million m^3) was for irrigating croplands and hay meadows or was stored in stock ponds; 2,555 acre-ft (3.15 million m^3) for municipal water supplies; 5,478 acre-ft (6.75 million m^3) for industrial uses; and 8,283 acre-ft (10.2 million m^3) for other unspecified uses (Knudsen and Danielson, 1977, table 1).

Irrigated agriculture is the major water use in the Yampa River basin, both in terms of withdrawals and consumption. A statewide study by Gray and McKean (1975) concluded that 91 percent of water withdrawals and 96 percent of total water consumption for all economic activities in Colorado could be attributed to irrigated agriculture. Between 64 and 72 percent of the total water currently used consumptively in the Yampa River basin can be attributed to the irrigated agriculture, according to estimates by the Colorado Water Conservation Board and U.S. Department of Agriculture (1969) and the U.S. Department of the Interior (1976a). Regional and statewide studies in Colorado have estimated that about 40 to 43 percent of water applied to irrigated croplands in the State is lost through evapotranspiration (Gray and McKean, 1975; Gray and others, 1977).

The range in estimates of consumptive use attributed to irrigated agriculture is due primarily to the exclusion of nonbeneficial losses of water (such as riparian vegetation and nonbeneficial phreatophytes) in the lower percentage figures. Such losses were estimated by the Colorado Water Conservation Board and U.S. Department of Agriculture (1969), where the dominant types of phreatophytes identified in the Yampa River basin were sedges, rushes, greasewood, willows, and cottonwood. It should be recognized, however, that such vegetation provides food and cover for certain species of wildlife. According to the Northwest Colorado Coal Environmental Statement (U.S. Department of the Interior, 1976a), the 1975 irrigated acreage in the part of the Yampa River basin in Colorado was slightly under 100,000 acres (40,500 ha). Revised figures by the Colorado State Engineer's Office (Kent Holt, written commun., 1977) increased this estimate to nearly 114,000 acres (46,100 ha). Indications are that the amount of irrigated acreage in the basin has remained fairly constant over the past 30 years (U.S. Department of Agriculture and Colorado Water Conservation Board, 1969). However, the amount of acreage for dryland crops has increased appreciably in the last 5 years (Charles Hogelin, oral commun., 1976).

To date, exports of water from the Yampa River basin to adjacent basins have been minor (about 1 percent) relative to total available surface water. The two known existing transbasin diversions consist of: (1) Export of approximately 7,800 acre-ft (9.6 million m^3) annually from the Little Snake River basin to Hog Park Creek in the North Platte River basin, and (2) export of from 600 to 2,800 acre-ft (0.7 to 3.5 million m^3) annually from the Bear River in the upper part of the Yampa River subbasin to Egeria Creek in the Colorado River basin.

Although the Northwest Colorado Coal Environmental Statement (U.S. Department of the Interior, 1976a) assumed no future increases of water exports from the Yampa River basin, an expansion of the diversion to the North Platte River basin plus other transbasin diversion projects have been proposed (see p. 108). Completion of the Hog Park Creek diversion may result in an estimated export of as much as 17 percent of the flow of the Little Snake River (The Denver Post, January 10, 1977). Two larger projects, the Four-County Project and the Vidler Tunnel Water Project, have been proposed and are competing for diversion of water from the western slope, including several headwater tributaries of the Yampa River basin. Diversions of surface water from the Yampa River basin south to the White River basin also have been proposed (U.S. Department of Agriculture and Colorado Water Conservation Board, 1969; U.S. Bureau of Reclamation, 1974a). The flurry of recent interest by proponents of several of these proposals has increased the desire of the inhabitants of the basin to implement water-development projects which would provide for in-basin uses.

Projections of increased consumptive use of water in the Yampa River basin, analyzed in the second assessment phase, are based upon certain assumptions regarding increased irrigated croplands, implementation of proposed reservoirs, and requirements for energy-resource development. As might be expected, one sensitive factor is the projection of irrigated agriculture. For example, the study by the Colorado Water Conservation Board and U.S. Department of Agriculture (1969) projected about a two-thirds increase from 96,500 to 165,000 acres (39,100 to 66,800 ha) in irrigated cropland (including the Vermillion Creek area) in the Yampa River basin by the year 2000. In contrast, the Northwest Colorado Coal Environmental Statement (U.S. Department of the Interior, 1976a) projected about a one-fourth increase in irrigated acreage in the basin by the year 1990. It would appear that the consumptive use of water from reservoir evaporation and for powerplant process and cooling waters which is given in the U.S. Department of the Interior (1976a) environmental study is subject to further investigation. In ongoing studies, the Yampa River basin assessment is looking at alternative cooling-tower systems and impacts on water use, inasmuch as this is the major consumptive use of water for coal conversion (R. M. Hirsch, written commun., 1977). Also, alternative configurations of reservoir development in the basin will be considered from the standpoint of evaporative losses as well as other hydrologic impacts.

Based upon the regional economic-analysis results by Udis and Hess (1976) for Moffat and Routt Counties in Colorado, water-use estimates for that part of the basin during 1975 are nearly 406,000 acre-ft (0.50 billion m^3) for water withdrawals and 141,000 acre-ft (1,739 million m^3) for water consumption (J. E. Schefter and R. M. Hirsch, written commun., 1977). This 1975 withdrawal figure compares favorably with a 1976 inventory compilation of water diversions totaling nearly 415,000 acre-ft (0.512 million m^3) for the basin by the Colorado State Engineer (Knudsen and Danielson, 1977, table 1). The water-consumptive-use estimate represents about a 40-percent increase over compiled average losses for the period 1943-60 of 102,000 acre-ft (1,258 million m^3) for the entire basin (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969, table 21) and an estimated consumptive use of 108,800 acre-ft (1,342 million m^3) for the Yampa River subbasin (U.S. Department of the Interior, 1976a).

INDIRECT EFFECTS OF ENERGY DEVELOPMENT

Increased energy development in the Yampa River basin will significantly affect the people, land use, air quality, and regional economic activity in the basin. New coal mines, expansion of existing coal mines, and construction of facilities to convert coal to gas or electricity will provide numerous employment opportunities. With new jobs will come an increase in the permanent population and the demand for increased social and commercial services. Land use will change as farmland is converted to industrial and urban uses. Recreational uses of the land, which already are significant in local areas, will increase. Air quality will be affected by the increase of industrial facilities and urban areas. The economic activity of the basin will be increased significantly as coal production increases. The following sections describe in greater detail the indirect effects of energy development on the people and environment of the Yampa River basin.

Population, Employment, and Services

Population and employment in the Yampa River basin serve as principal indications of the human-related effects of regional economic development. The historical trends in population from 1930 to 1967, and also the various projections of population due to expanded agriculture and mining operations in the basin are depicted in figure 35. The projections are adapted from three primary sources of demographic information:

1. Colorado Water Conservation Board and U.S. Department of Agricultu (1969).

2. U.S. Department of the Interior (1976a).

3. Udis, Adams, Hess, and Orr (1977).

In 1960, approximately 94 percent of the basin population lived in Colorado. One-half of these people lived in Moffat County and most of the balance lived in Routt County. Population in the Wyoming part of the Yampa River basin appears to have remained relatively constant (less than 1,000) since 1930.

These population figures (fig. 35) have been adjusted to reflect that part of the population directly in the basin. As shown by the figure, all of the population projections indicate a more rapid increase in projected population from 1975 to 1990 than from 1930 to 1967. The recent projections do not extend beyond the year 1990; however, these show that population is expected to increase from the 1975 base of 20,700 to somewhere between 31,400 and 53,500, depending upon the assumed employment and related-services needs of coal-resource development. The U.S. Department of the Interior (1976a) projections show a variable rate of increase, with a relatively large increase occurring between 1978 and 1982, after which considerable slacking of the population growth rate occurs when major construction of coal

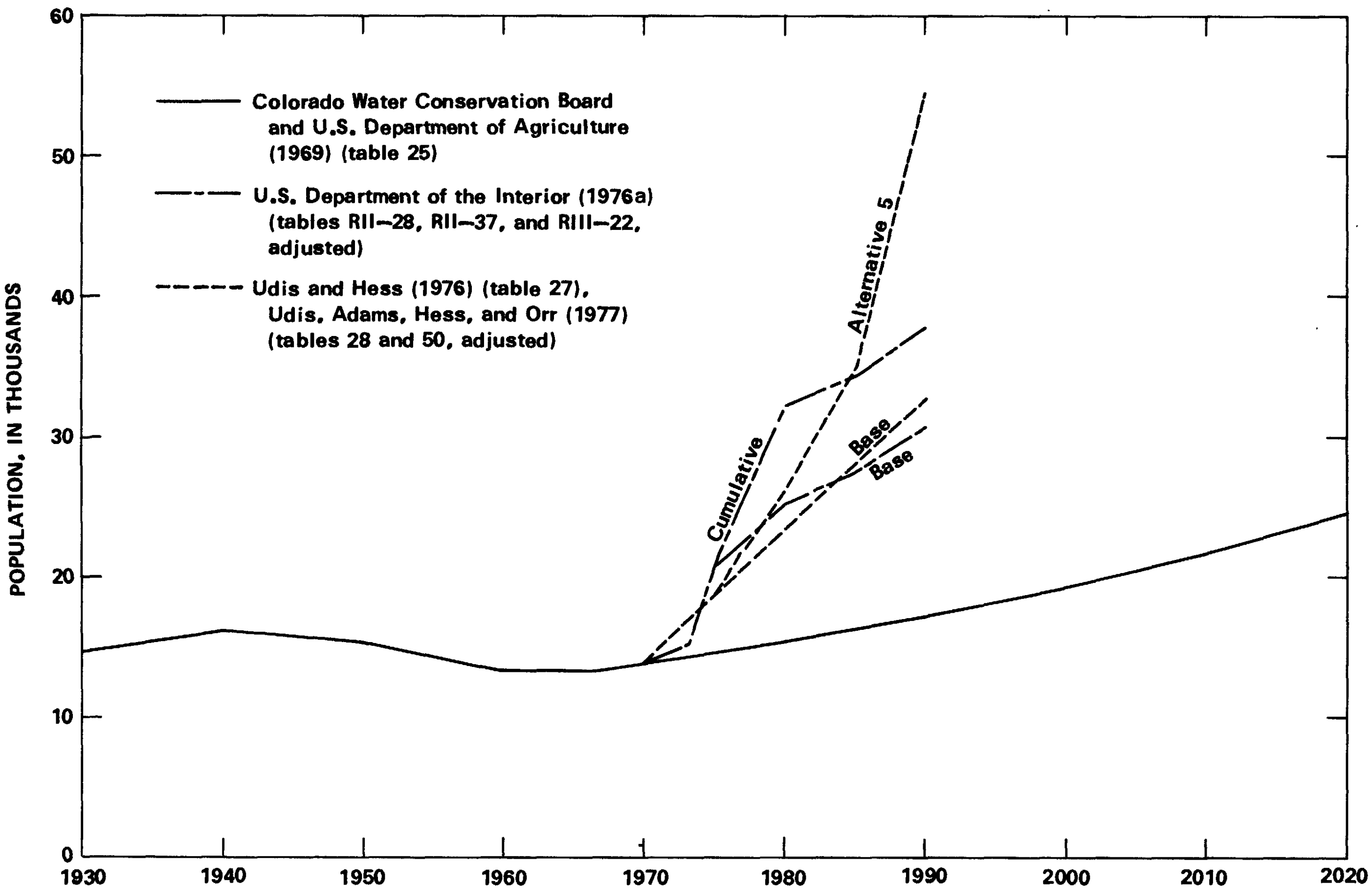


Figure 35.--Population levels and projections, Yampa River basin, 1930–2020.

conversion and mine facilities are assumed to decline. In contrast, the U.S. Geological Survey (Udis and others, 1977) projections reflect assumed continuing construction activities in the region well into the 1980's. In either instance, the effects of recent projections of coal-related development are apparent in the anticipated population growth. This growth, in conjunction with the various forms of economic activity in the basin, will result in increasing demands on water supply and needs in wastewater treatment.

Total employment in Routt and Moffat Counties was 5,030 in 1970, an increase of 8 percent compared with 1960 figures (U.S. Department of the Interior, 1976a). In 1970, unemployment was approximately 4 percent in the basin. More recent employment figures for the same two-county area are 6,565 for 1972 and 8,709 for 1975 (Udis and Hess, 1976), indicating the effect of increasing economic activity in the region. Economic activities with largest employment traditionally have been retail trade, agriculture, mining, and construction. The relative and total percentage figures for retail trade have been increasing since 1950. Conversely, the labor force for mining decreased by 75 percent between 1960 and 1970. About a 40-percent decrease in the agricultural labor force occurred between 1950 and 1970. About three-quarters of the total labor force is comprised of men, and the majority of workers are salaried through private sectors. Using 1970 figures, nearly 45 percent of the total labor force was involved in agriculture, construction, or retail trade.

Projected population increases for the basin imply additional needs for social services, such as housing, health, education, fire protection, and law enforcement. Increasing demands for social-support facilities in these areas have been outlined in the Northwest Colorado Coal Environmental Statement (U.S. Department of the Interior, 1976a). Of particular concern in the Yampa River basin assessment are increasing needs in the areas of water supply and wastewater treatment and the environmental consequences of increasing construction of housing and other service facilities. Needs for social services (including retail trade, health services, and education) constitute the majority of the "multipliers" built into economic models to depict the interactive economic relations for the area (Udis and others, 1973; U.S. Department of the Interior, 1976a; Udis and Hess, 1976).

Land Use and Ownership

Adapting information compiled by the Colorado Water Conservation Board and the U.S. Department of Agriculture (1969), nearly 72 percent of land in the Yampa River basin is used for grazing. This constitutes nearly 5,800 mi^2 (15,000 km^2) of the total drainage area of 8,080 mi^2 (20,900 km^2). An additional 942 mi^2 (2,440 km^2) of land managed by the U.S. Forest Service in the eastern part of the basin are used conjunctively for grazing and timber. About 6.5 percent (530 mi^2 or 1,370 km^2) of the basin area is in timber, consisting of both deciduous and evergreen trees. Another 5.5 percent (447 mi^2 or 1,160 km^2) of the basin is used for irrigated or dryland croplands. Agricultural crop production contributes significantly to the basin's economy, and irrigated croplands account for most of the current consumptive use of water in the basin (see p. 108). Less than 5 percent (366 mi^2 or 948 km^2) of the basin contains wilderness and recreation sites, townsites, transportation rights-of-way, and lands involving extraction of minerals.

Agriculture is the second largest contributor to the total gross output of the Upper Colorado River Basin (retailing being the largest). In the Upper Colorado River Basin, there has been a 33-percent reduction in the number of farms during 1949 to 1964, although the total land area farmed remained almost unchanged (Upper Colorado Region State-Federal Inter-Agency Group, 1971). This consolidation in land ownership for agricultural purposes is reflected in about a 20-percent reduction in the number of farms for the Yampa River basin over the same time period (Charles Gathers and Associates, Inc., 1976).

More than 54 percent (4,370 mi^2 or 11,300 km^2) of the land in the Yampa River basin is managed by the U.S. Bureau of Land Management, the U.S. Forest Service, and the U.S. Park Service. About 40 percent (3,230 mi^2 or 8,370 km^2) of the basin's land area is privately owned, and less than 6 percent (478 mi^2 or 1,240 km^2) is owned or controlled by State and local governments. The areal distribution of land ownership in the Yampa River basin is indicated in table 15.

The U.S. Forest Service manages Routt and Medicine Bow National Forests, both of which include lands in the eastern part of the basin. These lands generally are at altitudes equal to or greater than 8,000 ft (2,440 m) and are heavily forested. Designated timber-harvesting areas contribute significantly to the regional economy.

The majority of land controlled by State and local governments consists of public-school lands. Most of the lands that do not have school facilities are leased for grazing or agricultural crop production (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969). The private lands lie mostly in the eastern one-half of the basin, where the majority are used for grazing or farming. Lands administered by the U.S. Bureau of Land Management are predominantly in the western and northern sections of the basin. A checkerboard pattern of private and Federal lands, apparent in the northern part of the Little Snake River subbasin (U.S. Bureau of Land Management, 1974-75), reflects land grants of alternate sections by the Federal government to the Union Pacific Railroad in the late 1800's to promote development in the West (see p. 22).

The recreational resources of the Yampa River basin are considerable and varied, and they contribute substantially to the basin's economy. National forests, which occupy 18 percent (931,000 acres or 377,000 ha) of the basin (table 15), provide camping, fishing, and hiking. Dinosaur National Monument is located just west of the basin-assessment area and provides facilities for camping, boating, and hiking. Summer recreational uses of public lands managed by the U.S. Bureau of Land Management include camping, hunting, and hiking. A wide variety of wildlife species abound in the basin, and hunting

Table 15.--*Land ownership, Yampa River basin*

[Units are in acres. Adapted from Colorado Water Conservation Board and U.S. Department of Agriculture, 1969]

County	Private	State and local government	Federal lands			Total
			U.S. Bureau of Land Management[1]	U.S. Forest Service	U.S. National Park Service[2]	
Yampa River basin in Colorado						
Garfield------	---------	-------	---------	35,200	---	35,200
Grand---------	---------	-------	---------	5,600	---	5,600
Moffat--------	1,009,100	152,400	939,000	41,700	500	2,142,700
Rio Blanco----	64,200	-------	12,300	142,400	---	218,900
Routt---------	664,600	68,600	49,400	546,000	---	1,328,600
Total in Colorado--	1,737,900	221,000	1,000,700	770,900	500	3,731,000
Percent-----	46.6	5.9	26.8	20.7	0	100.0
Yampa River basin in Wyoming						
Carbon--------	258,100	75,900	479,600	160,100	---	973,700
Sweetwater----	72,300	9,000	385,000	-------	---	466,300
Total in Wyoming---	330,400	84,900	864,600	160,100	---	1,440,000
Percent-----	22.9	5.9	60.1	11.1	0	100.0
Total in Yampa River basin--	2,068,300	305,900	1,865,300	931,000	500	5,171,000
Percent-----	40.0	5.9	36.1	18.0	0	100.0

[1]U.S. Bureau of Reclamation and other withdrawal land pending classification included.

[2]Only that part of Dinosaur National Monument upstream from Deerlodge Park.

for such big-game species as deer and elk is popular. Winter sports, primarily alpine and downhill skiing, have brought a recent boom to the town of Steamboat Springs and adjacent areas. Scenic areas in the basin have been inventoried by the Colorado Water Conservation Board and U.S. Department of Agriculture (1969). One of the primary concerns of energy-related economic development in the Yampa River basin is that the recreational resources will continue to be attractive to tourists brought into the area, as well as to residents of the basin.

Alpine ski facilities in Routt County could accommodate 8,600 persons per day in 1973; proposed development in skiing facilities by 1995 will increase the capacity of the ski areas to between 17,400 and 29,400 skiers per day (Charles Gathers and Associates, Inc., 1976). Ski-area development in the basin is controlled by the U.S. Forest Service in coordination with the Routt County Planning Commission.

Air Quality

Ambient air-quality conditions in the Yampa River basin are subject to both Federal and State regulations. The Clean Air Act of 1953 (Public Law 88-206) with subsequent amendments (including Public Laws 89-272, 89-675, 90-48, 91-604, 92-157, and 93-313) has influenced the various standards specified by Colorado and Wyoming. Standards have been stipulated for the following air-quality variables: Carbon monoxide, nonmethane hydrocarbons, oxidents (in terms of ozone), sulphur dioxide, and particulates. The standards applicable to a given area may vary depending upon Federal or State specified standards or on an areal standard designation (Wayne May, Colorado Department of Health, Air Quality Division, written commun., 1976). The particular designation for northwestern Colorado allows for "controlled" increases in concentrations of air-quality variables over current ambient conditions (U.S. Department of the Interior, 1976a). Reclassification of this designation for public lands in the Yampa River basin is permitted.

Large-volume samplers for collecting suspended particulate have been maintained in the towns of Craig, Hayden (until 1975), and Steamboat Springs as part of a statewide network operated by the Colorado Department of Health, Air Pollution Laboratory. Measurements of suspended particulate and benzene-soluble concentrations in air made at these locations from 1971 to 1976 are summarized in table 16. According to this tabular summary, concentrations of total-suspended particulates in Steamboat Springs exceed the Federal primary standard of 75 $\mu g/m^3$ (micrograms per cubic meter) (1-year geometric mean); whereas, concentration of total-suspended particulates in Craig and Steamboat Springs exceed the Colorado air-quality standard of 45 $\mu g/m^3$ (1-year arithmetic mean) for nondesignated areas. The concentrations measured at Steamboat Springs may be a result of upslope airflow at the base of the mountains combined with local uses of fossil fuels by furnaces, fireplaces, and motor vehicles.

Table 16.--*Summary of suspended particulate concentrations in air in the Yampa River basin*

[Sources: U.S. Department of the Interior, 1976; Colorado Department of Health, Air Quality Division, written commun., 1975; and Stearns-Roger, Inc., 1973-76. All concentrations are given in micrograms per cubic meter]

Sampling site	Statistical measure[1]	Year					
		1971	1972	1973	1974	1975	1976
Town of Steamboat Springs (93) [2](123)---------------	AM	114	122	130	141	145	127
	GM	90	100	108	108	121	117
	MX	358	429	469	518	407	271
	NM	59	90	87	75	77	51
Town of Hayden (91)---------	AM	42	30	33	45	---	---
	GM	36	25	27	36	---	---
	MX	146	120	82	228	---	---
	NM	56	84	77	50	---	---
Hayden weather station (at powerplant)-----------	AM	30	26	26	36	35	46
	GM	24	22	23	27	29	30
	MX	116	163	83	163	106	552
	NM	61	67	48	50	53	66
Hayden pumphouse station (at Yampa River intake)---	AM	28	29	30	42	28	48
	GM	24	25	27	35	21	39
	MX	108	157	88	126	228	218
	NM	60	62	45	54	65	62
Town of Craig (89)----------	AM	72	68	77	91	103	135
	GM	63	64	67	75	80	119
	MX	190	202	220	234	322	441
	NM	61	87	89	82	73	80
Craig meteorological station (90) (at powerplant construction site)--------	AM	47	30	19	40	54	58
	GM	34	25	17	37	32	41
	MX	155	87	40	82	388	218
	NM	58	44	18	30	42	61

[1]AM = yearly arithmetic mean; GM = yearly geometric mean; MX = yearly maximum; NM = number of measurements.

[2]Station relocated approximately July 1, 1974. Numbers in parentheses indicate Colorado Department of Health code designation.

The arithmetic average annual concentration of 20 μg/m^3 is assumed to be characteristic of ambient conditions in rural areas of northwestern Colorado (U.S. Department of the Interior, 1976a). It is anticipated that maintenance of the State-operated monitoring network including measurement sites in and near the towns of Craig, Hayden, and Steamboat Springs will provide continuing data to determine long-term changes with economic growth and energy-related development in the region. Very few data are available for other air-quality variables stipulated in Federal and State standards. However, it is anticipated that data collected on some of these variables now and in the near future (Stearns-Roger, Inc., 1973-76) can be included in modeling applications (Kreider, 1975) in order to determine possible changes in ambient conditions in the region.

Regional Economic Activity

Because economic information is tabulated by county, data for Routt and Moffat Counties, which contain the bulk of the basin's population, are assumed to serve as an adequate measure of economic diversity in the region (Udis and Hess, 1976). The major economic activities in this part of the basin include agriculture (livestock grazing, irrigated croplands, and dryland farming), mineral production (primarily coal, oil, and gas production), and lumber production. Regarding the latter, a final environmental statement for a timber-management plan for Routt National Forest recently has been completed (U.S. Department of Agriculture, 1975).

Despite the dominance of agriculture (including forestry) and mining as primary sources of employment in the Yampa River basin, retail trade and construction recently have increased in relative prominence in terms of gross sales and employment. In fact, retail trade leads all other economic activities in number of employees (U.S. Department of the Interior, 1976a) and in 1960 contributed nearly one-third of the combined gross sales for Routt and Moffat Counties (Colorado Water Conservation Board and U.S. Department of Agriculture, 1969, table 9).

Through a technique known as regional economic input-output analysis (Miernyk, 1965; Udis and Hess, 1976; Udis and others, 1977), interactions of various economic activities in the basin are evaluated to derive anticipated changes in the economy. That is, increased coal production causes increased employment in the basin. As a result, population increases (fig. 35) and demands for housing, commercial facilities, and other services cause additional needs for what might be termed indirect employment. Thus, a dollar increase in the sales of coal generates more than a dollar increase in the level of economic activities in the basin; this is known as the multiplier effect. This means that the increase in water use or residuals discharged to the environment due to energy development exceeds the amount due to the mining, conversion, and transportation activities alone. Hence, the physical aspects of the basin of concern in this basin assessment (specifically, water resources) must consider these indirect effects, as well as the direct results of coal-resource development. In many instances, these indirect effects may be more important than the energy development itself.

For selected economic activities, water use and types and amounts of generated residuals are determined by coupling estimates of aggregate economic activity, total gross output, with appropriate water-use and residuals coefficients (Udis and others, 1973; Gray and others, 1977). Uncertainties exist in using both components of this empirical procedure. However, the method and resultant estimates may be adequate for assessing relative differences in environmental impacts for a range of development or residuals-management alternatives.

ENVIRONMENTAL ASPECTS BEING STUDIED

As indicated in the phase-II project work plan for the Yampa River basin assessment (Steele and others, 1976b), the second phase of the project consists of several studies for evaluating the primary and secondary effects of coal-resource development in the basin. The specific set of coal-resource development alternatives to be evaluated (table 4) includes a realistic range of possible implementation plans so that the assessment methods for evaluating their environmental impacts can be regarded with some confidence. As a preview to these in-depth analyses, the following two sections of this report describe areas of uncertainty in environmental controls and in developmental policies that could significantly affect the magnitude and direction of economic development related to coal resources in the Yampa River basin. A final section briefly outlines the investigative techniques being used in the second phase of the basin assessment.

Environmental-Control Legislation Uncertainties

Conflicts over interpretation of existing environmental-control legislation and uncertainties over possible changes in applicable regulations make it difficult to evaluate objectively the technical and economic factors in residual-discharge alternatives, which are functions of levels of treatment and modification processes. In the basin-assessment analyses, consideration of these uncertainties somehow must be incorporated, in order to identify and to depict realistically the range of areal and temporal environmental stresses resulting from those discharges.

Sometimes these uncertainties are the result of not being readily able to determine which governmental level has principal responsibility. For example, State and Federal air- and water-quality standards or mined-lands reclamation requirements seldom are expressed in identical terms or stipulated in equal limits of compliance. In the instance of determining the applicable regulations, considerable costs in terms of capital equipment and operating efficiencies are at stake. Within the past 2 years, considerable progress has been achieved in explicitly stating the hierarchy of State versus Federal standards and jurisdiction regarding environmental controls.

Uncertainties in Colorado's air-quality emission regulations have had significant fiscal implications relative to operation of existing and proposed power-generation plants in the Yampa River basin. For example, until recently there has been some confusion regarding Colorado's sulfur-dioxide standard applicable to northwest Colorado. Officials of the Colorado-Ute Electric Association, who manage the Hayden power-generation plant and will operate the Craig plant currently under construction, have speculated that consumers would have to spend as much as 20 percent more to achieve stringent air-quality standards (The Northwest Colorado Press, 1975). The matter involves requirements for "wet scrubbers" which are to be installed on the Craig generating-plant stacks to reduce sulphur-dioxide emissions. The utility company contends that coal from the Yampa River basin with a sulfur content of 0.3 to 0.7 percent could be burned in power-generation plants not equipped with sulphur-dioxide removal equipment without exceeding Federal standards for sulphur-dioxide emissions; however, the more stringent State standard would be exceeded (The Northwest Colorado Press, 1975).

Such equipment, required by a ruling of the Colorado Air Quality Control Commission, will cost $107.5 million in capital costs, and operating costs will be increased by $22 million per year, according to Colorado-Ute estimates. In addition, annual coal requirements would be increased by 178,500 tons (161,900 t) in order to provide the power for scrubber operations. In the process of removing sulphur dioxide, considerable amounts of power would be used, as well as limestone and water. This may result in a disposal problem with large quantities of sludge as a solid-residuals waste product (The Denver Post, October 1, 1977; I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976). The air-quality control equipment at the Hayden and Craig powerplants would use an estimated 3,000 acre-ft (3.7 million m^3) of water annually, and 149,000 tons (135,000 t) of sludge would be produced.

Concentrations of trace elements inherent in coal and emitted in fly and bottom ash are another example of residuals transformation. Without stack-gas precipitators or scrubbers, trace elements emitted from plant-stack gases fall to the ground downwind from the stack and may enter the hydrologic cycle when precipitation either moves the trace elements to streams in runoff or transports them into the ground-water system through infiltration (Kneese and Williams, 1977). Alternatively, disposal of solid-ash residuals in mine pits may increase concentrations of trace elements in ground water.

"Fugitive" dust, resulting from activities such as agriculture, construction of roads and buildings, transportation on unpaved roads, mining operations, and grazing, is another concern. An assessment of the anticipated incremental contributions of "fugitive dust" in the Yampa River basin and how this would impact on air-quality standards applicable to the region recently was completed (J. W. Ericson, written commun., 1977).

One method of dealing with uncertainties regarding applicable environmental-control regulations is to consider the range in environmental-quality standards and several alternatives of residuals treatment (I. C. James II, E. D. Attanasi, Thomas Maddock III, S. H. Chiang, and N. C. Matalas, written commun., 1976). In conducting such an analysis, residuals are never entirely eliminated; however, their forms may be modified, thus determining which environmental medium receives the discharge (Reiquam and others, 1975). Under consideration in the basin assessment are regulations regarding air quality, water quality, land use, and mining procedures, including rehabilitation. State and Federal land-rehabilitation legislation regarding controls on mining have been in a state of flux in recent years. In Colorado, a land-rehabilitation or mining-reclamation law recently has been passed. The Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) and draft interim regulations for implementation of this act currently are applicable to Federal lands (H. H. Hudson, written commun., 1977).

Policy Uncertainties Relating to Energy and Water Development

Recent attempts have been made to develop a new Federal coal-leasing policy. Such a plan was announced by the Secretary of the Interior on January 26, 1976, in Denver, Colo. Components of this new Federal policy include the following: (1) Careful analysis to determine needs for coal while minimizing environmental impacts, (2) a review of the existing leasing system, (3) development of regulations controlling mining operations and land reclamation, and (4) preparation of regional environmental-impact statements. Little resolution has been made between Federal and State interests regarding coal-leasing policy. States in the Rocky Mountain region are quite concerned as to what role they have to play in determining development policy. Several States, such as Colorado, also have formulated statewide and regional leasing plans. Earlier studies concerned with Federal, regional, or State policies regarding energy-resource development include the Federal Energy Administration (1974), the Upper Colorado Region State-Federal Interagency Group (1971), and the U.S. Department of the Interior (1974). Ongoing studies include one in the Rocky Mountain region begun by the Energy Research and Development Administration (1977).

Phase-II Investigations

A number of different study components comprise the second phase of the Yampa River basin assessment. Some are regional in scope; others consider specific areas of the basin. Several studies use quantitative modeling or analysis techniques; others are largely descriptive. The scope and intent of the several studies are outlined below.

Compilation and analysis of water rights and diversions will assist in an evaluation of possible legal and institutional contraints regarding water availability in the basin (Knudsen and Danielson, 1977). Currently, water rights in Colorado are readily transferable from agricultural to industrial uses through market transactions and water-court proceedings. Certain limits on surface-water development exist to comply with basin-compact requirements.

Using the coal-resource development alternatives included in this report (table 4), base-year (1975) and projected (to 1990) basinwide impacts can be evaluated in terms of associated economic development, population and employment, water use, and a suite of waste residuals. The first two aspects are documented by Udis and Hess (1976) and by Udis, Adams, Hess, and Orr (1977). The latter two aspects are being compiled and estimated with the assistance of a systems-analysis group in Reston, Va. (J. E. Schefter and R. M. Hirsch, written commun., 1977). Elements of this study component being evaluated include a comparative analysis of water use for alternative cooling systems for coal-conversion facilities, and relative differences in residual loadings for an equivalent amount of coal being used for in-basin conversion or transport alternatives or for varying amounts of coal being used as summarized in table 4. To assist in evaluating environmental trade-offs in transforming gaseous residuals to liquid or solid forms, air-quality simulation modeling (Kneese and Williams, 1977) is being conducted to assess the probability of exceeding applicable standards for electric powerplant facilities with and without controls on gas-stack emissions (A. B. Weissman, written commun., 1977).

Considering the potential amounts of residuals that may be generated and water-use implications of the various development alternatives, consequential effects on the hydrologic system are being evaluated using a range of investigative methods. Analysis of the effects of increased effluents from wastewater-treatment plants on a reach of the Yampa River was mentioned previously (see p. 81) (Bauer and others, 1978). Related to this analysis were determinations of traveltime, unit-concentration, longitudinal-dispersion, and reaeration characteristics of reaches of both the Yampa and Little Snake Rivers during varying flow conditions (Bauer and others, 1979).

To evaluate increasing demands for seasonal and year-round water availability, impacts of several configurations of proposed reservoirs are being analyzed relative to downstream changes in seasonal flow and salinity patterns (Steele and others, 1977; D. B. Adams, D. P. Bauer, R. H. Dale, and T. D. Steele, written commun., 1978). Models utilized in this analysis are the HEC-3 model developed by the U.S. Army Corps of Engineers (1968) for evaluating multireservoir downstream flows and a salinity-routing model developed by Ribbens (1975). Through such an analysis, changes in low-flow conditions in main-stem streams caused by reservoir releases can be evaluated. This analysis may consider estimated minimum instream flows thought to be needed for fish and aquatic life (Lee Carlson, U.S. Fish and Wildlife Service, written commun., 1977).

Effects of upstream water development (reservoirs, diversions, and water consumption) for a range of uses is of concern to downstream users in the Colorado River basin (Colorado Salinity Control Act of 1974, Public Law 93-320) and to environmental-interest groups (The Denver Post, August 23, 1977). To assist in characterizing water quality of the Yampa River as it enters the Green River (fig. 1), a low-flow hydrologic reconnaissance of the reach of the Yampa River in Dinosaur National Monument downstream from the confluence with the Little Snake River was conducted in mid-August 1976 (Steele and others, 1978).

Ground-water solute-transport digital modeling of aquifers in the Mesaverde Group (fig. 4 and table 1) will include areas south of the Yampa River between Steamboat Springs and Craig (fig. 1). Modeling of potential discharges from assumed sources of contamination, such as spoil piles and mine pits for disposal of fly and bottom ash from powerplants, will determine traveltime and dispersion of contaminants entering the ground-water systems (Warner and Brogden, 1976; J. W. Warner and R. H. Dale, written commun., 1978). Such analyses help to identify potential problems and to design a ground-water monitoring network.

Selected areas in the Yampa River basin have been classified with respect to land use, vegetative cover, and snow thickness, using Landsat-satellite imagery (Landgrebe, 1969). Aircraft photography taken during the summer of 1977 by the National Aeronautics and Space Administration provided a basis for distinguishing relative differences in stream turbidities as a possible indicator of suspended-sediment concentration (Heimes and others, 1978). A regional appraisal of total sediment loads carried by streams in the basin was made, using supplemental data collected intermittently at selected stream-gaging stations (Bennett, 1973; Andrews, 1977; 1978). Preliminary modeling of interactions between stream sediment and trout species gave insight to some of the economic benefits of stringent land-reclamation regulations (R. A. Smith, written commun., 1977).

SUMMARY

This report has described the physical setting of the Yampa River basin, which is located in northwestern Colorado and south-central Wyoming and encompasses an area of approximately 8,080 mi^2 (20,900 km^2). Aspects of physiographic provinces, basin geology, mineral resources and mineral-rights ownership, and energy resources are included. A preview to impending coal-resource development, which is beginning to affect the environment and the people in the basin, is provided. The majority of coal production in the basin, at least during the next 15 years, is expected to result from surface mining rather than underground mining. Total coal production in 1977 involved 10 mines and exceeded 7.4 million tons (6.7 million t). Coal production is expected to increase to 20 million tons (18 million t) per year by 1990, primarily obtained from lands controlled by federally leased mineral rights.

The various components affecting coal-resource development alternatives in the Yampa River basin are described. Each of seven alternatives for the base year 1975 and projected to the year 1990 allocates specified amounts of produced coal to electric powerplants, coal-gasification facilities, and transport out of the basin by railroad or slurry pipeline. Three of the seven alternatives consider a 50-percent uncertainty in the assumed 1990 projection of coal production in the basin.

Generally, water availability in the Yampa River basin is more abundant compared with other areas of the western slope of the southern Rocky Mountains. The majority of the precipitation falls on the basin during November to April in the form of snow. Average annual precipitation ranges from more than 50 inches (1,300 mm) along the Continental Divide to less than 9 inches (230 mm) in the western arid areas. To date, water-resources development primarily has utilized surface-water supplies. The estimated mean-annual flow from the entire basin is slightly more than 1.5 million acre-ft (1.8 billion m^3). Historical annual flows have varied widely, from 448,000 acre-ft (552 million m^3) in 1977 to more than 2.9 million acre-ft (3.6 billion m^3) in 1929. The flow of the Yampa River near Maybell averages about 2.7 times the flow of the Little Snake River. Most stream-diversion structures deliver water through a simple network of irrigation ditches for flooding grasslands and hay meadows during the summer months. In 1976, water withdrawals from surface waters in the Colorado part of the basin totalled nearly 415,000 acre-ft (512 million m^3). Numerous streams are impounded by earthfill dams to provide water for stock, irrigation, municipal-water supplies, and powerplant cooling. To date, these structures have barely altered the pattern of dominant flows from snowmelt runoff during each spring in the main-stem and tributary streams of the Yampa River basin. However, the seasonal pattern of streamflow may well be altered appreciably by construction of several major reservoirs which have been proposed for the basin. About 18 water-development projects have been proposed for the construction of as many as 30 reservoirs; these could impound as much as 2.2 million acre-ft (2.7 billion m^3), or 41 percent more water than the existing long-term streamflow from the basin.

Two approaches were used to assess ambient water-quality conditions in streams of the Yampa River basin. The first was to evaluate information gathered by past and ongoing data-collection programs. The second was to design basinwide reconnaissance and quarterly sampling programs that would supplement these historical data. Statistical and mathematical analyses of available data on stream temperatures, sediment, and major inorganic constituents are discussed. Regional regression relationships were developed for stream-temperature characteristics as a function of altitude and for major inorganic constituents as a function of specific conductance. Through an outlier analysis, stream-sampling sites were delineated where data indicated upstream sources of water-quality degradation, either from natural or human-induced causes. Based upon analysis of data collected during an August-September 1975 basinwide reconnaissance, the maximum likely ambient concentrations of selected chemical constituents in streams of the Yampa River basin were determined.

An analysis of the waste-load assimilative capacity of a reach of the Yampa River was conducted to identify possible streamflow-quality problems caused by wastewater treatment-plant effluents generated by existing and future levels of population in the Steamboat Springs area. Two steady-state water-quality models were calibrated using field data collected during low flows at 33 main-stem, tributary, and effluent sites along the study reach.

From the calibration and simulation modeling results, it was found that existing and projected concentrations of dissolved oxygen, fecal-coliform bacteria, and nitrate nitrogen probably would not exceed Colorado's water-quality goals proposed for 1978, 1983, and 1985. However, projected concentrations of nonionized ammonia in the Yampa River possibly may exceed a proposed State standard for assumed December conditions. This nutrient form, when associated with pH values above 8.5, is believed to be toxic to fish. Due to large seasonal variations in population in the Steamboat Springs area, greater wastewater treatment-plant effluent loadings to the Yampa River occur in December. Although flow conditions are comparable in December and September, waste-assimilation rates are generally smaller due to ice cover and lower water temperatures in December. Possible benefits of augmented flows released from a proposed upstream reservoir involved reducing impacts of wastewater treatment-plant loadings.

Ground water occurs in all of the sedimentary rocks underlying the Yampa River basin. The hydrologic and water-quality characteristics of each of the water-bearing geologic units found in the basin are described. The quality of ground water is highly variable throughout the basin; however, in general, ground water in the younger formations near the surface is better in quality than ground water in the older formations that are deeply buried. As water demands increase and surface-water supplies are fully used, greater utilization of potential ground-water resources of the basin may be considered.

Water availability in the Yampa River basin for any given use is controlled largely by the water-rights doctrines of Colorado and Wyoming. Also, the availability of water is influenced by interstate and regional compacts dictated for the Upper Colorado River Basin and the Colorado River basin in its entirety. The pertinent legal and institutional factors which affect water availability in the Yampa River basin are discussed.

Increased energy development in the Yampa River basin will significantly affect the people, land use, air quality, and regional economic activity in the basin. New coal mines, expansion of existing coal mines, and construction of facilities to convert coal to gas or electricity will provide numerous employment opportunities. With new jobs will come an increase in the permanent population and the demand for increased social and commercial services. Land use will change as agricultural land is converted to industrial and urban uses. Recreational uses of the land and water, which already are significant in local areas, will increase. Air quality will be affected by the increase of industrial facilities and urban areas. The economic activity of the basin will be increased significantly as coal production increases.

The basin-assessment studies and documentation of the assessment methods provide regional planners with information and techniques to evaluate the overall implications of coal-resource development on the basin's water resources. The uncertainties inherent in the planning process and the diffuse responsibilities in resource management are important considerations in determining the needs for physical-based information.

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