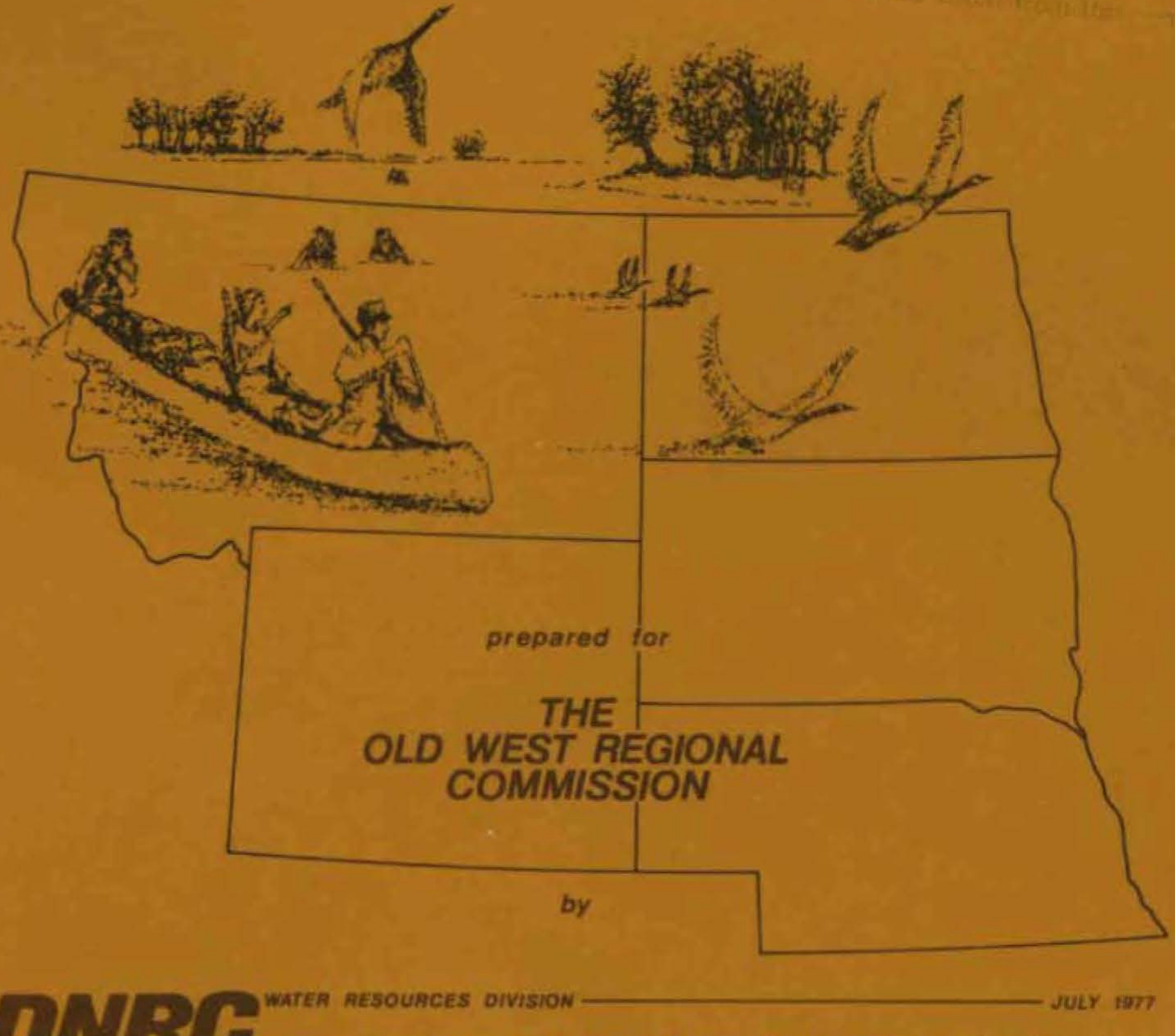
The effect of altered streamflow on the water quality of the Yellowstone River Basin, Montana

YELLOWSTONE IMPACT STUDY

TECHNICAL REPORT NO. 3



prepared for

THE OLD WEST REGIONAL COMMISSION

by

DNRC WATER RESOURCES DIVISION — JULY 1977
MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION

YELLOWSTONE IMPACT STUDY Water Quality 3

The effect of altered streamflow on the water quality of the Yellowstone River Basin, Montana

by

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YELLOWSTONE IMPACT STUDY

conducted by the

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The Old West Regional Commission is a Federal-State partnership designed to solve regional economic problems and stimulate orderly economic growth in the states of Montana, Nebraska, North Dakota, South Dakota and Wyoming. Established in 1972 under the Public Works and Economic Development Act of 1965, it is one of seven identical commissions throughout the country engaged in formulating and carrying out coordinated action plans for regional economic development.

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FOREWORD

The Old West Regional Commission wishes to express its appreciation for this report to the Montana Department of Natural Resources and Conservation, and more specifically to those Department staff members who participated directly in the project and in preparation of various reports, to Dr. Kenneth A. Blackburn of the Commission staff who coordinated the project, and to the subcontractors who also participated. The Yellowstone Impact Study was one of the first major projects funded by the Commission that was directed at investigating the potential environmental impacts relating to energy development. The Commission is pleased to have been a part of this important research.

George D. McCarthy
Federal Cochairman

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Abbreviations used in this report

af	acre-feet
af/y	acre-feet per year
APHA	American Public Health Association
APO	area-wide planning organization
b/d	barrels per day
BLM	Bureau of Land Management
BOD	biochemical oxygen demand
BOD_5	five-day biochemical oxygen demand
C	Celsius
cfs	cubic feet per second
cm	centimeters
COD	chemical oxygen demand
DHES	Department of Health and Environmental Sciences
DNRC	Department of Natural Resources and Conservation
DO	dissolved oxygen
E	estimated flow
EIS	environmental impact statement
EPA	Environmental Protection Agency
F	Fahrenheit
FC	fecal coliforms
FWPCAA	Federal Water Pollution Control Act Amendments of 1972
gpm	gallons per minute
hm^3	cubic hectometers
hm^3/y	cubic hectometers per year
JTU	Jackson Turbidity Units
km	kilometers
KWH	kilowatt hours
MBAS	methylene blue active substance--dye measure of apparent detergents
m	meters
me/l	milliequivalents per liter
mg/l	milligrams per liter
mg P/l	milligrams phosphorus per liter
mg N/l	milligrams nitrogen per liter
mi	mile
mmaf	million acre-feet
mmaf/d	million acre-feet per day
mmaf/y	million acre-feet per year
mmcfd	million cubic feet per day
mm	millimeter
mmt/y	million tons per year
MPDES	Montana Pollutant Discharge Elimination System
m^3/sec	cubic meters per second
mw	megawatts
N	nitrogen
NGPRP	Northern Great Plains Resources Program
NI	no information

NTAC	National Technical Advisory Committee
O&G	oil and grease
P	phosphorus
PHS	Public Health Service
RC	radiochemical
S	sensitive
SAR	sodium adsorption ratio
SC	specific conductance
SCF/D	standard cubic feet per day
ST	semi-tolerant
STORET	a national data storage & retreival system
T	tolerant
TA	total alkalinity
TDS	total dissolved solids
TH	total hardness
TOC	total organic carbon
TR	total recoverable
TSIN	total soluble inorganic nitrogen
TSS	total suspended sediment
Turb	turbidity
T/d	tons per day
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USDHEW	United States Department of Health, Education and Welfare
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WRCB	Water Rights Control Board
WQB	Water Quality Bureau
WQCB	Water Quality Control Board
WQI	water quality index
µ	micro
µg/l	micrograms per liter
µmhos/cm	micromhos per centimeter
<	less than
>	greater than

Preface

THE RIVER

The Yellowstone River Basin of southeastern Montana, northern Wyoming, and western North Dakota encompasses approximately 180,000 km^2 (71,000 square miles), 92,200 (35,600) of them in Montana. Montana's portion of the basin comprises 24 percent of the state's land; where the river crosses the border into North Dakota, it carries about 8.8 million acre-feet of water per year, 21 percent of the state's average annual outflow. The mainstem of the Yellowstone rises in northwestern Wyoming and flows generally northeast to its confluence with the Missouri River just east of the Montana-North Dakota border; the river flows through Montana for about 550 of its 680 miles. The major tributaries, the Boulder, Stillwater, Clarks Fork, Bighorn, Tongue, and Powder rivers, all flow in a northerly direction. The western part of the basin is part of the middle Rocky Mountains physiographic province; the eastern section is located in the northern Great Plains (Rocky Mountain Association of Geologists 1972).

THE CONFLICT

Historically, agriculture has been Montana's most important industry. In 1975, over 40 percent of the primary employment in Montana was provided by agriculture (Montana Department of Community Affairs 1976). In 1973, a good year for agriculture, the earnings of labor and proprietors involved in agricultural production in the fourteen counties that approximate the Yellowstone Basin were over \$141 million, as opposed to \$13 million for mining and \$55 million for manufacturing. Cash receipts for Montana's agricultural products more than doubled from 1968 to 1973. Since that year, receipts have declined because of unfavorable market conditions; some improvement may be in sight, however. In 1970, over 75 percent of the Yellowstone Basin's land was in agricultural use (State Conservation Needs Committee 1970). Irrigated agriculture is the basin's largest water use, consuming annually about 1.5 million acre-feet (af) of water (Montana DNRC 1977).

There is another industry in the Yellowstone Basin which, though it consumes little water now, may require more in the future, and that is the coal development industry. In 1971, the North Central Power Study (North Central Power Study Coordinating Committee 1971) identified 42 potential power plant sites in the five-state (Montana, North and South Dakota, Wyoming, and Colorado) northern Great Plains region, 21 of them in Montana. These plants, all to be fired by northern Great Plains coal, would generate 200,000 megawatts (mw) of electricity, consume 3.4 million acre-feet per year (mmaf/y) of water, and result in a large population increase. Administrative, economic, legal, and technological considerations have kept most of these conversion facilities, identified in the North Central Power Study as necessary for 1980, on the drawing board or in the courtroom. There is now no chance of their being completed by that date or even soon after, which will delay and diminish the economic benefits some basin residents had expected as a result of coal development. On the other hand, contracts have been signed for the mining of large amounts of Montana coal, and applications have been approved not only for new and expanded coal mines but also for Colstrip Units 3 and 4, twin 700-mw, coal-fired, electric generating plants.

In 1975, over 22 million tons of coal were mined in the state, up from 14 million in 1974, 11 million in 1973, and 1 million in 1969. By 1980, even if no new contracts are entered, Montana's annual coal production will exceed 40 million tons. Coal reserves, estimated at over 50 billion economically strippable tons (Montana Energy Advisory Council 1976), pose no serious constraint to the levels of development projected by this study, which range from 186.7 to 462.8 million tons stripped in the basin annually by the year 2000. Strip mining itself involves little use of water. How important the energy industry becomes as a water user in the basin will depend on: 1) how much of the coal mined in Montana is exported, and by what means, and 2) by what process and to what end product the remainder is converted within the state. If conversion follows the patterns projected in this study, the energy industry will use from 48,350 to 326,740 af of water annually by the year 2000.

A third consumptive use of water, municipal use, is also bound to increase as the basin population increases in response to increased employment opportunities in agriculture and the energy industry.

Can the Yellowstone River satisfy all of these demands for her water? Perhaps in the mainstem. But the tributary basins, especially the Bighorn, Tongue, and Powder, have much smaller flows, and it is in those basins that much of the increased agricultural and industrial water demand is expected.

Some impacts could occur even in the mainstem. What would happen to water quality after massive depletions? How would a change in water quality affect existing and future agricultural,industrial, and municipal users? What would happen to fish, furbearers, and migratory waterfowl that are dependent on a certain level of instream flow? Would the river be as attractive a place for recreation after dewatering?

One of the first manifestations of Montana's growing concern for water in the Yellowstone Basin and elsewhere in the state was the passage of significant legislation. The Water Use Act of 1973, which, among other things, mandates the adjudication of all existing water rights and makes possible the reservation of water for future beneficial use, was followed by the Water Moratorium Act of 1974, which delayed action on major applications for Yellowstone Basin water for three years. The moratorium, by any standard a bold action, was prompted by a steadily increasing rush of applications and filings for water (mostly for industrial use) which, in two tributary basins to the Yellowstone, exceeded supply. The DNRC's intention during the moratorium was to study the basin's water and related land resources, as well as existing and future need for the basin's water, so that the state would be able to proceed wisely with the allocation of that water. The study which resulted in this series of reports was one of the fruits of that intention. Several other Yellowstone water studies were undertaken during the moratorium at the state and federal levels. Early in 1977, the 45th Montana Legislature extended the moratorium to allow more time to consider reservations of water for future use in the basin.

THE STUDY

The Yellowstone Impact Study, conducted by the Water Resources Division of the Montana Department of Natural Resources and Conservation and financed by the Old West Regional Commission, was designed to evaluate the potential physical, biological, and water use impacts of water withdrawals and water development on the middle and lower reaches of the Yellowstone River Basin in Montana. The study's plan of operation was to project three possible levels of future agricultural, industrial, and municipal development in the Yellowstone Basin and the streamflow depletions associated with that development. Impacts on river morphology and water quality were then assessed, and, finally, the impacts of altered streamflow, morphology, and water quality on such factors as migratory birds, furbearers, recreation, and existing water users were analyzed.

The study began in the fall of 1974. By its conclusion in December of 1976, the information generated by the study had already been used for a number of moratorium-related projects--the EIS on reservations of water in the Yellowstone Basin, for example (Montana DNRC 1976). The study resulted in a final report summarizing all aspects of the study and in eleven specialized technical reports:

Report No. 1 Future Development Projections and Hydrologic Modeling in the Yellowstone River Basin, Montana.

Report No. 2 The Effect of Altered Streamflow on the Hydrology and Geomorphology of the Yellowstone River Basin, Montana.

Report No. 3 The Effect of Altered Streamflow on the Water Quality of the Yellowstone River Basin, Montana.

Report No. 4 The Adequacy of Montana's Regulatory Framework for Water Quality Control

Report No. 5 Aquatic Invertebrates of the Yellowstone River Basin, Montana.

Report No. 6 The Effect of Altered Streamflow on Furbearing Mammals of the Yellowstone River Basin, Montana.

Report No. 7 The Effect of Altered Streamflow on Migratory Birds of the Yellowstone River Basin, Montana.

Report No. 8	The Effect of Altered Streamflow on Fish of the Yellowstone and Tongue Rivers, Montana.
Report No. 9	The Effect of Altered Streamflow on Existing Municipal and Agricultural Users of the Yellowstone River Basin, Montana.
Report No. 10	The Effect of Altered Streamflow on Water-Based Recreation in the Yellowstone River Basin, Montana.
Report No. 11	The Economics of Altered Streamflow in the Yellowstone River Basin, Montana.

ACKNOWLEDGMENTS

A special thanks is due to Shari Meats, the editor, who saw this massive project through to completion single-handedly, even at the expense of leisure time (for months) and alteration of her personal plans. To save time, she typed most of this report herself.

Other DNRC personnel provided assistance. Barbara Williams and Janet Cawlfield typed parts of the report. Graphics were coordinated and performed by Gary Wolf, with the assistance of June Virag and of D.C. Howard, who also designed and executed the cover.

Cindi Koch, with the Billings office of the Montana Department of Health and Environmental Sciences' Water Quality Bureau, typed the first draft of the report.

Introduction

PURPOSE

The overall goal of this study was to investigate the impacts of coal development--existing and potential--on water quality in the Yellowstone River Basin. Specific tasks included:

1) the accumulation and analyses of water quality data for all significant surface waters in the area;

2) the investigation of water quality problems directly associated with mining and energy conversion;

3) an investigation of the effects of stream dewatering on water quality; and

4) recommendations on methods of improving the state's water quality program.

Alterations in water quality are expected to occur in streams of the Yellowstone drainage as a result of water withdrawals and development. To assess potential impacts on beneficial uses of these surface waters, the current baseline water quality status of the affected streams must be determined through analyses of available chemical and biological data. Baseline data provide a reference point for assessing the degree of potential impact.

For example, a particular surface water might be judged through such assessments as unsuitable for irrigation but of adequate quality for the maintenance of a warm-water fishery and of excellent quality for the watering of stock. Negative alterations of stream quality, therefore, would not affect its use for irrigation but could affect the stream's fishery and reduce the stream's value as a source of water for stock. Assessments of available data should illustrate such existing use-quality relationships and indicate the greatest potential point of impact.

These considerations describe the primary purposes for initiating this phase of the study: the gathering and analyses of water quality data for all significant surface waters in the prescribed areas. Such analyses were completed in part by delineating the critical water quality parameters of a system through the comparisons of its physical, chemical, and biological data with pertinent reference criteria and water quality standards.

SCOPE

In addition to a thorough inventory of baseline water quality of streams in the study area, present and potential activities in the basin that affect water quality were reviewed. Using mathematical models and computer simulations, estimates were made of future changes in water quality resulting from new diversions for irrigation, energy conversion, and municipal use projected in the three levels of development explained in appendix A. The primary water quality parameter modeled was total dissolved solids (TDS), but other parameters were considered where appropriate. The thirty-year period from 1944 to 1973 was the basis for all analyses.

MEASUREMENT

To completely describe the water quality in any given aquatic system, analyses of water samples must include a large number of physical and biological parameters. STORET has the potential to store data from the measurements of over 1,500 physical, chemical, and biological parameters. In addition, the United States Geological Survey (USGS) and the Water Quality Bureau (state WQB) of the Montana Department of Health and Environmental Sciences (Montana DHES), between 1965 and 1975, analyzed between 58 and 131 distinct water quality parameters in samples from the Yellowstone River above Custer, Montana (USDI 1966-1974b). Data from such analyses include the direct measurements of the concentrations of a variety of single chemical constituents in the samples either in their dissolved (on filtered aliquots) or total (on unfiltered aliquots) forms; calcium, magnesium, bicarbonate, carbonate, and the metals are some of the constituents measured, typically in milligrams per liter (mg/l) or micrograms per liter (μg/l) but occasionally as milliequivalents per liter (me/l). Determinations of particular parameters in combination have also been made, including total hardness (calcium plus magnesium), total alkalinity ($HCO_3^- + CO_3^= + OH^-$), sodium adsorption ratios (Hem 1970), dissolved solids as the sum of prominent constituents, and sums of cations-anions. Some constituents can be measured in a variety of different forms through the various steps of their analyses, such as phosphorus (total-P, total ortho-P, dissolved-P, dissolved ortho-P and organic-P, among others), and some of the parameters afford an indirect measurement of general features of the water. For example, specific conductance indicates salinity of dissolved solids and turbidity; suspended sediment, transparency, and chlorophyll indicate algal biomass. In addition, sample water can be used in various laboratory or field tests to define aspects of its quality apart from the chemical analyses, e.g., in bioassays which can be used to delineate a water's possible toxicity or eutrophic potential.

Data for all of these parameters can be used to characterize certain aspects of a water's quality. In general, however, complete descriptions of the water quality in a lake or stream cannot be made because analyses cannot be directed to the entire spectrum of possible parameters; rather, a small subset of parameters is defined by the objectives of the sampling program or study. In addition, the parametric composition of the subsets can vary among the various sampling programs within any given region. As a result, discussions of water quality must revolve around a small percentage of the total possible parameters; such parameters have data which are consistently available through the time frame and between the streams and locations under consideration.

Several parameters meet these criteria for this inventory and form the basis of a water quality discussion on the Yellowstone River Basin; these are listed in table 1 as common constituents, critical nutrients, metals, and field parameters. In addition to iron, boron, and arsenic, other metals with

TABLE 1. Methods of analysis.

Parameter	Method
Common Constituents--Cations	
Sodium	Atomic absorption[a]
Calcium	EDTA titration[a]
Magnesium	EDTA titration[a]
Potassium	Atomic absorption[a]
Hardness	EDTA titration[a]
Common Constituents--Anions	
Chloride	Mercuric nitrate titration[a]
Sulfate	Thorin titration[b]
Bicarbonate-Carbonate	Acid titration[a]
Fluoride	Complexone[c]
Alkalinity	Acid titration[a]
Critical Nutrients	
Ammonia-Nitrogen	Phenylate[c]
Nitrate + Nitrite-Nitrogen	Hydrazine reduction, diazotization[a,c]
Orthophosphate-Phosphorus	Single reagent[c]
Total Phosphorus	Persulfate digestion, single reagent[c]
Metals	
Most metals	Atomic absorption[a]
Iron	Ferron-orthophenanthroline[b]
Boron	Carmin[a]
Arsenic	Silver diethyldithiocarbamate[a]
Field Parameters	
Dissolved oxygen	Modified Winkler[c]
pH	Potentiometric (meter)
Specific conductance	Wheatstone bridge (meter)[a]
Temperature	Calibrated mercury thermometer
Turbidity	Nephelometric[a]
Fecal coliforms	Membrane filter, colony counts[a,d]
Biochemical oxygen demand	Incubation, modified Winkler[a,c]

NOTE: Many of these analyses were completed using a Technicon auto-analyzer.

[a]APHA et al. 1971.
[b]Brown et al. 1970.
[c]Millipore Corporation 1976.
[d]U.S. Environmental Protection Agency 1974a.

relatively consistent data include manganese, copper, zinc, cadmium, and mercury; however, several of the metals were only sporadically analyzed through the various sampling programs in the region. These and other parameters with less consistent data (e.g., pesticides and radiochemical variables) were considered as available for a particular stream or basin.

PARAMETER GROUPS

Related water quality parameters can be combined into various groups for the general purpose of organizing the water quality discussions. The grouping employed for this inventory was adapted from that used by the U.S. Environmental Protection Agency (EPA) in its National Water Quality Inventory (USEPA 1974b); the EPA's system was modified slightly to better conform with the types and amounts of data available on the Yellowstone Basin. As a result, five parameter groups were defined for this inventory: (1) physical factors, (2) oxygen status, (3) eutrophic potential, (4) salinity and common ions, and (5) toxic and harmful substances and health hazards. These groups and their associated parameters are briefly described below; more complete descriptions of these groups and their associated implications as pollutants are available in the EPA's report (USEPA 1974b).

There is some similarity between groups; many of the parameters placed into one of the groups could easily fit into one or two of the others in particular situations. Some of the parameters in these groups definitely cause pollution and detract from the quality of water for man's activities; considerations of such pollutants formed the crux of the EPA's national inventory. However, some of the water quality parameters are not so obviously pollution-causing because they arise from natural features or nonpoint sources. Nevertheless, they still detract from water quality and its beneficial use. Both types of parameters are considered in this inventory. Following are descriptions of the five parameter groups.

Physical Factors

Flow, which describes the size of a stream and provides part of the data necessary for calculating loads, can be classified as a physical factor. Load data for a parameter provides the requisite information for judging the potential effect of a tributary stream or point discharge upon the receiving waters.

Temperature is another physical factor. Changes in temperature primarily detract from the biotic aspects of an aquatic system by altering its biological composition and the rates of biological activity.

Transparency is another physical factor that can, upon alteration, affect biological systems (e.g., by reducing light penetration). Transparency is generally measured indirectly through turbidity. High levels of turbidity imply low transparencies and aesthetic degradation of a stream or lake.

Suspended sediment and suspended solids are physical factors that can be determined directly or, through the measurement of turbidity, indirectly. High levels of suspended materials can also directly affect biotic systems and can restrict other uses of the water, such as recreation and public surface supply. High levels of suspended sediment in a stream are typically derived from natural or nonpoint sources.

Color is another physical factor, but inadequate data are available for consideration of this parameter. Only a few measurements of water color have been made in the Yellowstone Basin.

Oxygen Status

Adequate levels of dissolved oxygen (DO) are critical in aquatic systems for the maintenance of most aquatic life. Low levels of DO (less than that expected on the basis of a system's temperature and pressure profile--less than 100 percent saturation) often indicate organic pollution and oxidation of organic materials. Organic pollution can arise from a variety of point and nonpoint sources (including runoff from agricultural areas, municipal and industrial point-source discharges, storm sewers, sanitary sewer overflows, and unsewered discharges) and from natural sources, e.g., inputs of soil organic matter (humus), animal droppings, and vegetative debris such as leaves. DO expressed as percentage of saturation is an inverse measure of organic pollution; i.e., lower values suggest greater levels of organic input into the water tested. Other parameters, such as five-day biochemical oxygen demand (BOD_5), are more valuable in directly quantifying the magnitude of this type of problem. Considerable BOD_5 and DO data are available from streams in the Yellowstone Basin. Data for two other common indices of organic pollution--chemical oxygen demand (COD) and total organic carbon (TOC)--are relatively sparse and sporadic in this drainage.

Eutrophic Potential

Eutrophication is the process of nutrient enrichment in a body of water, typically accompanied by increases in plant growth and production which can lead to nuisance algal blooms and macrophyte growths with associated odor and taste problems, oxygen reductions upon decay, and aesthetic degradation. Eutrophication occurs naturally with the normal aging (in geologic time) of streams and lakes, but this process can be and has been greatly accelerated by inputs from point and nonpoint sources of pollution in recent historic time.

Numerous chemical elements are required by aquatic plants in varying degrees for their optimum growth and development; such constituents in the water are classified as nutrients. This includes the macronutrients, a group of elements required by plants in relatively large amounts (Ca, Mg, S, C, P, and N, among others). Plants also require, in extremely small amounts, a group of elements called the micronutrients (Zn, Cu, B, Co, Mn, Mo, and Fe), but all of these parameters, occurring below critical concentrations, can be equally limiting to plant growth. Attention is generally directed to nitrogen (N) or phosphorus (P) as the most likely limiting factor(s) in aquatic systems. High concentrations of these constituents imply a high eutrophic potential in a lake or stream, and additional inputs of N and P, when limiting, have been found to greatly increase plant production. For this inventory, N and P are assumed to be the critical limiting nutrients in the Yellowstone River Basin.

There are several forms of phosphorus in water; this is also true of nitrogen. However, N and P data in the Yellowstone drainage are available primarily as $(NO_2 + NO_3)$-N or NO_3 - N and as ortho-P. Some analyses have also been completed for ammonia-nitrogen and total-P, but available data are incomplete for the bulk of the N and P species, including total-N, Kjeldahl-N, organic-N, and organic-P. As a result, $NO_2 + NO_3$ (or NO_3, and NH_3 as available) and ortho-P (and/or total-P) are considered to be the prime indices of eutrophic potential in this inventory. Ortho-P, NO_3, NO_2, and NH_3 are the forms usually absorbed by plants and therefore most directly involved in the stimulation of plant growth.

Salinity and Common Ions

This grouping consists of a large number of water quality parameters. In many instances, salinity (total dissolved solids) is considered to be the main factor in assessing or describing a water quality. However, many of the common ions that comprise the TDS concentration of a water can individually detract from a water use when in extremely high concentrations. The common constituents listed for this parameter group include primarily the anions and cations described in table 1 and silica.

The salinity of a water can be measured or estimated in several ways--indirectly, via the specific conductance of a sample or as the sum of individual constituents (predominantly the common ions) after chemical analyses, or directly, by weighing the filterable residue of an aliquot of water sample after evaporation at 180°C. High levels of salinity and of certain common ions in a pond, lake, or stream are commonly derived from natural sources, but this problem can be intensified by inputs of TDS from nonpoint sources (e.g., from saline seep areas aggravated by poor agricultural practices or from irrigation return flows) and, in some cases, by unique point-source discharges.

Other parameters placed in this group are hardness and alkalinity, which can also detract from water use and its quality, although adequate levels of alkalinity are important in acting as a buffer to acid inputs to a stream. The sodium adsoption ratio (SAR) is also included in this group because it is a summary variable describing the Na: Ca-Mg relationships of a water relative to irrigational use. In addition, pH is considered to belong to this group.

Excluding silica, considerable amounts of data are available for most of these parameters.

Toxic and Harmful Substances and Health Hazards

Numerous constituents potentially present in the water can act as toxic, harmful substances (affecting the biota) or as health hazards (affecting man). This includes some of the parameters described previously in other groupings, although a set of parameters not yet discussed is generally placed into this category--the metals, pesticides and herbicides, radiochemical parameters, phenols, oil and grease, the coliforms (total, fecal, and strep), and the polychlorinated biphenyls. Most of these constituents are pollution-causing, many are abiotic, and most do not usually arise in high concentrations from natural sources.

Only sparse data are available for most of these parameters. As a result, this inventory was directed primarily to certain of the metals and to the fecal coliforms. This latter feature is an indirect indicator of a potential health hazard when measured at high levels in a sample. The other parameters that fit into this group are briefly considered for those streams on which such data are available. Even for some of the metals, only sporadic analyses were made.

WATER QUALITY INDEX

Because the water quality information available for a region under consideration was collected by a variety of agencies and is often variable in time, location, and scope, comparison and interpretation of this information is often difficult. The National Sanitation Foundation has attempted to develop a water quality index (WQI) which would: "(1) Make available a tool for dependably treating water quality data and presenting them as a single numerical index, and (2) promote utilization of a process for effectively communicating water quality conditions to all concerned" (McClelland 1974).

The WQI has been defined as a "single numerical expression which reflects the composite influence of nine significant physical, chemical, and microbiological parameters of water quality" (McClelland 1974). Nine variables are included in the WQI: DO as percentage of saturation, fecal coliform density, pH, BOD_5, nitrates (NO_3-N), phosphates (PO_4-P), temperature departure from equilibrium, turbidity, and total solids. These parameters basically reflect polluted conditions when they deviate from a qualitative, prescribed norm. The WQI is derived from a multiplicative model in which the nine parameters are weighted (as ordered above) with respect to their overall importance to water quality. The resulting WQI ranges from zero to 100 with the higher values indicative of a better water quality relative to these variables. A value of 100 for a sample would reflect a case where none of the parameters had deviated from the norm.

One disadvantage of this WQI lies in the necessity of knowing all nine values and in the possibility of missing data. According to Inhaber (1975), "Almost no environmental information is now (or has been) collected with an index in mind, and so the data tend to be highly non-uniform and difficult to amalgamate." As a result, certain of the nine parameters may be missing from the analysis, in which case the WQI would be incalculable. In addition, the WQI, developed in part by McClelland (1974), may not represent the best index for regions with particular problems; a different weighting, exclusion of some of the nine parameters, or the inclusion of other variables could afford a more appropriate WQI for some areas. In any event, WQI's have been calculated for those streams in the Yellowstone drainage sampled by the state WQB for all of the critical parameters. Determinations of these nine variables have been stressed in the analysis of recent samples obtained by the state WQB.

More complete considerations of the rationale, procedures, calculations, historical background, and applications of the WQI are available from Brown et al. (1970), Brown et al. (1973), McClelland (1974), and Brown and McClelland (1974).

DESCRIPTION OF STUDY AREA

Three segments of the Yellowstone River can be delineated in Montana, defined on the basis of the type of drainage associated with each. The upper, southwestern reach comprising about 168 miles (270 km) above Laurel, Montana, has tributaries that drain primarily mountainous areas; several of these streams are relatively large, and many of the streams in this drainage segment have continuous, natural flows. Most of the smaller tributaries also have mountainous origins.

In contrast, although the larger streams in the 253-mile (407-km) middle segment (Laurel to Terry, Montana) also have their headwaters in mountainous areas, they also have an extensive prairie drainage. The larger streams in the middle segment typically have a continuous flow, but many of the smaller tributaries are ephemeral or intermittent in nature and have a plains rather than a mountainous origin. Poorer qualities of water are typically associated with streams that have extensive prairie watersheds than those with mountainous drainage systems.

Low volumes of tributary flow characterize the 129-mile (208-km) segment of the river between Terry and Fairview, Montana. Tributaries are typically small and often intermittent streams of prairie origin. This lower, northeastern segment, along with the upper and middle segments and associated drainages, roughly correspond to the three water quality management planning areas defined by the state WQB for the Yellowstone River drainage. The water quality in these three segments of the mainstem and the changes in quality through the reaches are in part a reflection of the types and magnitudes of surface water contributions to the mainstem from the drainages associated with the segments.

DRAINAGE BASINS EXAMINED AND ASSOCIATED STREAMS

The study area has been divided into a primary and secondary area, each of which is subdivided into several subregions (figure 1). Subregions are natural hydrological basins and generally correspond to combinations of two or three minor drainage basins delineated by the Montana Department of Natural Resources and Conservation (Montana Water Resources Board, no date).

The secondary, less extensive survey area extends from the Yellowstone National Park border to the mouth of the Clarks Fork Yellowstone River and consists of two minor drainage basins (43B and 43QJ). The associated drainage basins of the major tributaries to the mainstem in this upper segment--the Shields (43A), Boulder (43BJ), Stillwater (43C), and Clarks Fork (43D) rivers, and Sweetgrass Creek (43BV) drainages--were not considered in this inventory; tabular summaries and discussions of the chemistry and quality of water in these minor basins are available in a water quality management planning report prepared by Karp et al. (1976). Water quality information for the secondary study area of this inventory is available from several sequential sampling locations along the river. One of the sites, at Corwin Springs, about 6.5 miles (10.5 km) below Gardiner, is the most westerly location, while the one at Laurel, Montana, is located near the eastern border of this secondary area.

Yellowstone River Basin

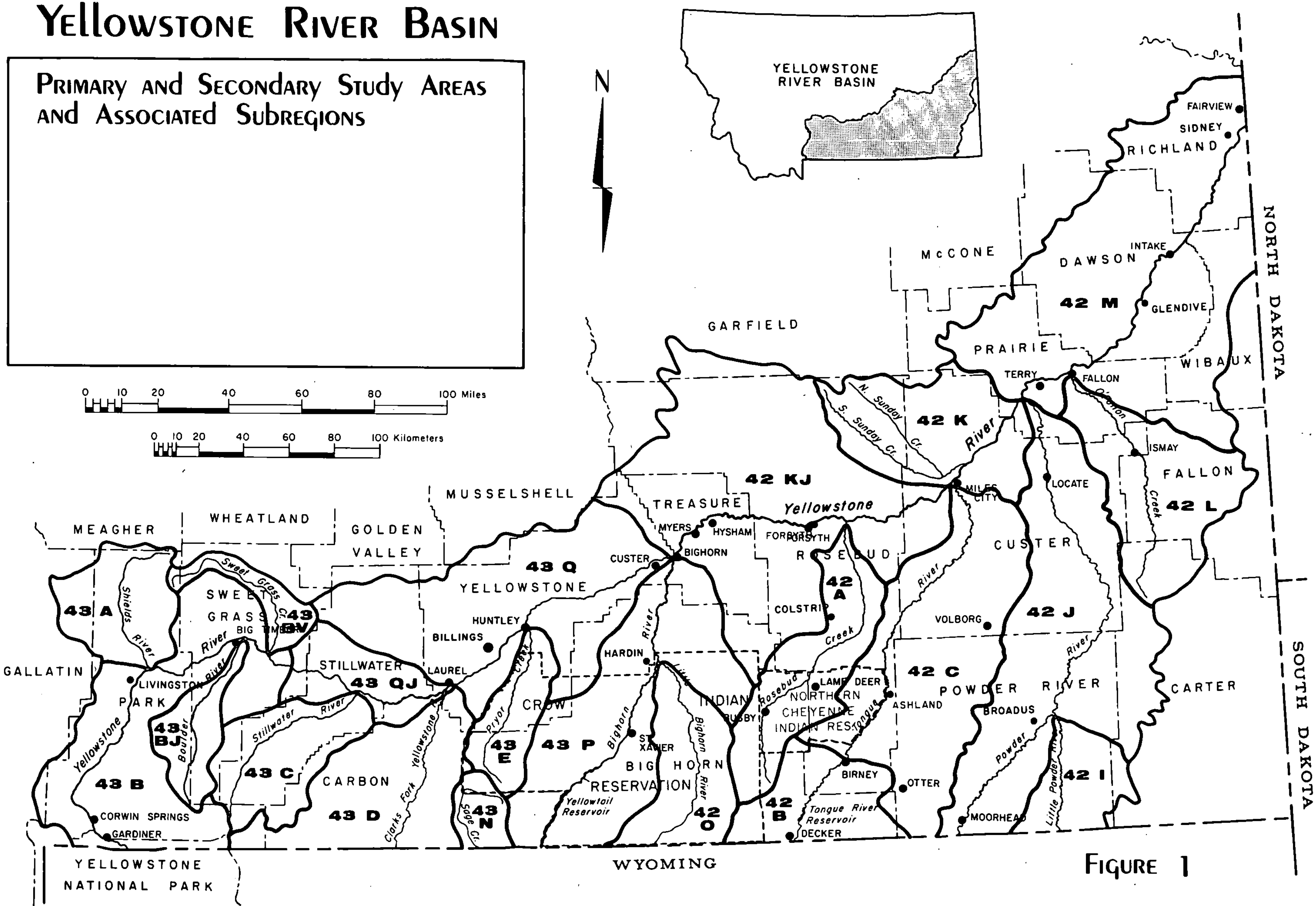

Figure 1

Six major subregions were defined for the primary inventory portion of the Yellowstone drainage; these subregions were further subdivided. Three of the subregions in the primary study area had segments of the Yellowstone mainstem as the major stream whereas the other three subregions consisted of the drainage area associated with a major tributary to the Yellowstone:

1) Yellowstone mainstem between the mouths of the Clarks Fork Yellowstone and Bighorn rivers;

2) Yellowstone mainstem between the mouths of the Bighorn and Powder rivers;

3) Yellowstone mainstem from the mouth of the Powder River to the state line;

4) Bighorn River;

5) Tongue River; and

6) Powder River.

Mainstem Subregions

The most western subregion of the primary inventory area that includes a segment of the mainstem consists of the Yellowstone River and tributaries between the confluences of the Clarks Fork Yellowstone (at Laurel) and Bighorn rivers (at Bighorn) (basin 43Q). The major tributary of the Yellowstone in this segment is Pryor Creek (43E) which originates in the Pryor Mountains and flows northward to join the mainstem at Huntley, Montana. Relatively complete chemical data (i.e., various common ions such as Ca and SO_4, critical nutrients such as NO_3+NO_2-N and PO_4-P, several metals such as Fe and Zn, calculated information such as sodium adsorption ratio and total dissolved solids, and field parameters--e.g., specific conductance, dissolved oxygen coliforms, and temperature) are available for this creek and a few small tributary streams (e.g., Hay Creek) and for several locations on the mainstem through this segment, including Laurel to the west and Custer to the east. In addition, complete chemistry data is available for several of the smaller streams in this region--Arrow and Fly creeks east of Huntley and Canyon and Duck creeks west. Of these four and Pryor Creek, only Canyon Creek drains an area north of the Yellowstone River. Partial chemical data (analysis of a few specific parameters such as suspended sediment, conductivity, and critical nutrients) are available for several mainstem locations and for numerous small creeks west of Huntley (Fivemile, Alkali, and Blue creeks in addition to Canyon and Duck creeks). These more specific water quality data were collected in conjunction with a waste-load allocation investigation of the Yellowstone River in the vicinity of Billings being completed by the state WQB (Karp et al. 1976b, Klarich 1976).

The second mainstem subregion extends from the confluence of the Bighorn River to the confluence of the Powder River near Terry, Montana. This middle region consists of two unequal minor basins--42KJ to the west and a small basin to the east (42K), which consists primarily of the Sunday Creek drainage north of the river near Miles City. The drainage areas of the two major tributaries that delimit this middle area (the Bighorn and Powder rivers) plus that of the Tongue River located between these two streams were considered separate subregions. As a result, Rosebud Creek is the major tributary within this middle subregion (basin 42A). The creek has its headwaters in the Rosebud Mountains in southeastern Montana and flows in a north to northeasterly direction from its origin, joining the Yellowstone River near Forsyth, Montana. Rosebud Creek is close to the town of Colstrip, the site of extensive coal-fired, electrical generation development. Considerable water quality data has been gathered for several locations on this stream through sampling programs for environmental impact statement (EIS) purposes (Montana DNRC 1974). This was also the case for two minor Yellowstone tributaries in the drainage--Sarpy and Armells creeks south of the mainstem between Hysham and Forsyth. In addition to Sunday Creek, complete chemical data are available for other mainstem tributaries in this middle subregion (Froze-to-Death, Great, and Little Porcupine creeks north of the river, and Reservation, Sweeney, and Moon creeks south and for several of the Rosebud Creek tributaries (Davis, Lame Deer, and Muddy creeks near Busby and Lame Deer on the Northern Cheyenne Indian Reservation). Many of these are small, and some are intermittent. Data for the mainstem in this subregion are available for several locations, including Myers (to the west), Miles City, and Terry (near the eastern boundary).

Tributaries to the mainstem in the eastern or lower segment of the Yellowstone River (a relatively expansive minor basin (42M) that extends from the mouth of the Powder River to the Montana-North Dakota border) are typically small with generally low volumes of flow; many of these streams are intermittent. Some complete water quality data are available for a few of these small streams including Cabin, Cedar, and Glendive creeks south of the mainstem between Fallon and Glendive and Fox Creek north of the river near Sidney. The Yellowstone River has been sampled at several locations in this lower subregion, including sites (in downstream order from the southwest to the northeast) at Terry-Fallon, Glendive, Intake, and Sidney, plus a site in North Dakota between Cartwright and Fairview, Montana (Highway 200 bridge). One of the major tributaries to the Yellowstone in this subregion is O'Fallon Creek (basin 42L). Complete chemical data are available for this stream and for two of its tributaries--Sandstone and Pennel creeks near Ismay, Montana.

Tributary Subregions

Three major tributaries join the Yellowstone River in the primary inventory area--the Bighorn, Tongue, and Powder rivers. All of these streams enter the mainstem from the south and have their origins in the mountainous regions of Wyoming (the Bighorn and Owl Creek mountains and the Rattlesnake Range). The drainage areas of these large tributaries were considered separate subregions due to the large amount of water quality data available for these basins. Complete chemical information is generally available for several well-spaced locations on the main river in each of these subregions and for several locations on its major tributaries. Similar to the sampling sites on the mainstem, the sampling locations on these major streams were dispersed along the length of the river in Montana. In addition, chemical data are available from at least one location on many of the smaller creeks in each of these subregions.

The three tributary subregions and associated major rivers are the Bighorn-Little Bighorn rivers drainage (43P and 430) located in the southwestern portion of the primary study area, the Powder-Little Powder rivers drainage (42J and 42I) covering the southeastern sector, and, contiguous in the extreme southern segment of Montana to both of these drainages, the intermediately located Tongue River drainage (42B and 42C). The Clarks Fork-Pryor Creek-Fly Creek drainages lie to the west of the Bighorn system, and the O'Fallon Creek-Little Missouri systems lie to the east of the Powder-Little Powder rivers drainage.

The upstream portion of the Bighorn River in Montana is inundated by Yellowtail Reservoir (Bighorn Lake). One set of chemical data is available for several streams (e.g., Black Canyon and Dry Head creeks) that drain partially unsurveyed terrain around Yellowtail Reservoir in Montana and Wyoming and then empty into the reservoir. Water quality data also are available for the Bighorn and Little Bighorn rivers and for several of the smaller streams in their drainage, including Pass, Owl, Lodge Grass, and Reno creeks, which are tributaries of the Little Bighorn River, and Soap, Rotten Grass, Beauvais, and Tullock creeks, tributaries of the Bighorn. Additional data are available for a few miscellaneous creeks in this drainage (e.g., Sioux Pass Creek). In addition, some data have been collected for Sage Creek (basin 42N) near Warren, which originates in the Pryor Mountains of Montana but has the bulk of its drainage in Wyoming where it joins the Bighorn River. Many of the streams in the Bighorn-Little Bighorn system are located totally or in part on the Crow Indian Reservation.

Major tributaries in the Tongue River and Powder River systems are Hanging Woman, Otter, and Pumpkin creeks in the former, and Mizpah Creek and the Little Powder River in the latter; a considerable amount of complete chemical data are available for these particular streams. In addition, many small, generally intermittent streams have been sampled during the past year in the Decker-Birney-Ashland area of the Tongue River drainage by the Bureau of Land Management (BLM) under contract to the USGS for an EIS related to the leasing of federal land for coal mining in this region. Examples of such streams include Fourmile, Bull, and Cook creeks near Birney; Threemile, Beaver, and Liscom creeks near Ashland, and Bear Creek at Otter, Montana (USDI 1976). Other small streams in the Tongue River drainage for which some chemical data are available include Young, Squirrel, and Deer creeks near Decker and Little Pumpkin Creek near Volborg. Complete water quality information for the Powder-Little Powder River subregion was collected primarily from these two rivers and from Mizpah Creek. Single sets of data are available for two minor streams in this drainage--Sand Creek near Volborg and Sheep Creek near Locate.

The three segments described on page 12 were not defined strictly on the basis of hydrological basins as were primary and secondary survey areas and their respective subregions. However, the upper segment of the Yellowstone above Laurel generally corresponds to the subregion defined as the mainstem above the confluence of the Clarks Fork River. The next two downstream subregions in the primary study area--the mainstem from the Clarks Fork Yellowstone to the Bighorn and from the Bighorn to the Powder--closely relate to the middle segment of the river (extending from Laurel to Terry). The lower segment of the Yellowstone below Terry closely corresponds to the final downstream subregion from the Powder River confluence to the Montana-North Dakota border.

Theoretically, the adjustments should be made to Q_T and $LTDS_T$ (figure 2) before initiating the process detailed in table 20 so that increased salt concentrations would be considered in the water diverted for, and returned from, irrigation. Computational problems would have increased by at least a factor of 30, however, and that consideration, plus time and logistic factors, made that course of action prohibitive. Adjustments to the salt loads were small in most cases, and only a fraction of Q_T, the total flow, was diverted in a given month. Consequently, any errors introduced by adjusting salt loads after, instead of before, simulating water quality were judged to be minor.

Methodology for Other Parameters

Most conservative parameters can be estimates from total dissolved solids through the use of linear regression equations. Therefore, common ions and hardness were related to TDS by simple linear regression equations developed from data published by the USGS (1966-1974). Two to four years of data were used for each station. Generally, excellent results were obtained (regression coefficients greater than 0.9). Consequently, once future TDS concentrations were calculated by methods described previously, concentrations of individual ions were computed from regression equations. Determination of hardness, also a linear function of TDS, was obtained in the same manner. Sodium, sulfate, chloride, and bicarbonate ions were examined for each basin and, along with hardness, are discussed under "Other Parameters" for each subbasin where changes in concentration are significant.

Sodium adsorption ratio is a nonlinear function of the concentrations of sodium, calcium, and magnesium ions. SAR was estimated by two methods: (1) SAR as a linear function of TDS, and (2) SAR as a function of sodium, calcium, and magnesium ion concentrations, which were obtained from regression equations applied to simulated TDS values. Results of the two methods generally were similar.

No attempt was made to simulate nonconservative parameters such as dissolved oxygen, fecal coliform bacteria, nutrients, and water temperature. Regression equations were obtained for average monthly water temperature as a function of average monthly air temperature and monthly discharge for the Yellowstone River near Sidney during July and August. Results, although not always statistically significant, were used as a guide in estimating the effect of decreased streamflows on water temperature. Generally, however, estimates of the effects of the levels of development on nonconservative parameters, including sediment, were only qualitative and based on the judgement of the authors.

Methods

Two levels of water quality inventory and survey were conducted for this study. Because the major water use impacts from water withdrawal and development were expected to occur in the middle and lower portions of the Yellowstone drainage in association with the Fort Union coal formation, an intensive survey was designed for the Yellowstone River system below the mouth of the Clarks Fork Yellowstone River, which corresponds to the middle and lower segments described above. In this case, the inventory was directed not only to the Yellowstone mainstem but also to all significant surface waters in the drainage, including major tributaries such as the Little Bighorn, Bighorn, Tongue, and Powder rivers, the significant streams in their drainages (e.g., Tullock, Otter, and Hanging Woman creeks and the Little Powder River), and small but significant tributaries of the Yellowstone River, e.g., Sarpy, Armells, and Rosebud creeks. For comparative purposes and to describe the quality of water entering the intensive survey region, a second, less intensive level of inventory was planned for the Yellowstone drainage above the Clarks Fork Yellowstone River--the upper segment described previously. In this case, none of the numerous major or minor streams in the drainage (e.g., the Shields, Boulder, Stillwater, and Clarks Fork Yellowstone rivers, and Tom Miner, Bill, Big Timber, Sweetgrass, and Deer creeks) were considered to any great detail; only the water quality status of the upper Yellowstone River mainstem was surveyed.

Eighty percent of the additional agricultural development and all of the future energy development is projected to occur in eastern Montana (see appendix A). Consequently, only that portion of the basin east of Billings was analyzed for changes in water quality. To facilitate the analysis, the watershed was divided into six subbasins along hydrological boundaries. Each subbasin, and the station used to gage outflow at the subbasin's lower boundary, is listed below:

1) upper Yellowstone--Yellowstone River at Billings;
2) Bighorn--Bighorn River at Bighorn;
3) mid-Yellowstone--Yellowstone River near Miles City;
4) Tongue--Tongue River at Miles City;
5) Powder--Powder River near Locate; and
6) lower Yellowstone--Yellowstone River near Sidney.

DATA SOURCES AND CHEMICAL ANALYSES

UNITED STATES GEOLOGICAL SURVEY

One major source of water quality information used in this inventory was the USGS. The USGS is primarily a contractual agency that maintains several water quality monitoring stations on various streams throughout the inventory area and the state as funded by interested groups (e.g., the Montana Department of Fish and Game, the Environmental Protection Agency, and the United States Bureau of Reclamation) (USDI 1976). The chemical, physical, and biological data obtained from their sampling programs are summarized by water year in

Water Resources Data for Montana, Part 2--Water Quality Records. Because the period since September 1965 was defined as "current" for this inventory, only data obtained since then were used for this review with a few exceptions (USDI 1966-1974b). Water quality information obtained during water year 1975 and the first part of 1976 had not yet been published at the time of this writing.

The water quality sampling program of the USGS prior to 1966 was directed to only a few streams and locations in the Yellowstone River Basin of Montana. In addition, neither the amounts (sampling frequency, historic record) nor the parametric spectrum of the chemical data were particularly extensive during this pre-1966 period. A large part of this pre-1966 data was obtained during an extensive suspended sediment-temperature investigation of Bluewater Creek (to collect baseline data for determining the feasibility of placing a fish hatchery on the stream) and from four irrigation network stations--the Yellowstone River at Billings and Sidney, the Bighorn River at Bighorn, and the Tongue River at Miles City. In the former case, daily temperature and suspended sediment information, but no related chemical data, were collected for several years. However, Bluewater Creek is not considered a part of the secondary area for this inventory since it is a tributary of the Clarks Fork River. Temperature data and some chemical information, primarily for those parameters that more directly influence the irrigative use of water, were obtained from the irrigation network stations.

Since about 1968-1969, water quality sampling programs in the Yellowstone Basin have increased in the number of stations, spectrum of parameters, and frequency of collections (table 2). The irrigation network stations, now more comprehensive in the range of data gathered, have been continued. The USGS National Stream Quality Accounting Network and the International Hydrological Decade Station programs have added a few water-quality stations to the region, as has the establishment of hydrologic benchmark stations in the drainages of Montana. The development of radiochemical, pesticide, and suspended sediment stations has also further increased the water quality data base for the region in recent years.

As an example of this increased emphasis on water quality sampling since 1968, in water year 1966, only eleven water quality sites, including two on the Yellowstone River, three on Bluewater Creek (only temperature and sediment data), and two on the Bighorn River where only temperature data were obtained, were sampled in the Yellowstone River Basin of Montana. At the USGS station in Billings, about 18 parameters were directly analyzed, including discharge and chemical analyses (common ions plus NO_3, boron, dissolved solids, specific conductance, and pH). In contrast, 10 sites were sampled on the Yellowstone River in 1974, and 26 within the Yellowstone Basin of Montana during this time. In water year 1971, 54 rather than 18 parameters were analyzed in samples taken at Billings, including a number of pesticides, radiochemical parameters, some metals, and some suspended sediment measurements in addition to the analyses listed previously.

Table 3 summarizes the streams and associated locations for which water quality data between October, 1965 and September, 1974 are available from USGS publications (USDI 1966-1974b). Specific parameters analyzed at these sites are considered on pages 83 to 305 in this report. Table 4 presents a list

TABLE 2. Water quality monitoring stations in the Yellowstone River Basin of Montana operated by the USGS between September 1965 and September 1974.

Site Designation	Location[a]	Years of Record[b]		
		Chemical	Temperature	Sediment
North Fork Bluewater Creek near Bridger	06S 24E 15CB	--	1/66-9/70	3/60-9/62 10/63-9/70
Bluewater Creek near Bridger	06S 24E 09AA	--	5/60-9/66[c] 10/67-9/70	4/60-9/70
Bluewater Creek at Sanford Ranch, near Bridger	06S 24E 06CD	--	10/63-9/70	3/60-9/62 10/63-9/70
Bluewater Creek near Fromberg	05S 23E 27DC	--	10/63-9/70	3/60-9/62 10/63-9/70
Bluewater Creek at Fromberg	05S 23E 21CB	--	8/61-9/64 1/66-9/70	4/60-9/70
Yellowstone River at Billings	01N 26E 34AA	10/50-9/58 7/63-9/74	12/50-9/58 7/63-9/74	--
Yellowstone River at Huntley	02N 27E 24C	10/50-9/52 7/72-9/74	--	--
Bighorn River near St. Xavier	06S 31E 16AB	10/66-9/74	12/62-9/74	--
Bighorn River near Hardin	01S 33E 24DA	1/51-9/51 7/69-9/73	12/62-9/73	--
Bighorn River at Bighorn	05N 34E 33AA	11/45-8/47 8/48 3/49-9/74	4/49-9/51 8/52-11/58 6/59-9/74	5/46-9/54 10/55-9/58 10/59-6/72
Tongue River at Miles City	07N 47E 23D	9/48-9/49 1/51-9/74	4/49-9/74	6/46-9/51
Powder River at Moorhead	09S 48E 08B	2/51-9/53 10/55-9/57 7/69-7/72 4/74-9/74	2/51-9/53 10/55-9/57	--
Yellowstone River at Sidney	22N 59E 09CAC	9/48-9/74	1/51-9/74	10/71-9/74

[a]Locations given as township-range-section and in quarter sections as available.

[b]Years of record before 1965 are shown for some stations where applicable.

[c]Unreliable data.

TABLE 3. Water quality monitoring stations in operation between October 1965 and September 1974 with published records maintained by the USGS on the Yellowstone River and in the Yellowstone River Basin of Montana below this confluence.

Site Designation	Location[a]	Period of Record between 9/65 and 9/74
Yellowstone River at Corwin Springs	08S 08E 30BD	7/69-12/73[b]
Yellowstone River near Livingston	03S 09E 12BBA	10/69-9/74[c]
Yellowstone River at Laurel[c]	02S 24E 15CCC	2/74-9/74[c]
Yellowstone River near Laurel[d]	02S 25E 04A	7/69-6/72[b]
Yellowstone River at Billings	01N 26E 34AA	10/65-9/74[c]
Yellowstone River at Huntley	02N 27E 24C	7/72-9/74[c]
Fly Creek at Pompeys Pillar	03N 30E 23DB	10/68-9/74[c]
Yellowstone River at Custer	05N 33E 35AD	7/69-6/70[b]
Bighorn River near St. Xavier	06S 31E 16AB	10/65-9/74[e]
Beauvais Creek near St. Xavier	04S 30E 15	9/67-10/74[c]
Bighorn River near Hardin	01S 33E 24DA	10/65-9/73[b,e,f]
Little Bighorn River below Pass Creek, near Wyola	07S 35E 35C	10/69-9/74[c]
Little Bighorn River near Hardin	01S 34E 19AA	10/69-9/74[c]
Bighorn River at Bighorn	05N 34E 33AA	10/65-9/74[c]
Yellowstone River at Myers	06N 35E 21DCC	4/74-9/74[c]
Yellowstone River at Forsyth	06N 40E 22AAD	4/74-9/74[c]
Yellowstone River near Miles City	08N 47E 31CD	10/68-9/74[c]
Tongue River at state line, near Decker	09S 40E 33AB	10/65-9/74[c]
Tongue River below Hanging Woman Creek, near Birney	06S 42E 01DDC	4/74-9/74[c]
Tongue River below Brandenburg Bridge, near Ashland	01N 45E 06BCA	4/74-9/74[c]
Tongue River at Miles City	07N 47E 23D	10/65-9/74[c]
Yellowstone River near Shirley	10N 49E 32	5/70-9/70[b,e]
Powder River below Fence Creek, near Moorhead in Wyoming	58N 75W 31CBC	6/74-10/74[b,e]
Powder River at Moorhead	09S 48E 08B	7/69-7/72, 4/74-9/74[c]
Little Powder River near Wyoming-Montana state line in Wyoming	58N 71W 36BA	10/69-5/70[b]
Yellowstone River near Terry	12N 51E 10CD	4/74-9/74[c]
Lower Yellowstone Project Main Canal at Intake	18N 56E 25CDC	10/70-9/71[b,e]
Lower Yellowstone Project Main Canal Drain near Cartwright, N.D.	151N 104W	10/70-9/71[b,e]
Sears Creek near Crain	21N 58E 27CBC	10/70-9/71[b,e]
Yellowstone River near Sidney	22N 59E 09CAC	10/65-9/74[c]

[a]Given in township-range-section and in quarter sections as available.
[b]Station discontinued.
[c]Above the confluence of the Clarks Fork Yellowstone River.
[d]Below the confluence of the Clarks Fork Yellowstone River.
[e]Temperature records only are available for some years at these sites.
[f]Continued as a continuous thermograph station in water year 1974.

TABLE 4. Water quality monitoring stations maintained by the USGS in the study area for which information is being or has been obtained on several parameters.

Site Designation	Parameters[a]					
	Temp	SC	TSS	Pest	RC	SG
Yellowstone River at Corwin Springs				c		
Yellowstone River near Livingston	b,c	b,c				
Yellowstone River near Laurel				c		
Yellowstone River at Billings	b,c	b,c	d	c	b,c	
Fly Creek at Pompeys Pillar	b,c	b,c				
Yellowstone River at Custer				c		
Bighorn River near St. Xavier	b,c	b,c		c		
Beauvais Creek near St. Xavier			b,c	c	c	
Bighorn River near Hardin	c					
Little Bighorn River below Pass Creek, near Wyola	c	c	c			
Little Bighorn River near Hardin	b,c	b,c	b,c			
Bighorn River at Bighorn	b,c	b,c	c,d			
Sarpy Creek near Hysham					b	b
Armells Creek near Forsyth					b	b
Rosebud Creek at mouth, near Rosebud					b	b
Yellowstone River near Miles City	b,c	b,c	d			
Tongue River at state line, near Decker	b,c	b,c	e			
Otter Creek at Ashland					b	b
Tongue River below Brandenburg Bridge, near Ashland	b	b	b,e		b	b
Pumpkin Creek near Miles City					b	b
Tongue River at Miles City	b,c	b,c	d			
Powder River at Moorhead	b		b	c	b	b
Powder River at Broadus	b		b			
Mizpah Creek near Mizpah					b	b
Powder River near Locate	b	b	b	d		
Yellowstone River near Sidney	b,c	b,c	b,c	b,c		

NOTE: Temperature-only stations are not included on this list.

[a]Information is being or has been obtained for the following parameters: temperature (Temp), daily specific conductance (SC), daily total suspended sediment (TSS), pesticide (Pest) levels, radiochemical (RC) analyses, and spectrographic (SG) analyses.

[b]Data obtained during 1976.

[c]Data available for some periods during 10/65-9/74.

[d]Recent periphyton-phytoplankton sampling station.

[e]Recent continuous turbidity, dissolved oxygen, and pH monitoring site.

of sites for which once-daily or continuous temperature, specific conductance, or suspended sediment data are available and where pesticide, radiochemical, or spectrographic data are being or have been collected by the USGS. Biological sampling programs have also increased in recent years; table 4 shows bacteriological analyses at many locations in the basin and phytoplankton-periphyton assessments at sites on the Yellowstone and Tongue rivers. Algae collections are being made on the Yellowstone River at Myers and near Terry and on the Tongue River below Hanging Woman Creek near Birney.

The trend towards greater data accumulation has accelerated during the past two years because of concern about the potential dewatering and polluting impacts of irrigation and coal development. Several additional water quality stations have been recently put into operation by the USGS. The sampling of a number of small creeks in the Decker-Birney-Ashland area is being funded by the BLM. In addition, the EPA and the USGS are funding the operation of several stations in the lower two-thirds of the Yellowstone River Basin. Table 5 lists additional water quality monitoring sites maintained by the USGS in 1976 but for which no published records are yet available (USDI 1976).

In addition to water quality monitoring stations, the USGS operates numerous flow gaging stations in the Yellowstone River Basin (USDI 1966-1974a, USDI 1976). Many of these are coincident with the water quality sampling sites, and many are located independently of water quality sites. Some of the water quality sites do not have a corresponding continuous flow measuring capability; instantaneous or estimated flows can be obtained at these locations. A number of the gaging stations are located on the mainstem and major tributaries, and several sites are also located on the smaller and minor streams in the region (e.g., Tullock Creek near Bighorn, Sarpy Creek near Hysham, and Sunday Creek near Miles City).

Methods of chemical analysis utilized by the USGS are generally referenced in their <u>Water Quality Records</u> publications (USDI 1966-1974b). Examples would include the following: Rainwater and Thatcher (1960), Guy (1969), Hem (1970), Brown et al. (1970), <u>Standard Methods for the Examination of Water and Wastewater</u> (1971), and Slack et al. (1973).

MONTANA WATER QUALITY BUREAU

Since about 1973, the Water Quality Bureau of the Montana Department of Health and Environmental Sciences has undertaken in the Yellowstone Basin several water quality sampling programs designed to obtain comprehensive water quality baseline data for several studies being completed by the Bureau. Some of these efforts have been finished, and final reports, including tabular summaries of water quality data collected by the state WQB (and the USGS) along with general discussions of the status of water quality in the related drainage basins, are now available.

Included among these reports are three water quality inventory and management plans prepared by the Bureau for three large sections of the Yellowstone Basin in Montana--the upper Yellowstone drainage (above Pryor Creek), the middle Yellowstone River drainage (between Pryor Creek and the Tongue River), and the

TABLE 5. Additional USGS water quality monitoring sites in operation during 1976 which had no published records as of July 1976.

Site Designation	Location[a]
Sarpy Creek near Hysham	06N 37E 30DD
East Fork Armells Creek near Colstrip	03N 41E 28CCD
West Fork Armells Creek near Forsyth	04N 40E 21BCC
Armells Creek near Forsyth	06N 39E 26ABD
Rosebud Creek near Colstrip	01S 42E 08ACD
Greenleaf Creek near Colstrip	01N 43E 29BBB
Rosebud Creek above Pony Creek near Colstrip	02N 43E 29DDA
Rosebud Creek near Rosebud	04N 42E 12CAC
Rosebud Creek at mouth, near Rosebud	06N 42E 21ABC
Squirrel Creek near Decker	09S 39E 14BB
Deer Creek near Decker	09S 41E 10CCB
Tongue River at Tongue River Dam near Decker	08S 40E 13A
Fourmile Creek near Birney	07S 41E 28ABA
Bull Creek near Birney	06S 42E 28BCA
Hanging Woman Creek near Birney	06S 43E 19DB
Cook Creek near Birney	05S 42E 25BAC
Bear Creek at Otter	07S 45E 02
Threemile Creek near Ashland	04S 45E 03DDB
Otter Creek at Ashland	03S 44E 11DAA
Beaver Creek near Ashland	01N 44E 34ADB
Liscom Creek near Ashland	02N 45E 27BBD
Foster Creek near Volborg	03N 46E 12BDA
Pumpkin Creek near Sonnette	03S 48E 29DDA
Pumpkin Creek near Loesch	01S 49E 31B
Little Pumpkin Creek near Volborg	01S 49E 06
Pumpkin Creek near Volborg	01N 49E 05
Pumpkin Creek near Miles City	06N 48E 35CBD
Powder River at Broadus	05S 51E 03
Mizpah Creek at Olive	03S 50E 26C
Mizpah Creek near Volborg	02N 51E 09C
Mizpah Creek near Mizpah	06N 51E 24CAB
Powder River near Locate[b]	08N 51E 14CB
Burns Creek near Savage	19N 57E 27DDA

[a]Locations given in township-range-section and in quarter sections as available.

[b]Some historical water quality data are available on this stream.

lower Yellowstone region (below the Tongue River). These plans were prepared under the direction of the EPA (Karp and Botz 1975a, Karp et al. 1975b, Karp et al. 1976a). In addition, data were collected by the state WQB in a large section of the Yellowstone Basin (from parts of the middle and lower drainages) in conjunction with the state's EIS concerning electrical generation developments at Colstrip, Montana (Montana DNRC 1974). The state WQB has also recently prepared a report dealing with the salinity-water quality aspects of the saline seep phenomenon in Montana (Kaiser et al. 1975); several of the water samples collected and analyzed for the purposes of this study were obtained from the Yellowstone Basin. Appropriate data from all of these sampling programs were considered in their application to this particular inventory.

Some of the investigations recently undertaken by the state WQB in the Yellowstone Basin have not been completed at present; however, in most instances the field work has been largely terminated with the associated data now available for review. In some cases, preliminary drafts of the study reports have been completed, with final drafts anticipated in the coming year. Some of the sampling programs initiated by the state WQB were designed primarily as data-gathering efforts, with no reports expected. All of the information collected from these sampling programs, now on file with the state WQB, has been reviewed for applicability to this inventory. These additional studies can be summarized as follows:

1) As previously noted, a waste load allocation investigation of the Yellowstone River between Laurel and Huntley, Montana is near completion. This study was funded by the EPA and both chemical and biological aspects were considered; final drafts of two corresponding reports are available (Karp et al. 1976b, Klarich 1976).

2) A limnological investigation of the Tongue River Reservoir in conjunction with strip mining activity in the area is also near completion; a final report for the EPA should soon be available.

3) An extension of the saline seep sampling program described above was funded by the Montana Department of State Lands for the collection of additional biological and chemical data from afflicted areas.

4) The Yellowstone-Tongue Area-wide Planning Organization has funded the chemical analyses of samples collected from the Tongue River in relation to the closure of the Tongue River dam for repairs in the fall of 1975.

5) The BLM, in cooperation with the USGS and the Montana Departments of Fish and Game and Natural Resources and Conservation, has funded the chemical analysis of a number of samples collected at eighteen sequential sites along the Yellowstone River from Corwin Springs to Sidney, Montana ("water quality runs"). Several sets of such samples were collected at different times of the year.

In addition, numerous supplemental water quality samples were collected from the Yellowstone drainage through the past two years as a part of this study funded by the Old West Regional Commission.

Most of the sampling programs initiated by the state WQB are best described as geographically complete rather than historically. The intent of these programs was to supplement the data available from the USGS; as a result, sampling was conducted at numerous sites in a study area but with collections at any particular site relatively few in number. Relative to the USGS data, the main disadvantage of the state WQB's data is the lack of extensive sample replication at a site through time; the main advantage is that the state WQB's sampling efforts have provided information on a variety of streams and locations for which no previous data are available. In addition, many of the sampling programs completed by the state WQB on the larger streams of the basin utilized water quality runs wherein several sequential sites were sampled on a stream within a short period of time. Such runs provide some insight into the downstream changes in a stream's water quality and can provide information on any selected phase of the stream's hydrological cycle at any time of the year.

For these reasons, USGS and state WQB data appear to be generally complementary. The state WQB programs provide some data on current water quality status of the smaller streams; the USGS programs provide in-depth water quality information for a few locations on the major streams. Therefore, the USGS information lends itself more readily to historical interpretation than the state WQB data. However, the water quality runs of the state WQB are more helpful in judging the longitudinal changes that occur in the water quality of major streams for the particular time of year that the run was made.

Table 6 summarizes by basin the streams in the secondary and primary study areas that have been sampled by the state WQB through these programs. The number of locations sampled on each of the streams and the number of samples collected by the state WQB are also included in the table. Only those samples that underwent a complete chemical analysis have been tabulated for this summary.

Field procedures and methods of chemical analyses of water samples collected by the state WQB, summarized in a manual available through the state WQB, were generally in accord with standard techniques (Jankowski and Botz 1974). Chemical analyses of most parameters were completed by the Chemistry Laboratory Bureau of the Laboratory Division, Montana DHES; field parameters were analyzed by state WQB personnel shortly after collection of each sample. Methods of analysis are summarized in table 1.

Suspended solids were determined gravimetrically after filtering an appropriate aliquot of the sample through fiberglass filters and drying. Dissolved solids were calculated as the sum of constituents. Sodium adsorption ratios (SAR) were calculated from sodium, calcium, and magnesium milliequivalency data following an equation in Hem (1970). Metals were determined primarily as "total recoverable" rather than dissolved because most analyses were completed on unfiltered samples preserved with concentrated nitric acid (five milliliters of acid per liter of sample (Jankowski and Botz 1974). Flow measurements were made on many of the smaller streams in association with the collection of grab samples. "Gurley" or pygmy current meters were used to measure the velocity of discharge along with the appropriate depth and width measurements to assess the areal component of flow (Carter and Davidian 1968, Jankowski and Botz 1974). In some cases, the instantaneous discharge of a creek was estimated, but, whenever possible, flow measurements were obtained either from a USGS gaging station on the stream or as indicated above.

TABLE 6. Streams sampled by the state WQB in the secondary and primary inventory areas of the Yellowstone River Basin since the summer of 1973.

Stream and Basin	Locations Sampled	Number of Samples
Yellowstone River above confluence Clarks Fork Yellowstone River		
Mainstem (secondary area)[a,b,j]	10	42
Yellowstone River drainage between Clarks Fork and Bighorn rivers[c]		
Mainstem[a,b,h,j]	4	27
Spring Creek[d]	1	1
Duck Creek	1	1
Canyon Creek	1	1
Pryor Creek[j]	2	9
Hay Creek	1	2
East Fork Pryor Creek	1	2
East Fork Creek	1	1
Arrow Creek[e]	2	5
Fly Creek[a,j]	1	3
Bighorn-Little Bighorn rivers drainage		
Little Bighorn River[a,j]	4	9
Spring Creek	1	1
Pass Creek	1	2
East (Little) Owl Creek	1	1
Sioux Pass Creek	1	1
Owl Creek	2	3
Gray Blanket Creek	1	1
Lodge Grass Creek	1	4
Reno Creek	1	1
Bighorn River[a,f,j]	3	13
Sage Creek	2	2
Crooked Creek	1	2
Porcupine Creek[g]	1	1
Dry Head Creek[g]	1	1
Hoodoo Creek[g]	1	1
Big Bull Elk Creek[g]	1	1
Little Bull Elk Creek[g]	1	1
Black Canyon Creek[g]	1	1
Soap Creek[j]	1	2
Rotten Grass Creek	2	5
Tullock Creek	2	15

TABLE 6. Continued

Stream and Basin	Locations Sampled	Number of Samples
Yellowstone River drainage between Bighorn and Powder rivers		
Mainstem[a,b,h,j]	6	43
Sarpy Creek[j]	2	9
Reservation Creek	1	3
East Fork Armells Creek	3	9
West Fork Armells Creek[j]	2	3
Armells Creek[j]	2	9
Sheep Creek	1	1
Smith Creek	1	2
Rosebud Creek[j]	6	30
Indian Creek	1	1
Davis Creek	1	2
Muddy Creek	1	1
Lame Deer Creek	1	3
Sweeney Creek	1	2
Moon Creek	1	2
Alf Creek	1	1
Froze-to-Death Creek	1	1
Starve-to-Death Creek	1	2
Great Porcupine Creek	2	3
Little Porcupine Creek	1	3
Sunday Creek	1	9
Tongue River drainage		
Mainstem[a,i,j]	10	54
Youngs Creek	1	1
Squirrel Creek	1	1
Deer Creek	1	1
Stroud Creek	1	1
Canyon Creek	1	1
Cow Creek	1	1
Hanging Woman Creek[j]	2	11
Logging Creek	1	1
Otter Creek[j]	3	11
Pumpkin Creek[j]	2	16
Little Pumpkin Creek	1	1
Powder River drainage		
Mainstem[a,j]	6	26
Little Powder River[a]	1	12
Sheep Creek	1	1
Mizpah Creek	3	12
Sand Creek	1	1

TABLE 6. Continued

Stream and Basin	Locations Sampled	Number of Samples
Yellowstone River drainage below confluence Powder River		
Mainstem[a,b,j]	7	28
O'Fallon Creek[j]	3	14
Sandstone Creek[j]	1	2
Pennel Creek	1	1
Cabin Creek	2	3
Cedar Creek	1	2
Sevenmile Creek	1	1
Glendive Creek	1	3
Fox Creek	1	3
Lonetree Creek	1	1
Second Hay Creek	1	1
Totals	149	512

[a]Some published water quality records between the years of 1965 and 1975 are available for these streams from the USGS.

[b]Several of the locations in these reaches were utilized for the Yellowstone water quality runs; two additional sets of samples have been collected from these sites on recent runs but not tabulated because the results of the chemical analyses are not yet available.

[c]Numerous samples from the mainstem and certain tributaries have not been tabulated for this region; these were collected for partial chemical analyses as part of the waste load allocation investigation of the Yellowstone River between Laurel and Huntley.

[d]This creek joins the Clarks Fork River very near the river's mouth.

[e]Several other samples were collected from this stream but not tabulated; these were obtained as part of an irrigation study dealing with specific parameters. Data are also available for irrigation return flows and canals.

[f]Water quality information is available from the USGS for the Beauvais Creek tributary of the Bighorn River.

[g]These creeks are Bighorn tributaries in the vicinity of Yellowtail Reservoir (Bighorn Lake).

[h]Samples tabulated include those obtained from several Yellowstone River backwater areas.

[i]Samples tabulated include those collected for complete analyses during the closure of the Tongue River Dam for repairs; however, the listing does not include those samples collected for partial analyses as a part of the Tongue River Reservoir strip mining study.

[j]Partial chemical analyses are also available for these streams; these samples were not included in the tabulations.

MISCELLANEOUS SOURCES AND OTHER INVESTIGATIONS

Water quality data from various streams in the Yellowstone River Basin are also available from STORET (a national data storage and retrieval system). Although this information was surveyed for this inventory, a major portion of the data stored in this computer system was originally obtained by the USGS and is therefore published in its annual Water Quality Records publications (USDI 1966-1974b). The main value of STORET to this study was in the retrieval of more recent and currently unpublished water quality data collected by the USGS (from October of 1974 to January of 1976).

Unpublished and provisional water quality data collected by the USGS in the last two years was obtained directly from the USGS in conjunction with monitoring activities of the state WQB (e.g., to supplement continued monitoring on Armells and Rosebud creeks in the Colstrip area). Data collected by the USGS during the closure of the Tongue River Dam in the fall of 1975 was also reviewed for this inventory.

In addition to the programs of the USGS and the state WQB, water-quality-related studies and planning efforts have been or are being completed in the Yellowstone River Basin by other state and federal agencies. These range from broad, general studies covering large geographic areas to specific investigations typically concerned with particular streams, stream segments, lakes-reservoirs, or with particular water quality problems. The Missouri River Basin Comprehensive Framework Study (Missouri River Basin Inter-Agency Committee 1969), a Bureau of Reclamation resources report (USDI 1972), the interagency Northern Great Plains Resources Program (NGPRP 1974), and the Decker-Birney Resource Study of the Bureau of Land Management and the United States Forest Service (USDI and USDA 1974b) all serve as examples of the more general type of study. The earliest effort was directed at broadly describing water and related resources in the upper Missouri River Basin of which the Yellowstone drainage is a part. The Bureau of Reclamation study was directed at more specifically delineating the resources in the basins of eastern Montana, including considerations of the basins' water resources and water quality attributes. The Water Quality Subgroup of the NGPRP has attempted to provide alternative methods for the development of water resources in the basins of southeastern Montana; water quality aspects were considered in the study as well as the effects of in-stream flow variations on aquatic life (Boree 1975, USEPA 1974). The Decker-Birney Resource Study was initiated in conjunction with the federal leasing of lands for coal and energy development. In addition, the National Commission on Water Quality has become involved in the Yellowstone drainage, and the Missouri River Basin Commission is preparing a Level B study which will attempt to resolve conflicts between industrial and agricultural development and in-stream flow requirements.

The recently established area-wide planning organizations (APOs) funded through the EPA are also directing their efforts to water quality problems in their respective regions (208 planning districts). Two such districts are located in parts of the Yellowstone drainage--a Mid-Yellowstone APO headquartered in Billings, and the Yellowstone-Tongue APO located in Broadus--with a statewide 208 covering the remainder of the basin.

A research group from Montana State University directed by Dr. J. C. Wright has recently completed an extensive limnological investigation of

Yellowtail Reservoir (Soltero 1971, Soltero et al. 1973, Wright and Soltero 1973). The Cooperative Fishery Research Unit at Montana State is conducting a limnological-fishery study of the Tongue River Reservoir in relation to strip mining activities in the area (Whalen et al. 1976). Other important studies of a more specific nature in the Yellowstone Basin include the work of the Montana University Joint Water Resources Research Center and the ground and surface water quality monitoring efforts of the Montana Bureau of Mines and Geology in the Colstrip and Decker strip mine areas (Van Voast 1974, Van Voast and Hedges 1976). The study of the Water Resources Research Center involved a chemical and biological analysis of the upper Yellowstone River as baseline data in response to the possibility of construction of Allenspur Dam on the mainstem above Livingston, Montana. Similar information is also available from Stadnyck (1971). Other examples of specific investigations in the basin include:

1) the strip mine spoils and reclamation research of the Montana Agricultural Experiment Station (Hodder et al. 1972, Hodder et al. 1973);

2) studies of sediment problems originating from the Clarks Fork Yellowstone River drainage (Beartooth Resource Conservation and Development Project et al. 1973); and

3) an interagency land use study of the Pryor Mountains which also considered the problem of siltation in Crooked Creek (USDI and USDA 1973, 1974a).

In addition, the EPA is completing a national eutrophication survey which includes the Tongue River and Yellowtail reservoirs (USEPA 1975).

More detailed listings and descriptions of the water quality and planning studies in the Yellowstone Basin are available in the three management plans prepared for the region by the state WQB (Karp and Botz 1975, Karp et al. 1975b, Karp et al. 1976).

WATER QUALITY REFERENCE CRITERIA

RATIONALE

Water quality considerations are relative--that is, the suitability of water is dependent upon its intended use. For example, the quality needed for stockwater is different from that necessary for man's consumption and domestic use. Criteria and standards have been developed through the years to serve as reference points for evaluating a body of water and the levels of its various chemical, physical, and biological constituents in relation to various water uses. These criteria and standards can also serve as reference bases for the general assessment and evaluation of surface waters in a given study region. Literature sources were reviewed for those criteria and standards that would delineate the critical concentrations of parameters in relation to the common uses of water in the Yellowstone River Basin. These criteria serve as the basis for the discussions of this inventory.

In addition to these reference criteria, other classification schemes, descriptive in nature and not delineative of critical concentrations relative to some water use, have been developed for certain water quality parameters. These systems are of value in verbally describing and summarizing certain water quality attributes. The Water Quality Index serves as one example. As further examples, classification systems have been proposed that describe various levels of hardness and salinity. These systems are summarized in table 7.

TABLE 7. Hardness and salinity classification.

Hardness[a]		Salinity[b]	
Range (mg/l as $CaCO_3$)	Description	Range (mg/l as TDS)	Description
0 to 60	Soft	<50	Non-saline (rain and snow)
61 to 120	Moderately hard	<1,000	Non-saline (most freshwater)
121 to 180	Hard	1,000 to 3,000	Slightly saline (some freshwater)
>180	Very hard	3,000 to 10,000	Moderately saline (estuaries)
		10,000 to 35,000	Very saline (oceans and estuaries)
		>35,000	Briny (miscellaneous systems)

[a]Durfor and Beckner 1964.

[b]Robinove et al. 1968.

The range of values delineating a "very hard" water was not defined as delimiting particular water uses, nor was the "very saline" category of dissolved solids. However, waters with such high levels of salinity and hardness are not suitable for certain uses. Although the American Water Works Association considers a water with less than 80 mg/l hardness "ideal" (Bean 1962), no definite limits for hardness in public water supply can be specified because consumer ". . . sensitivity is often related to the hardness to which the public has become accustomed, and acceptance may be tempered by economic considerations" (USEPA 1973). In contrast, the United States Public Health Service (1962) recommends that waters containing dissolved solids in excess of 500 mg/l should not be used for drinking water if other more potable and less mineralized sources are available.

MONTANA STREAM AND WATER-USE CLASSIFICATIONS

The State of Montana had, by 1960, classified the streams of the state according to their most beneficial uses and has also established water quality criteria for the streams relative to these uses. This classification system designated that streams in the state were to be kept, for the large part, in suitable condition for water supply, fishing and other recreation, agriculture, and for industrial water supply (Montana DHES 1973). Compliance with the water-use classifications required the treatment of wastewaters untreated prior to 1960 and the improvement of some of the existing treatment facilities in order to meet the new requirements. The stream classifications and water quality criteria of the state were updated and upgraded after 1965 with the passage of the Federal Water Quality Act; minor revisions were also added in response to the Federal Water Pollution Control Act Amendments of 1972. Classifications and standards currently in effect became official on November 4, 1973 (Montana DHES 1973).

All surface waters in the primary and secondary inventory areas of this study have been assigned a B-D classification by the State of Montana. The water-use description for this class of surface water has been summarized as follows (Montana DHES undated):

> The quality is to be maintained suitable for drinking, culinary and food processing purposes after adequate treatment equal to coagulation, sedimentation, filtration, disinfection and any additional treatment necessary to remove naturally present impurities; bathing, swimming, and recreation; growth and (1) propagation of salmonid fishes (a $B\text{-}D_1$ stream), (2) marginal propagation of salmonid fishes (a $B\text{-}D_2$ stream), or (3) propagation of non-salmonid fishes (a $B\text{-}D_3$ water) and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

The water-use descriptions of the B-D streams contrast to that applied to E-F waters which have a more limited use: "The quality is to be maintained for agricultural and industrial water uses other than food processing" (Montana DHES undated).

$B\text{-}D_1$ surface waters in the Yellowstone River Basin (self-sustaining trout fisheries) include the Yellowstone drainage above Laurel, the Pryor Creek drainage, and the upper portions of the Little Bighorn-Bighorn and Clarks Fork River drainages. $B\text{-}D_2$ waters in the region (marginal trout fisheries) include the Yellowstone River and tributaries between Laurel and Billings, the lower Little Bighorn-Bighorn and Clarks Fork River drainages, the upper Tongue River drainage, and Fox Creek in eastern Montana. The Yellowstone River and certain of its tributaries below Billings (e.g., the Powder River drainage and the lower Tongue River drainage) have been designated non-salmonid, warm-water fisheries and given a $B\text{-}D_3$ classification (Montana DHES undated).

MONTANA WATER QUALITY CRITERIA

Water quality standards have been established by the State of Montana for the B-D stream classification. For some parameters, such as turbidity, the standard specifies an allowable maximum change in stream concentration rather than a specific upper limit; this type of standard is not amenable to use as a reference criteria. However, definite limits or allowable ranges have been established for other parameters by the state, and these standards can be utilized for this purpose (Montana DHES undated); these are summarized in table 8. In addition, Montana's water quality standards reference the 1962 U.S. Public Health Service Drinking Water Standards (or later editions) for recommended limits on a number of water quality parameters including inorganic materials and heavy metals (USDHEW 1962).

TABLE 8. Montana water quality criteria.

Stream Classification	Fecal Coliforms (number per 100 ml) Average Number	10% [a] Maximum	Minimum Dissolved Oxygen[b]	pH[c] Range	Maximum[d] Temperature	Oil and Grease	as pCi/L Radium-226	Gross Beta Radioactivity
$B\text{-}D_1$	200	400	7.0 mg/l	6.5-8.5	67 F (19.4 C)	10 mg/l	1.0	100
$B\text{-}D_2$	200	400		6.5-9.0	67 F (19.4 C)	10 mg/l	1.0	100
10/1-6/1			7.0 mg/l					
6/2-9/30			6.0 mg/l					
$B\text{-}D_3$	200	400	5.0 mg/l	6.5-9.0	80 F (26.7 C)	10 mg/l	1.0	100
YR, B-I[e]					82 F (27.8 C)			
YR, I-ND[f]					85 F (29.4 C)			

SOURCE: Montana DHES undated.

[a]Ten percent of the total number of samples obtained in a thirty-day period are not to exceed this value.

[b]Dissolved oxygen concentrations are not to be reduced below these limits.

[c]No changes of pH are allowed outside of these values.

[d]No increases of temperature are allowed above these limits when the water's naturally occurring temperatures are 0.5 F less than these values.

[e]YR, B-I: Yellowstone River between Billings and the Intake diversion structure near Glendive, Montana.

[f]YR, I-ND: Yellowstone River from Intake to the Montana-North Dakota border.

DRINKING WATER AND SURFACE PUBLIC SUPPLY CRITERIA

Several communities located along the Yellowstone River, including Livingston, Laurel, Billings, and Miles City, use this stream as a source of public supply for drinking water and other purposes. U.S. Public Health Service recommendations for the maximum concentrations of various water quality parameters in drinking water, as referenced in Montana Water Quality Standards (Montana DHES undated), are summarized in table 8. Standards for fluoride in this reference are variable depending upon the "annual average of maximum daily air temperatures" in a region (USDHEW 1962). Lower concentrations are recommended for the warmer climates. Data to provide some idea of the magnitude of this temperature variable in the study region of this inventory were obtained from Karp et al. (1975b) for several weather stations in eastern Montana; this temperature factor was estimated as the annual average of these stations (6.3°C, 43.3°F) plus the addition of four to eight degrees Celsius (seven to fifteen degrees Fahrenheit) to afford an adjustment to the maximum. Fluoride standards relative to this temperature estimation are included in table 9.

In addition to the Public Health Service standards for drinking water, other sources were reviewed for criteria applicable to public (USEPA 1973) and surface supply (Montana DHES undated). These criteria are also summarized in table 9. In general, the recommended standards for specific parameters are similar among the three sources.

AGRICULTURAL CRITERIA

Water use for stock and water use for irrigation are the major agricultural uses of streams, lakes, and ponds in the inventory area. In general, waters that have been judged to be safe for human consumption (relative to the criteria in table 9) can also be used for the watering of stock. Animals can, for the most part, tolerate waters with significantly higher salinities and higher levels of dissolved constituents than can humans, although their overall productivities may be curtailed to some extent through the utilization of such waters (McKee and Wolf 1974). The more lenient water quality standards typically applied to stock water reflect this greater tolerance of animals to dissolved materials. Criteria for stock water, including standards for specific dissolved constituents and for salinity along with the salinity requirements of several domestic animals, were obtained from the EPA (1973), McKee and Wolf (1974), and Seghetti (1951), and are summarized in tables 10-14. Threshold levels denote the concentration of a particular constituent where its physiological effects are first observed in an animal.

In contrast to the specific reference criteria available for animals (including man), criteria for irrigation water are, of necessity, more arbitrary and flexible due to the variables involved: type of soil, climate, type of crop, and management practices. As a result, specific analyses of particular systems can become complex, and absolute limits and general criteria cannot be rigid (McKee and Wolf 1974).

Waters for irrigation are typically divided into broad classes such as "excellent," "good," "injurious," and "unsatisfactory," with a set of applicable chemical criteria associated with each water class. Groups of plants are classified as tolerant, semi- or moderately tolerant, or sensitive in relation to each water class in accordance with the plants' ability to tolerate its chemical characteristics. McKee and Wolf (1974) conducted an extensive

TABLE 9. Selected water quality criteria and standards for drinking water and public surface supply.

Constituent	PHS		NTAC		EPA
	Standard[a]	Rejection[b]	Permissible Criteria	Desirable Criteria	Recommendation
Ammonia-N	--	--	0.5	<.01	0.5
Arsenic[c]	0.01	0.05	0.05	absent	0.1
Barium[c]	--	1.0	1.0	absent	1.0
Boron[c]	--	--	1.0	absent	--
Cadmium[c]	--	0.01	0.01	absent	0.01
Chloride[c]	250	--	250	<25	250
Chromium (C_r+6)[c]	--	0.05	0.05	absent	0.05
Copper[c]	1.0	--	1.0	near zero	1.0
Total dissolved solids[c]	500	--	500	<200	--
Fecal coliforms	(f)	(f)	2000	<20	2000
Iron	0.3	--	0.3	near zero	0.3
Lead[c]	--	0.05	0.05	absent	0.05
Manganese[c]	0.05	--	0.05	absent	0.05
Mercury[c]	--	--	--	--	0.0002
Nitrate[c,d]	45	--	--	--	--
Nitrate-N[c,d]	10.2	--	--	--	10
NO_3+NO_2-N[c,d]	--	--	10.0	near zero	--
Nitrite-N[c,d]	--	--	--	--	1.0
Oxygen (dissolved)	--	--	>3	saturated	--
pH	--	--	6.0-8.5	--	5.0-9.0
Phenols	0.001	--	0.001	absent	0.001
Selenium[c]	--	0.01	0.01	absent	0.01
Silver[c]	--	0.05	0.05	absent	--
Sulfate[c]	250	--	250	<50	250
Turbidity (JTU)	5	--	75	near zero	--
Zinc[c]	5.0	--	5.0	near zero	5.0
Radioactivity as pCi/l:					
Gross beta[c]			1000	<100	--
Radium-226[c]			3	<1	--
Fluoride:[c,e]					
Upper limit	1.5-1.7	2.2-2.4			2.2-2.4
Optimum	1.1-1.2	--	(same)		--
Control limits	0.8-1.7	--			--

SOURCES: U.S. Public Health Service (PHS) 1962, National Technical Advisory Committee (NTAC) 1968, and the U.S. Environmental Protection Agency (EPA) 1972.

NOTE: Concentrations given in mg/l unless otherwise specified; fecal coliforms given as the number per 100 ml.

[a]These chemical substances should not be present in water supplies in excess of the listed concentrations where other suitable supplies are or can be made available.

[b]The presence of these substances in excess of the listed concentrations constitutes grounds for rejection of the supply.

[c]Treatment--defined as coagulation, sedimentation, rapid sand filtration, and chlorination--has little effect on these constituents.

[d]Adverse physiological effects on infants may occur in extremely high concentrations.

[e]Criteria varies with the annual average of maximum daily air temperatures; with fluoridation, average fluoride levels should be kept within the control limits.

[f]Criteria varies with the volume of sample, sampling frequency, and analytical technique.

TABLE 10. Water quality criteria for stock as set forth by the California Water Quality Control Board.

	Threshold Level	Limiting Level
pH	6.0 and 8.5	5.6 and 9.0
TDS	2500	5000
HCO_3	500	500
Ca	500	1000
CI	1500	3000
F	1.0	6.0
Mg	250	500
Na	1000	2000
SO_4	500	1000
As		1.0

SOURCE: California Water Quality Control Board 1963.

NOTE: Concentrations expressed in mg/l.

TABLE 11. Water quality criteria recommended by the EPA for stock.

Chemical Constituents	Recommended Concentrations (in mg/l)
Al	5
As	0.2
B	5.0
Cd	0.05
Cr	1.0
Co	1.0
Cu	0.5
F	2.0
Pb	0.1
Hg	0.01
NO_2+NO_3-N	100
NO_2-N	10
Se	0.05
V	0.1

SOURCE: U.S. Environmental Protection Agency 1973.

TABLE 12. Threshold salinity (TDS) levels for farm animals.

Animal	Salinity Level
Poultry	2,860
Pigs	4,290
Horses	6,435
Dairy cattle	7,150
Beef cattle	10,000
Adult dry sheep	12,900

SOURCE: McKee and Wolf 1974.

NOTE: Concentrations expressed in mg/l.

TABLE 13. Use and effect of saline waters on livestock and poultry.

Use and Effect	Salinity Level
Excellent for all stock	<1,000
Very satisfactory for livestock and poultry; temporary effects, if any	1,000-3,000
Satisfactory for livestock; poor for poultry	3,000-5,000
Permissible for livestock; unacceptable for poultry and lactating animals	5,000-7,000
Somewhat risky with older livestock and poor for swine; unacceptable for young and lactating animals and for poultry	7,000-10,000
Generally unsuitable for most animals	>10,000

SOURCE: U.S. Environmental Protection Agency 1973.

NOTE: Concentrations expressed in mg/l.

TABLE 14. Montana salinity classification of waters.

Water Class	Salinity Range
Good	<2500
Fair	2500-3500
Poor	3500-4500
Unfit	>4500

SOURCE: Seghetti 1951.

NOTE: Measurements expressed in mg/l.

survey of the literature and developed the classification scheme for irrigation waters presented in tables 15 and 16. Also included in this table are recommendations for the maximum concentrations of trace elements that should be present in irrigation waters used continuously on all soils (USEPA 1973). The chemical criteria in this table can be used to judge the quality of Yellowstone River Basin water for irrigative use. Classification of the boron and salinity tolerances of Yellowstone Basin crops, garden plants, and forage are presented in table 17 (Allison 1964, Hem 1970).

Agricultural Handbook No. 60 (USDA 1954) lists four broad ranges or classes of salinity in relation to a water's use for irrigation--a low salinity hazard with specific conductances (SC) less than 250 µmhos/cm at 25°C, a medium salinity hazard (SC = 250 to 750 µmhos), a high salinity hazard (SC = 750 to 2250 µmhos), and a very high salinity hazard (SC > 2250). These classes, in combination with four sodium hazard ranges based on the sodium adsorption ratios of a water (Hem 1970) provide sixteen classes of water with varying levels of value for irrigation use (Richards 1954). The C1-S1 class of water is probably suitable for the watering of most plants under most conditions, whereas the C4-S4 class is probably unsuitable for irrigation except in a few unique cases.

BIOLOGICAL CRITERIA

Water quality criteria in this case deal with two aspects of the biology of aquatic systems: (1) critical nutrient levels that indicate eutrophic conditions, and (2) the concentrations of particular parameters that might prove to be toxic or harmful to aquatic life. As with irrigation waters, such criteria are difficult to establish in a definitive sense due to the variability among biological systems and among individual organisms. However, general levels can be established for some parameters that at least serve as first-order approximations of critical concentrations, and these can be used as reference criteria in water quality inventories.

Nitrogen and Phosphorus

Lund (1965), in his extensive literature review, concluded that "nitrogen and phosphorus can still be considered as two of the major elements limiting primary production." Gerloff and Skoog (1957) suggested that nitrogen appears to be the more critical factor in the limitation of algal production in natural waters because phosphorus is often stored in excess in algal cells beyond actual need (luxury uptake). But phosphorus concentrations can be very low in some waters, and this parameter may be the more limiting parameter in these particular cases (Lund 1965). Specific criteria describing the critical levels of nitrogen and phosphorus limiting to aquatic systems and necessary to promote nuisance algae blooms have not been firmly established due to the complexity of the relationships between these two constituents and between these two constituents and the remaining chemical and physical-biological components of an ecosystem (USEPA 1973). As a result, such criteria, as developed through several investigations, are variable. For example, the EPA (1974b) in its National Water Quality Inventory used 0.1 mg/l of total-P and 0.3 mg/l of dissolved phosphate (0.1 mg/l of PO_4-P) and 0.9 mg/l of nitrite plus nitrate (as N) as reference criteria for these constituents. However, based on information from

TABLE 15. Summary classification of irrigation waters and associated water quality criteria and recommended maximum concentrations of trace elements for all plants in continuously used irrigation waters.

Water Class	Boron (mg/l)	SAR	Cl (me/l)	SO_4 (me/l)	Specific Conductance	TDS (mg/l)	Salinity Hazard
I	<1.0	<1.0-4.2[a]	<2-5.5	<4-10	<500-1000[b]	<700	low-medium
II	<2.0	1.0-11.6	2-16	4-20	500-3000	350-2100	medium-very high
III	<3.0	>9.0-11.6	>6-16	>12-20	>2500-3000	>2500-3000	very high

SOURCE: McKee and Wolf (1974).

NOTE: The water classes are defined for two purposes. First, for purposes of overall soil/climate management, they are defined as follows:

- I Excellent to good; suitable under most conditions.
- II Good to injurious; harmful under certain conditions of soil, climate, and practices.
- III Injurious to unsatisfactory; unsuitable under most conditions.

Second, water classes as they relate specifically to plants are defined as follows:

- I Suitable for irrigation of all or most plants, including salinity- and boron-sensitive species.
- II Not suitable for most salinity- and boron-sensitive plants; suitable for all tolerant and many semi-tolerant species.
- III Unsatisfactory for most plants except those that have a high tolerance to saline conditions and to high boron levels.

[a]Recent work favors the upper limit.

[b]In μmhos/cm at 25°C.

TABLE 16. Recommended maximum concentrations of trace elements for all plants in continuously used irrigation waters.

Trace Element	Recommendation
Al	5.0
Be	0.1
Cd	0.01
Cr	0.1
Co	0.05
Cu	0.2
F	1.0
Fe	5.0
Pb	5.0
Li	2.5
Mn	0.2
Mo	0.01
Ni	0.2
Se	0.02
V	0.1
Zn	2.0

SOURCE: U.S. Environmental Protection Agency (1973).

NOTE: Recommendations expressed in mg/l.

TABLE 17. Relative tolerances of various crops and forage to salinity and boron.

	Salinity				Boron[a]
	Tolerant (12 to 6)[b]	Moderately or semi-tolerant (8 to 4)[b]	(6 to 3)[b]	Sensitive (3 to 1.5)[b]	
Field, truck, and fruit crops					
Barley	X				ST
Sugar beet	X				T
Rape	X				NI
Garden beets		X			T
Kale		X			NI
Asparagus		X			T
Spinach		X			NI
Rye		X			NI
Wheat		X			ST
Oats		X			ST
Corn		X			ST
Flax		X			NI
Sunflower		X			ST
Tomato			X		ST
Broccoli			X		NI
Cabbage			X		T
Cauliflower			X		NI
Lettuce			X		T
Sweet corn			X		ST
Potatoes			X		ST
Bell pepper			X		ST
Carrot			X		T
Onion			X		T
Peas			X		ST
Squash			X		NI
Cucumber			X		NI
Field beans				X	T
Radish				X	ST
Green beans				X	T

TABLE 17. Continued

	Salinity: Tolerant (12 to 6)[b]	Salinity: Moderately or semi-tolerant (8 to 4)[b]	Salinity: Moderately or semi-tolerant (6 to 3)[b]	Salinity: Sensitive (3 to 1.5)[b]	Boron
Field, truck, and fruit crops					
Apple				X	S
Boysenberries				X	NI
Blackberries				X	S
Raspberries				X	NI
Strawberries				X	NI
Forage crops					
Saltgrass	X				NI
Bermudagrass	X				NI
Tall wheatgrass	X				NI
Rhodesgrass	X				NI
Canada wildrye	X				NI
Western wheatgrass	X				NI
Tall fescue	X				NI
Barley (hay)	X				NI
Birdsfoot trefoil	X				NI
Sweetclover			X		NI
Perennial ryegrass			X		NI
Mountain brome			X		NI
Harding grass			X		NI
Beardless wildrye			X		NI
Strawberry clover			X		NI
Dallisgrass			X		NI
Sudangrass			X		NI
Hubam clover			X		NI
Alfalfa			X		T
Rye (hay)			X		NI
Wheat (hay)			X		NI
Oats (hay)			X		NI
Orchardgrass			X		NI

TABLE 17. Continued

	Salinity			Boron[a]
	Tolerant (12 to 6)[b]	Moderately or semi-tolerant (8 to 4)[b] (6 to 3)[b]	Sensitive (3 to 1.5)[b]	
Forage crops				
Blue grama		X		NI
Meadow fescue		X		NI
Reed canary		X		NI
Big trefoil		X		NI
Smooth brome		X		NI
Tall meadow oatgrass		X		NI
Milkvetch		X		NI
Sourclover		X		NI
White dutch clover			X	NI
Meadow foxtail			X	NI
Alsike clover			X	NI
Red clover			X	NI
Ladino clover			X	NI
Burnet			X	NI

SOURCES: Allison (1964), Hem (1970).

[a]Tolerance to boron is defined as follows:
- T tolerant
- ST semi-tolerant
- S sensitive
- NI no information for the species of plant

[b]Numbers denote the range of specific conductance for each plant group in millimhos/cm at 25°C.

other sources, lower, more stringent criteria for N and P have been adopted for use in this inventory in judging the eutrophic potential of streams.

Phosphorus levels exceeding 0.2 mg/l have produced no problems in some potable supplies (USEPA 1973). In uncontaminated lakes, phosphorus has been found in the range of 0.01 to 0.03 mg/l and higher (Salvato 1958). Federal surveys have indicated that 48 percent of the aquatic sites sampled across the nation had phosphorus concentrations in excess of 0.05 mg/l (Gunnerson 1966). The EPA (1973) has suggested that total phosphorus in concentrations less than 0.05 mg/l would probably restrict nuisance plant growths in flowing waters.

In contrast, much higher concentrations of inorganic nitrogen are necessary to initiate algal blooms; studies have indicated that excessive growths of plants are avoided when inorganic nitrogen concentrations are less than 0.35 mg/l (Mackenthun 1969, Muller 1953). These two values--0.05 mg/l for phosphorus and 0.35 mg/l for inorganic nitrogen--can serve as general reference criteria for nitrogen and phosphorus in waters of the Yellowstone Basin. Streams or lentic systems in the basin with total-P (or PO_4-P if total-P data are unavailable) or inorganic nitrogen (or NO_3-N, NO_2+NO_3-N) concentrations less than 0.05 mg/l and 0.35 mg/l, respectively, might be reliably judged as noneutrophic or oligotrophic. Waters with phosphorus and nitrogen concentrations in excess of 0.1 mg/l and 0.9 mg/l, respectively (USEPA 1974b), can be judged as eutrophic. Intermediate concentrations of P and N (i.e., 0.05-0.10 mg/l and 0.35 to 0.90 mg/l, respectively) suggest, at a lower degree of predictive success, potentially eutrophic waters.

Other Constituents

In addition to nitrogen and phosphorus, a variety of other water quality constituents affect aquatic life. Such effects can be positive and beneficial to the biota of an ecosystem at particular concentrations (e.g., availability of essential elements in appropriate concentrations, appropriate temperatures, adequate dissolved oxygen levels, absence of toxic substances, and appropriate salinity and turbidity levels), but can be detrimental at other levels (e.g., low and limiting concentrations of an essential element, excessively high temperatures, low dissolved oxygen concentrations and high organic loads, presence of toxic substances, high concentrations of TDS and suspended materials). Most commonly, attention is directed toward the potential detrimental effects of these constituents on a biota when their concentrations become too high or too low in a water--either in a toxic-lethal or depressing sense on individual organisms or in the sense of reducing the biomass or number of individuals and species in a community (thereby altering its diversity and structure) and of lowering its primary and secondary productivity. A list of such affecting parameters would include the most obvious--oxygen, temperature, pH, salinity, various common constituents, turbidity-suspended sediment, nitrogen, and phosphorus--along with the trace elements and such toxic substances as herbicides, pesticides, and heavy metals. Reference criteria for dissolved oxygen, pH, and temperature in Montana's B-D_1, B-D_2, and B-D_3 streams have been described previously (table 8). The ranges of pH listed for such streams are similar to those recommended by the Committee on Water Quality Criteria to afford a moderate-to-high level of protection in a body of water (USEPA 1973). The criteria for dissolved oxygen in a $B\text{-}D_3$ stream is identical to that recommended by Ellis (1944) for a mixed, warm-water fish population.

Suspended Sediment and Turbidity

Concerning suspended sediment, the European Inland Fisheries Advisory Commission (1965) and the EPA (1973) came to the following conclusions:

1) There is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries (a high level of protection at 25 mg/l).

2) It should usually be possible to maintain good or moderate fisheries in waters that normally contain 25 to 80 mg/l suspended solids; other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in the preceding category (a moderate level of protection at 80 mg/l).

3) Waters normally containing from 80 to 400 mg/l suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at lower concentrations within this range (a low level of protection at 400 mg/l).

4) Only poor fisheries are likely to be found in waters that contain more than 400 mg/l suspended solids (a very low level of protection over 400 mg/l).

These conclusions form a reference for this important variable. For the Yellowstone system, suspended sediment concentrations can be converted to turbidity in Jackson Turbidity Units (JTU) with some degree of precision (r=0.95) using a graph available in Karp et al. (1976b), resulting in the reference system shown in table 18.

TABLE 18. Impact reference system for turbidity and suspended sediment.

Class of Fishery[a]	Suspended Sediment Range (mg/l)	Corresponding Turbidity Range (JTU)
Excellent	<25	<8
Good to Moderate	25 to 80	8 to 26
Fair to Poor	80 to 400	26 to 91
Very Poor	>400	>91

[a]This assumes that other factors are not limiting.

Table 18's reference levels for suspended materials and turbidity imply a relatively constant exposure of a fishery to the indicated concentrations (e.g., as expressed by a median value) in order to invoke the associated type of fishery (excellent to very poor), as fish can tolerate relatively high concentrations for limited periods of time (Whalen 1951). Waters with median levels of suspended solids and turbidity of 15 mg/l and 5 JTU and occasional extremes of 100 mg/l and 30 JTU would be expected to provide conditions for a better fishery than a stream with medians of 70 mg/l and 23 JTU and occasional extremes of 150 mg/l and 40 JTU, and waters with medians of 100 mg/l and 30 JTU should be more productive than streams with medians of 300 mg/l and 70 JTU. However, ". . . although several thousand parts per million suspended solids may not kill fish during several hours or days exposure, temporary high concentrations should be prevented in rivers where good fisheries are to be maintained. The spawning grounds of most fish should be kept as free as possible from finely divided solids" (USEPA 1973). A stream with generally low median suspended sediment and turbidity levels (e.g., <100 mg/l and <30 JTU) but with high and temporary concentrations of sediment at certain periods of the year (e.g., 400 mg/l and 91 JTU) may be able to support a migratory or stocked fishery in its waters but not a resident (breeding) population, because the pulse of sediment could eliminate spawning grounds.

Salinity

The salinity level (dissolved solids concentration) of freshwater lentic and lotic systems is important in the assessment of its aquatic biota as well as in judging its potential for irrigation. According to the EPA (1973):

> The quantity and quality of dissolved solids are major factors in determining the variety and abundance of plants and animals in an aquatic system. . . . A major change in the quantity or composition of total dissolved solids changes the structure and function of aquatic ecosystems . . .

However, " . . . such changes are difficult to predict" (USEPA 1973).

Hart et al. (1945) observed that only five percent of the inland waters supporting a mixed biota had salinities in excess of 400 mg/l (as specific conductance greater than about 600 μmhos/cm at 25°C; however, ten percent of these waters had dissolved solid concentrations greater than 400 mg/l. This discrepancy between percentages may illustrate a breaking point in the success of freshwater communities at 400 mg/l. Ellis (1944) recommends that a maximum specific conductance of 1000 μmhos (about 670 mg/l of dissolved constituents), and possibly approaching 2000 μmhos, is permissible in western alkaline streams in order to support a good mixed fish fauna. Incorporating these sources yields the following general reference criteria: healthy, mixed aquatic communities would be expected to be found in waters with dissolved solid concentrations less than 400 mg/l given no other affecting factors; some adverse effects might be expected with salinities greater than 400 mg/l and approaching 670 mg/l. In turn, a salinity in excess of 2000 μmhos (about 1350 mg/l) would be detrimental to most freshwater systems.

Trace Elements and Toxic Substances

In addition to the more common parameters described previously, a variety of trace elements and toxic substances can also dramatically affect aquatic systems. These are generally difficult to assess because their effects are often variable among individual organisms and species and are dependent upon the nature of the remaining chemical constituents of a water; for example, effects can vary with the level of hardness in a system. As a result, such factors as acclimatization and antagonistic-synergistic reactions would have to be considered for a complete discussion of one of these parameters in a particular body of water. However, the Committee on Water Quality Criteria (USEPA 1973) has established, for certain of these constituents, recommendations for an absolute or maximum concentration that should be present in freshwater or seawater; lower concentrations could be recommended for particular cases. General recommendations from this committee and from other references for certain of these parameters, including the metals, are summarized in table 19. These recommendations can be used as reference criteria for the corresponding variables in water quality discussions. Recommendations developed by the Committee on Water Quality Criteria (USEPA 1973) and other sources for other trace elements and toxicants are considered for those streams where appropriate data are available.

TABULAR AND STATISTICAL CONSIDERATIONS

In tables summarizing the water quality information available for the Yellowstone River Basin (primary and secondary inventory areas), the common constituents and metals are designated by their accepted chemical symbols. Concentrations are given as milligrams per liter (mg/l). Distinctions are made between total recoverable and dissolved metals. Parameters consistently tabulated through the basin discussions of this report include those for which data are regularly available from the USGS or the state WQB for the various stream stations. Other water quality variables, such as the pesticides, which have less consistent data for the basin, will be considered separately for those streams where such data are available. The concentrations of critical nutrients (phosphorus and nitrogen species) are listed in the tables according to their P or N components rather than their radical weights; where available, total-P and (NO_2+NO_3)-N data were used in the statistical determinations; where unavailable, the concentrations of the ortho-PO_4-P and NO_3-N species were used as subsets of the preferred forms. Additional abbreviations and concentration units that have been used for other water quality parameters summarized in the tables can be listed as follows:

- BOD — five-day, biochemical oxygen demand (BOD_5) in mg/l
- DO — dissolved oxygen in mg/l
- E — an estimated flow
- FC — fecal coliforms as counts (colonies) per 100 ml of sample
- Flow — stream discharge in cubic feet per second (cfs); flow in cfs can be converted to flow in cubic meters per second (m^3/sec) as follows: $m^3/sec = 0.0283 \times cfs$
- Max — the maximum value of a parameter that occurs in a set of data from a particular stream station (high extreme)
- Med — the median value of a parameter that occurs in a set of data from a particular stream station--the middle value in an ordered or ranked set of figures, i.e., 50 percent of the remaining values occur above the median and 50 percent below the median concentration

TABLE 19. Recommended maximum concentrations of trace elements for freshwater aquatic life and for marine aquatic life.

Trace Element	Recommended Maximum Concentrations
Al	0.1 mg/l (B); >1.5 mg/l hazard, <0.2 mg/l minimal risk (C)
Ag	>.005 mg/l hazard, <.001 mg/l minimal risk (C)
As	1.0 mg/l (A); >.05 mg/l hazard, <.01 mg/l minimal risk (C); arsenic tends to be concentrated by aquatic organisms
B	>5.0 mg/l hazard, <5.0 mg/l minimal risk (C)
Ba	5.0 mg/l (tentative)(A); >1.0 mg/l hazard, <.5 mg/l minimal risk (C); barium tends to be concentrated by aquatic organisms
Be	>1.0 mg/l hazard, <0.1 mg/l minimal risk (C); based on data from hard freshwater
Cd	0.03 mg/l if hardness >100 mg/l as $CaCO_3$, 0.004 mg/l if hardness <100 mg/l (B); >.01 mg/l hazard, <.2 ug/l minimal risk (C); synergistic with copper and zinc
Co	about 1.0 mg/l (tentative) (A)
Cr	0.05 mg/l (A,B); >.1 mg/l hazard, <.05 mg/l minimal risk (C); particularly toxic to lower forms of aquatic life--accumulates at all trophic levels
Cu	0.02 mg/l freshwater, 0.05 mg/l seawater (A); >.05 mg/l hazard, <.01 mg/l minimal risk (C)
Cyanide	0.005 mg/l (B); >0.01 mg/l hazard, <.005 mg/l minimal risk (C)
F	1.5 mg/l (A); >1.5 mg/l hazard, <.5 mg/l minimal risk (C)
Fe	<.2 mg/l (A); >.3 mg/l hazard, <.05 mg/l minimal risk (C)
Total Hg	0.2 ug/l (grab sample), 0.05 ug/l (average)(B); >.1 ug/l hazard (C)
Mn	1.0 mg/l (A); >.1 mg/l hazard, <.02 mg/l minimal risk (C); manganese tends to be concentrated by aquatic organisms
NH_3 (unionized)	0.02 mg/l (B); >0.4 mg/l hazard, <.01 mg/l minimal risk (C)
Ni	>.1 mg/l hazard, <.002 mg/l minimal risk (C)
Pb	<.1 mg/l (A); 0.03 mg/l (B); >.05 mg/l hazard, <.01 mg/l minimal risk (C)
Phenols	0.2 mg/l (A); 0.1 mg/l (B); 0.02 mg/l to 0.15 mg/l, potential tainting of fish flesh (B); 0.001 mg/l reference criteria (D)
Se	>.01 mg/l hazard, <.005 mg/l minimal risk (C)
Zn	>.1 mg/l hazard, <.02 mg/l minimal risk (C)

SOURCES:
(A) McKee and Wolf (1974).
(B) U.S. Environmental Protection Agency (1973) ("Freshwater Aquatic Life and Wildlife").
(C) U.S. Environmental Protection Agency (1973) ("Marine Aquatic Life and Wildlife").
(D) U.S. Environmental Protection Agency (1974).

Min the minimum value of a parameter that occurs in a set of data from a particular stream station (low extreme)

N concentration of nitrogen species in mg/l as elemental nitrogen excluding organic and ammonia nitrogen

N. the number of data points comprising a parametric set of data

P concentration of phosphorus species in mg/l as elemental phosphorus

pH in standard units

SAR sodium adsorption ratio; see Hem (1970), pp. 228-229, for definition

SC specific conductance in µmhos/cm at 25°C

TA total alkalinity as mg/l of $CaCO_3$

TDS total dissolved solids in mg/l calculated as the sum of constituents or determined as the weight of filterable residue after evaporation at 82°C (180°F)

Temp temperature in degrees Celsius

TH total hardness as mg/l of $CaCO_3$

TSS total suspended solids in mg/l

Turb turbidity in Jackson Turbidity Units (JTU)

Minimum, maximum, and median values listed for temperature and specific conductance were those obtained from grab samples rather than from continuous or once-daily records.

In addition to the more common parameters listed previously, miscellaneous constituents can also be important in some instances in reducing the quality of water in streams. As a result, these parameters will also be considered for those streams and stations where appropriate data are available. Such parameters and associated symbols, concentrational units, and related information can be summarized as follows:

COD chemical oxygen demand in mg/l is a measure of oxidizable compounds in a sample through dichromate reduction (APHA et al. 1971, USDI 1966-1974b)

Color an aesthetic evaluation in platinum-cobalt units (APHA et al. 1971); color in water is generally caused by unknown, dissolved organic materials of high molecular weight and is generally unnoticeable to the human eye at less than 10 units (Hem 1970)

MBAS methylene blue active substance in mg/l; MBAS is a measure of apparent detergents after the formation of a blue color when the methylene blue dye reacts with synthetic detergent compounds (USDI 1966-1974b)

O&G oil and grease in mg/l as measured gravimetrically after petroleum ether extraction and evaporation (APHA et al. 1971)

TOC total organic carbon in mg/l

Phenols are determined in milligrams per liter following methods outlined in Standard Methods (APHA et al. 1971).

When large amounts of water quality data are available, a statistical summary is necessary for each sampling station. In the STORET summaries, the mean, variance, and other statistics from the available data for each parameter are presented for each sampling location. This approach compacts the data and allows for overall comparisons; however, a mean, in most cases, is probably not the best estimator of central tendency. Since the concentrations of water quality parameters tend to be affected by flow quantities to varying degrees, parametric concentrations do not generally approach a normal distribution but are most often skewed to some extent, which weights the mean. For example, the distribution of dissolved solids levels (concentrations versus the percentage of samples having a particular concentration) may be skewed to the right (high) because high concentrations are obtained for a large proportion of the year at low flows but with a few samples of extremely low concentrations obtained during the high-flow periods of much shorter duration. These low values then can weight the mean concentration of a parameter toward low, so that the mean would not reflect the most common concentration of the constituent over the year. The opposite would be true for parameters which have concentrations directly related to flow, e.g., suspended sediment and fecal coliforms, with a weighting toward high producing excessively large means.

The EPA (1974b) took a different approach in its National Water Quality Inventory andused the median concentration of a parameter as an expression of central tendency; it also determined the 15th (low concentration) and the 85th (high concentration) percentiles of a parametric data set which served to illustrate the degree of dispersion or typical concentration range, excluding the extreme values (USEPA 1974a). With one modification, this approach was generally utilized in the Yellowstone Basin water quality inventory conducted by the state WQB for this study. Since post-1965 data from the basin were of insufficient magnitude for the calculation of meaningful 15th and 85th percentiles, the maximum and minimum values of a data set were used to indicate the degree of dispersion; these are representative of the true concentration range of a parameter since the extreme values are included. In a few cases in which uniquely high concentrations were obtained for particular constituents, the next highest value served as the maximum value. In general, the median would appear to be a better indicator of central tendency in non-normal data than the mean since the median provides a definite middle point of reference.

Two types of water quality parameters were recognized in this survey:

1) the major parameters most typically considered in water quality

surveys (e.g., common ionic constituents, dissolved oxygen, suspended sediment, pH, and critical nutrients) and for which there are generally large amounts of data; and

2) the miscellaneous constituents and trace elements which are not as commonly considered in inventories or are related to specific problems (e.g., MBAS, fecal strep, cyanide, various metals, ammonia, and so forth) and/or for which data are comparatively sparse in most cases.

Due to these differences, two distinct approaches were used in the statistical summaries of these two parameter groups.

An attempt was made to classify according to flow all of the data available for the major parameters at each sampling station. This classification, based primarily on the discharge cycle of the Yellowstone River, consisted of four periods: months which generally have high flows (spring runoff in May, June, and July), warm-weather low flows (August, September, and October), cold-weather low flows (November, December, January, and February), or spring flows (March and April). The March-April period was distinguished because many of the lowland streams have a runoff period at this time, earlier than the May-July runoff period in streams with mountainous origins. Parametric medians and ranges were then determined from these seasonally classified subsets of data.

For stations (typically the non-USGS sites) on which data for the major parameters were missing for some seasons or for which only a few readings were available for this seasonal separation, the data were directly classified according to flow (where possible) by developing two subsets of parametric values--one for samples obtained during relatively high flows (>8.0 cfs) and one for samples obtained during low-flow periods (<8.0 cfs in this instance). Medians and maximum-minimum values for each parameter were then determined from these flow-classified subsets.

For some stations, data were insufficient for even this latter type of separation, and the parametric median, maximum, and minimum values for these stations were determined from the entire set of data. In some instances, water quality data from closely related stations on a stream were combined and the statistics then determined either directly from the combined set of data or from subsets as described above. Statistics thus derived would describe a stream reach rather than a specific location. For some drainage areas, data from closely associated streams were combined to increase the sample size, this data would describe a region rather than a stream location or reach. In all water quality tables presented in the following section of this report, the sample sizes of each of the parameter-data sets (N) involved in the median, maximum, and minimum determinations are given to provide a basis for judging reliability.

Due to the general lack of information, no attempt was made to classify by flow the miscellaneous constituents or trace elements. In most instances, data for these parameters from two to several adjacent locations on a stream or from several stations on associated streams in a drainage were amalgamated to increase sample size for the median, maximum, and minimum determinations.

Through these various statistical approaches, some order should be imparted to the large amounts of diverse water quality data now available for the Yellowstone River Basin. Some meaningful conclusions concerning the status of water quality in the drainage might then be derived from this data.

IMPACTS OF WATER WITHDRAWALS

DESCRIPTION OF METHODS

Introduction

TDS was the principal water quality parameter modeled; it was chosen for several reasons:

1) it can be a limiting factor for several beneficial uses, including drinking water, irrigation, industrial, and fish and aquatic life;

2) common constituents and hardness generally are linearly related to TDS;

3) adequate records of TDS are available from publications of the USGS;

4) TDS is relatively easy to model, being a conservative substance that is transported with the water;

5) for a given reach of stream, TDS is highly correlated with electrical conductivity, which can be measured easily and inexpensively; and

6) TDS is an indicator of the overall chemical quality of the water.

Nonconservative parameters such as temperature, dissolved oxygen, biochemical oxygen demand, and coliform bacteria generally are not a problem in the Yellowstone River Basin. Detailed analysis of these parameters was not a primary goal of this study; however, streams on which future development seems likely to adversely affect nonconservative parameters are identified.

General

The basic principle governing the analysis is that mass must be conserved. All water and dissolved minerals available to the basin in a given time period (a month in this case) will be removed permanently from the system, stored temporarily for release later, or discharged from the basin via the stream or groundwater during the same month. The quantity of water available is obtained from hydrologic simulations (refer to task 9); the corresponding salt load is computed from regression equations relating average monthly TDS to total monthly discharge.

Figure 2 illustrates the gross movement of water and salt within the basin. The following equations account mathematically for the water and salt:

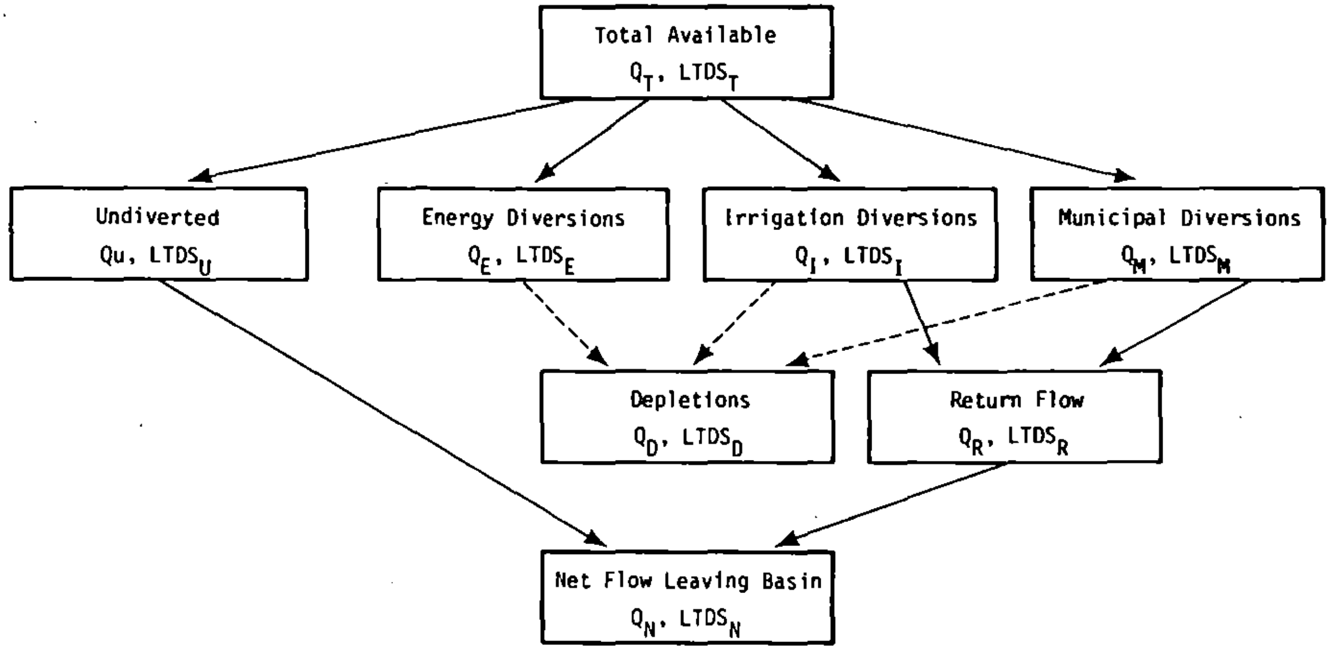

Figure 2. Simplified diagram of water and salt movement.

1) $Q_N = Q_T - Q_E - Q_I - Q_M + Q_R$

2) $LTDS_N = LTDS_T - LTDS_E - LTDS_I - LTDS_M + LTDS_R$

where:

Q_N is net flow leaving the basin

Q_T is total flow available before diversions

Q_E is diversion for energy

Q_I is diversion for new irrigation

Q_M is diversion for new municipal use

Q_R is return flow

$LTDS_N$ is net salt load leaving the basin

$LTDS_T$ is total load of salt in Q_N

$LTDS_E$ is salt load in Q_E

$LTDS_I$ is salt load in Q_I

$LTDS_M$ is salt load in Q_M

$LTDS_R$ is salt load in Q_R

The flows are in acre-feet and salt load is in tons. Therefore, the concentrations of TDS in mg/l is calculated as follows:

$$3)\quad TDS = \frac{LTDS}{Q\ (.00136)}$$

The equations are applied for each month. Additional details are described in the following sections.

Regression Equation for TDS

Published records of the USGS were used to obtain basic data on discharge and TDS. Water quality data are reported as concentrations (mg/l) for periods usually ranging from one to thirty days. Samples are collected daily and composited by discharge before analysis so that results represent discharge-weighted averages for the compositing period. Published values for TDS were weighted by water volume for each compositing period during a month in order to obtain monthly discharge-weighted values. For example, the following information was published for the Yellowstone River at Miles City:

Date	Discharge	TDS
Nov. 1-12, 1974	11,200 cfs	503 mg/l
Nov. 13-30, 1974	9,740 cfs	477 mg/l

The discharge-weighted average monthly TDS is computed as follows:

$$TDS_{ave} = \frac{12 \times 11,200 \times 503 + 18 \times 9,740 \times 477}{12 \times 11,200 + 18 \times 9,740} = 488 \text{ mg/l}$$

Where the compositing period covered parts of two months, the water volume was linearly apportioned according to the number of days in each month covered by the composite analysis.

The quantity of dissolved minerals in natural water is primarily a function of the type of rocks or soils with which the water has been in contact, the duration of contact, and the pH of the water. Groundwater, which supplied much of the flow in dry, low-flow months is normally more highly mineralized than surface runoff. Hence, TDS of water in the stream is usually less when streamflow is high because surface runoff tends to dilute the base flow from groundwater. Both surface runoff and groundwater, however, vary in quality with time and location in response to natural geologic and hydrologic phenomena and as a result of man's activities such as agriculture, mining, oil well drilling, and industrial and municipal pollution. Consequently, the expected inverse relationship between TDS and Q may not be well-defined mathematically for all stations, or the "best-fit" equation may take different forms for different stations or for different periods of the year at a given station.

Regression equations were obtained for TDS (average monthly total dissolved solids in mg/l) as a function of Q (total monthly discharge, acre-feet). Resulting equations were of the following forms:

4) TDS = a + b Q
5) TDS = c + d log Q
6) log TDS = e + f log Q
7) log TDS = g + h Q

Generally, data most often fit equations 5 and 6 better than 4 or 7. Equations were obtained for all stations in the basin with adequate records. For some stations, sufficient records were available to enable equations to be derived for each month of the year. Equations were tested for statistical significance using tables developed by Snedecor (1946). Generally, the significant regression equations produced r^2 values ranging from 0.60-0.90, indicating that Q accounted for 60 to 90 percent of the variation in TDS.

Conservation of Water and Salt

Generally, water quality records for 1951-1974 were used to develop the regression equations. No station, however, had more than 19 years of record during this period; most had less. It was assumed that these data represented the normal situation, i.e., the cause-effect relationship was constant. For calculation purposes, any changes in the causative factors were assumed to be superimposed upon the normal relationship. For example, the Q the TDS used in deriving the regression equations represent the "total available" values indicated in figure 2. The Q_T and $LTDS_T$ are for the basin outflow under normal conditions. Therefore, in order to use the equation derived for TDS versus Q, Q must be the normal unaltered value at the basins outlet, which then makes it possible to obtain the corresponding normal TDS. Once Q_T and $LTDS_T$ are established (see the explanations below for columns 1, 2, and 3), the logic of figure 2 and equations 1 and 2 can be employed. Table 20 illustrates the application of the regression equations and equations 1, 2, and 3 to a representative subbasin, the Tongue River. An explanation of each column is presented below.

Column 1. Total Available, Water (af). These numbers represent the flow that would pass Miles City if no diversions occurred other than those occurring under normal conditions; in other words, historical flows.

Column 2. Total Available TDS (mg/l). These values are obtained from the regression equations between TDS and Q, using column 1 values for Q. For April the appropriate equation is TDS = 1524.7 - 217.70712 log Q, which yields a TDS of 580 for a Q of 21,888.

Column 3. Total Available TDS (tons). The load of dissolved salts in tons is obtained from equation 3 by multiplying column 1 x Column 2 x 0.00136 (a conversion factor).

Column 4. Energy Diversion. Water. The amount of water diverted for energy purposes, given from the level of development assumed.

TABLE 20. Sample calculation of TDS in the Tongue River at Miles City assuming a low level of development.

Month	(1) Total Available	(2)	(3)	(4) Energy Diversion	(5)	(6) Irrigation Diversion	(7)	(8) Return Flow	(9)	(10) Outflow	(11)	(12)
	Q_T (af)	TDS (mg/l)	$LTDS_T$ (tons)	Q_E (af)	$LTDS_E$ (tons)	Q_I (af)	$LTDS_I$ (tons)	Q_R (af)	$LTDS_R$ (tons)	$LTDS_N$ (tons)	Q_N (af)	TDS (mg/l)
Apr	21,888	580	17,265	955	753	220	174	293	471	16,809	21,006	588
May	168,998	347	79,754	955	451	2,855	1,347	805	1,294	79,250	165,993	351
June	299,879	186	75,857	955	242	3,730	944	1,025	1,647	76,318	296,219	189
July	24,285	370	12,220	955	481	7,030	3,537	1,318	2,117	10,319	17,618	431
Aug	7,859	510	5,451	955	662	5,490	3,808	1,317	2,117	3,098	2,731	834
Sept	8,549	535	6,220	955	695	2,415	1,757	732	1,176	4,944	5,911	615
Oct	5,458	655	4,862	955	851	200	196	585	941	4,756	4,868	718
Nov	17,487	592	14,079	955	769	0	0	366	588	13,898	16,898	605
Dec	14,643	672	13,383	955	873	0	0	293	471	12,981	13,981	683
Jan	11,647	677	10,724	955	879	0	0	220	353	10,198	10,912	687
Feb	12,734	586	10,148	955	761	0	0	146	235	9,622	11,925	593
Mar	28,346	479	18,466	955	622	0	0	220	353	18,197	27,611	485
Annual	621,773	317	268,429	11,460	8,039	21,960	11,763	7,370	11,763	260,390	595,673	321

NOTE: These calculations are based upon 100 percent of the Northern Great Plains Resource Program fish and game flows; salt pickup 0 tons per acre (1944-1945).

Column 5. Energy Diversion, Salt. The amount of salt dissolved in the water diverted for energy, obtained from equation 3 by multiplying column 4 x column x 0.00136.

Column 6. Irrigation Diversion, Water. The amount of water diverted for irrigation during the month, given from the level of development assumed.

Column 7. Irrigation Diversion, Salt. The amount of salt dissolved in the water diverted for irrigation, obtained from equation 3 by multiplying column 6 x column 2 x 0.00136.

Column 8. Return Flow, Water. The amount of return flow that appears in the stream during the month. It was assumed that energy diversions would produce no return flow and that one-third of irrigation diversions and one-half of municipal diversions would eventually return to the stream. Return flow is allocated according to the following percentages of the total annual return flow, beginning with April: 4, 11, 14, 18, 18, 10, 8, 5, 4, 3, 2, 3 (Koch 1977). Therefore, the total annual return flow is one-third of 21,960--7,320. Four percent, or 293, return in April; eleven percent, or 805, in May; and so forth. No municipal diversions were made under the level of development illustrated, but had there been a municipal diversion, one-half of the yearly total would have appeared as return flow, distributed in the same manner as irrigation return flow. This assumption was made for ease of calculation. Actually, most water used for domestic purposes will be returned to the stream during the month it is diverted. Only that portion used for irrigation of lawns, parks, and cemetaries will behave as irrigation return flow. In all levels of development, however, municipal diversions were so small (less than three percent of total diversions) that no further refinement was deemed necessary.

Column 9. Return Flow, Salts. The salt load that will return to the stream is unknown and varies from place to place. Ideally, return flow from irrigation should remove, as a minimum, the salt contained in the applied water. Otherwise salt will accumulate in the soil and eventually reduce productivity. It is common where water is plentiful to over-irrigate, a practice which often leaches naturally occurring salts from the soil. Under the assumptions of this study, over-irrigation would not occur; thus, leaching should not be excessive. For purposes of analysis, three levels of salt pickup were considered: zero, one-half, and one ton per acre per year. The total at the bottom of column 9 represents the dissolved salt in the irrigation return flow. It is obtained by adding zero, one-half, or one ton per acre times the number of acres irrigated to the salt in the applied water, the total of column 7 (in the example, zero salt pickup is assumed). This load was distributed monthly according to the distribution used for column 8. The quality of irrigation return water can vary considerably throughout the year in response to a multitude of factors: quantity of applied water, quality of applied water, method of irrigating, type of soil, crop, growth stage, drainage system, and others. Normally, some return flow will percolate through the soil and return as subsurface return flow, which is usually higher in dissolved salts than surface return flow. Obviously, return flows in the non-irrigation months (November-March) will consist entirely of subsurface flows and will have a higher concentration than return flows during the irrigation months (April-October) when a portion of the return flow is surface. With the low application rates assumed in this study (three af/acre), surface return flows will probably be small. It is likely that subsurface return flows, which should exhibit more uniform concentrations, will predominate. Therefore, no attempt was made to differentiate in quality between surface and subsurface return flows. The value for April, for example, is simply four percent of the annual total of 11,763 tons.

Column 10. Outflow, Salt. Salt load is obtained from equation 2: column 10 = column 3 - column 5 - column 7 + column 9. If municipal diversions had been significant, they would be subtracted. Return flow from municipal diversions would be added.

Column 11. Outflow, Water. The values of Q_N in the table were obtained from equation 1: column 11 = column 1 - column 4 - column 6 + column 8; municipal diversions, if significant, would be handled as described in the previous paragraph. These illustrative calculations follow the logic of figure 2. Actually, however, values for Q_N were simulated by the hydrologic model (refer to task 9, Water Model Calibration and River Basin Simulations for an explanation of the model). Basically, the model used more refined techniques to simulate water movement in the basin, so the resulting basin outflow was used for Q_N instead of the value from equation 1.

Column 12. TDS of Outflow (mg/l). The concentration of the basin outflow is obtained from equation 3: column 12 = column 10 ÷ column 12 ÷ 0.00136.

Adjustments for Storage

The procedure outlined above assumes that the historical relationship between TDS and Q will be preserved, subject only to the effects of diversions and return flows under the various levels of development. Construction of a dam, however, will alter the relationship between TDS and Q below the dam by virtue of the storage and mixing that occurs within the reservoir. The effects of an impoundment can be evaluated if the waters of the reservoir are sufficiently mixed so that an assumption of complete mixing of inflow and storage does not lead to large errors. If stratification occurs, the complete mixing assumption is invalid, but the state of the art generally does not permit a prediction of the stratification of planned reservoirs.

The simplest technique assumes that reservoir outflow during a given time period is of constant quality. Further, it is assumed that inflow occurs independently of outflow and that reservoir quality is determined by both a salt and water balance at the end of the time period. The reservoir lessens water quality variations, with a slightly higher mean concentration (because of evaporation).

The equations for the quality of reservoir water and discharge are given below.

For water:

8) $VR_1 = VR_0 + VI_1 + P_1 - E_1 - VO_1$

where:

VR_1 = volume in reservoir (storage) at end of month 1

VR_0 = volume in reservoir at end of month 0 (or at beginning of month 1)

VI_1 = volume of inflow to reservoir during month 1

P_1 = precipitation on reservoir during month 1

E_1 = evaporation from reservoir during month 1

VO_1 = volume of outflow during month 1

For salt:

$$9)\quad (VR_1)(CR_1) = (VR_0)(CR_0) + (VI_1)(CI_1) - (VO_1)(CO_1)$$

where:

VR_1, VR_0, VI_1, and VO_1 are volumes described previously and CR_1 =

concentration of water in reservoir at end of month 1

CR_0 = concentration of water in reservoir at beginning of month 1 (end of month 0)

CI_1 = concentration of inflow during month 1

CO_1 = concentration of outflow during month 1

Note that precipitation and evaporation are assumed to have 0 concentrations.

In applying equations 8 and 9 all quantities must be known except the outflow (volume and quality) and final reservoir storage (volume and quality); that is, VR_1, CR_1, VO_1, and CO_1. The relationship between water quantities, VR_1 and VO_1, will be determined by the operating rules for the reservoir, resulting in three equations and four unknowns. The necessary fourth equation is obtained by making an assumption regarding CR and CO. One approach is to assume complete mixing of reservoir contents before outflow occurs, or CR_1 equals CO_1. Combining this assumption with equations 8 and 9 yields the following:

$$10)\quad CO_1 = \frac{(VR_0\ CR_0) + (VI_1)(CI_1)}{VR_1 + VI_1 + P_1 - E_1}$$

The analysis is repeated for successive months until the quality routing is completed. Other assumptions involving CR and CO are possible, such as averaging inflow and outflow quality at the beginning and end of each month and using an iterative process, but equation 10 was used in this analysis.

The historical relationship between TDS and Q is used to obtain inflow quality (CI_1) from inflow quantity (VI_1) VI_1. The other quantities were available from the hydrologic simulations. Equation 10 was used to obtain the quality of reservoir outflow (CO_1), which became the basis for the calculations outlined in figure 2. In effect, the quantities of water and salt represented by VO_1 and CO_1 replace Q_T and $LTDS_T$ in equations 1 and 2. Thereafter, calculations proceed as described previously.

Adjustments for Upstream Changes in Water Quality

The historical relationship between TDS and Q at a given point in a river can be altered also by changes in diversion patterns upstream. Substantial diversions for irrigation above Miles City, for example, would increase TDS concentrations and render invalid the equation based on historical records of TDS and Q at Sidney. Therefore, calculations for the two subbasins with major new upstream diversions, the mid-Yellowstone and lower Yellowstone, required significant modifications to the basic procedure described previously.

Essentially, such modifications consist of adding the increased salt produced by diversions above the subbasin in question to the salt load at the mouth of the subbasin calculated assuming no change in the TDS-Q relationship. The procedure is demonstrated by the following example for the mid-Yellowstone subbasin.

1) First, the procedure outlined in figure 2 using the regression equation between TDS and Q to obtain the initial TDS was followed to produce simulated Q and TDS values. These values reflect only the effect of diversions within the subbasin.

2) The flow at Miles City essentially is the sum of discharges from two other subbasins, the upper Yellowstone and the Bighorn. Therefore, adjustments to the TDS values from step 1 were based on the difference in TDS (for the two upper subbasins) between historical and simulated TDS concentrations for identical discharges. For example, from step 1, Q and TDS for the Yellowstone at Miles City during August 1954 would be 215,827 af and 673 mg/l, respectively for the high level of development. During the same month, the discharge from the Bighorn would be 31,549 af. Historically, the Bighorn flow of 31,549 af in August would produce a TDS of 475 mg/l; under the high level of development, however, TDS would increase to 564 mg/l. Therefore, the Bighorn would contribute, under the high level of development, 31,549 x (564 - 475) x .00136 = 3,819 more tons of salt than it would naturally (1 mg/l = 0.00136 tons/af). Similarly, the upper Yellowstone would contribute 204,654 af of water with a concentration 1.5 mg/l higher than naturally, or 204,654 x 1.5 x .00136 = 418 tons more. Of the August 1954 flow of the mid-Yellowstone, 4.8 percent would be diverted for energy use which has no return flow. Thus, only 95.2 percent of the additional salt would leave the subbasin at Miles City. Consequently, .952 (3,819 + 418), or 4,034 tons must be added to the salt load of the Yellowstone River at Miles City during August 1954. The adjusted concentration would be 687, or 14 mg/l (2 percent) higher than the value simulated, ignoring upstream effects.

Water quality problems in the Yellowstone River Basin

INTRODUCTION

Many diverse and complex phenomena, both natural and man-caused, influence water quality in streams of the Yellowstone River Basin. The major water quality problems are associated with man's activities. Those described in this section include mining, coal-fired power plants, synthetic fuel plants, slurry pipelines, municipalities and industries, agriculture, and construction. Also discussed are methods of alleviating water pollution resulting from these activities. Treatment systems are well established for some pollutants, such as domestic waste; control methodologies are not well defined for other pollutants, such as nonpoint wastes and effluents from synthetic fuel plants. Acceptable and potentially acceptable techniques for treating or controlling wastewaters are described.

MINING

Large-scale surface mining of coal in the northern Great Plains is a rather recent development. Consequently, the long-term effects of surface mining on the environment, including water quality, have not been fully documented. The NGPRP (1974) study included a general discussion of water quality impacts associated with coal mining. Van Voast (1974), Van Voast et al. (1975), Hodder (1976), Pollhopf and Majerus (1975), and Van Voast and Hedges (1975, 1976), have reported results of research on the effect of Montana strip mining on water quality, but few data are available on water quality after strip mining ceases. Onsite water pollution problems of Montana mines are categorized and discussed below.

DRAINAGE WATER

In many cases coal beds are aquifers. Removal of the coal results in an accumulation of water in the pit being mined, necessitating its drainage. Although water occurring naturally in the coal bed may be of potable quality, activities resulting from mining can contaminate the water with silt, coal fires, oil and grease from machinery, nitrates from blasting agents, and sulfurous or other compounds, including undesirable trace elements dissolved from the coal or overburden. Discharge of pit water would require a permit from the Montana DHES. The discharge permit would specify allowable levels of contaminants in the effluent. Treatment may be required in order for the effluent to meet the criteria specified in the permit. Often pit water will be stored and used for dust control.

EROSION AND SEDIMENTATION

Strip mining severely disturbs the surface of the ground not only in the mining area, but also in the provision of ancillary facilities such as roads, buildings, parking lots, water control structures, crushing and screening facilities, and loading areas. Any surface disturbance increases the erosion potential and changes the quality of runoff. Montana law requires that during active mining, sedimentation basins be constructed to contain sediment within mine boundaries.

Proper grading, reapplication of top soil, and establishment of vegetation will minimize erosion and sedimentation after mining ceases. The Bureau of Land Management (1975) estimates that at the Otter Creek Coalfield, annual sediment yield of the overburden after the soils and perennial vegetation have stabilized will be approximately the same as before mining, but sediment yields will be approximately doubled during the five-to-ten-year reclamation period. The maximum potential for erosion occurs immediately after grading and before vegetation has developed a root system. If seeding is done in the spring, it coincides with the period of intense thunderstorms, which, combined with vulnerable soils, can produce substantial erosion. Such an event in May 1976 at Western Energy Company's mine near Colstrip severely eroded a newly planted reclamation site and filled a settling pond. The automatic discharge device for the pond failed to operate, necessitating the release of sediment-laden water into a tributary of Rosebud Creek (Schmidt 1976).

Thus, prevention of water pollution by surface runoff depends to a large extent on the success of reclamation. If reclamation is successful in retaining rainfall on the soil, runoff and erosion will be reduced accordingly. Jensen (1975) describes a project to maximize moisture retention by mechanically manipulating the surface to create depressions which reduce surface runoff and improve plant growth. Success of that project and others led Hodder (1976) to conclude that "in general, water pollution problems associated with mining in Montana have been minimal as far as surface water is concerned."

LEACHING

Over geologic time, natural drainage systems have developed within soil and rocks overlying coal beds. Strip mining entails removal and stockpiling of this overburden and the destruction of those drainage systems. After mining, the overburden is replaced prior to grading, topsoiling, and revegetation. The resultant drainage pattern, both surface and subsurface, will differ considerably from the old, due to the general lowering of the ground surface, elimination of the coal seam (which might have been an aquifer), and refilling the pit with a heterogeneous mixture of soil, rock, and waste coal--which may become a new aquifer.

Consequently, overburden material which was in contact with water infrequently or not at all before mining, may be used to refill the void left by removal of the coal seam. This material may become saturated and thus continuously exposed to the water's persistent solvent action. Therefore, after mining and reclamation are completed, groundwater in the spoil areas could be more highly mineralized than water in nearby undisturbed aquifers. This has been documented by Van Voast and Hedges (1975) for the Rosebud Mine near Colstrip. But, they point out, although ". . . alterations of groundwater quality will occur within the downgradient from mined and reclaimed areas . . . the simple acknowledgement of hydrologic effects has little meaning without establishment of their significance."

The crux of the matter is the significance of changes in groundwater quality caused by strip mining: the degree to which such changes would be detrimental to the aquifer, whether toxic elements would travel downgrade and render the water a health hazard for humans and livestock, whether undesirable chemicals would discharge via the groundwater into a stream and adversely affect fish and aquatic life, wildlife, and beneficial uses of the stream's water, whether water quality in the spoils would improve or deteriorate with time, and whether effects would be localized or contaminate entire aquifers downstream of the mine. These and similar questions can be answered only with time and considerable field data. Also, answers valid for one site may not be valid at another because of differences in geology, hydrology, precipitation, and other physical and chemical factors.

Van Voast and Hedges (1976) have summarized hydrogeologic conditions near Colstrip for areas undisturbed by mining, areas currently being mined, and areas that were mined and abandoned or reclaimed. Among their observations are the following:

1. Water quality data "exemplify the striking lack of uniformity or predictability of groundwater quality in the Colstrip area." Water quality varied widely at different locations and depths, even within the same aquifer. Spoils in younger parts of the mined area contain waters that are chemically similar to waters from undisturbed aquifers, but water from older spoils is more mineralized than water in nearby undisturbed aquifers.

2. "Occurrences and concentrations of trace elements in mine-area waters are sporadic and do not relate definitely to past mining operations."

3. "Chemical qualities of active-mine effluents will be similar to those of other area waters; dissolved solids concentrations will range between 500 and 3,000 mg/l. Leachates from spoils will probably have dissolved solids concentrations ranging between 1,000 and 5,000 mg/l, of which the principal constituents will be magnesium and sulfate, and the general quality of groundwater in the mined areas will ultimately alter to become more representative of waters in other non-coal aquifers."

Van Voast and Hedges (1975), through research on areas before, during, and after strip mining and with the development of simulation techniques believe that potential hydrologic effects (including water quality) of "future mine operations will become predictable." In the interim, the safe approach requires thorough monitoring of groundwater quality downgrade from active and reclaimed mining areas in order to detect significant changes in undesirable or potentially toxic substances before they reach hazardous levels.

MISCELLANEOUS

Several other activities at a mine have the potential to contribute to water pollution, including the following:

Sanitary Facilities

Wastewaters from showers, washrooms, bathrooms, cooking and eating facilities, and cleaning operations should present no unusual difficulties if proper treatment and disposal systems, e.g., lagoons or septic tanks, are used.

Equipment Wastes

Equipment maintenance requires the handling of a variety of substances, including fuels, lubricants, and antifreeze, which, along with detergents used in cleaning operations, are potential pollutants. Disposal sites for these wastes should be located where the threat of water pollution is minimal.

Air-borne Wastes

Water pollution can result from air-borne contaminants such as soil and coal dust from construction, haul roads, crushing and loading, wind erosion, and chemicals emitted from diesel and gasoline engines.

Coal Washing

Although no mines in Montana presently wash the coal before loading, it may become necessary in the future at existing or new mines. If so, additional water would be required by the mine and another wastewater stream would be created. It is likely that wash water would be recycled to avoid a discharge, and that solid material washed from the coal would be evaporative-dried and eventually buried.

CONTROL OF WASTEWATERS FROM MINING

Mining techniques to minimize water pollution are described by Persse (1975). Possible methods of controlling water pollution at strip mines include the following:

1. Water collected in the pits can be pumped to storage basins where settleable solids will be deposited. If the decantate is of sufficient quality, it can be discharged; otherwise, it must be treated or stored until evaporated. Often pit water will be used for dust control or irrigation of reclaimed land.

2. Diversion channels can be constructed to direct surface runoff away from the highly erodible spoil piles.

3. Sediment basins can be formed to collect internal surface runoff from spoil piles and thus prevent sediment from leaving the mine area. If necessary for flood control or to prevent surface runoff from polluting streams below the mine, the sediment-control basins could be expanded to act as storage reservoirs during the period of active mining.

4. Reclamation can be designed to retain precipitation on-site to be used by vegetation, and thereby minimize surface runoff.

5. Known toxic spoil material can be buried between impervious layers or otherwise separated from contact with water.

6. Waste oil and other substances resulting from equipment maintenance can be stored in leak-proof containers for possible recycling, or disposed of in a manner to prevent water pollution, such as oiling roads or placing in impervious landfills.

7. Properly designed and operated septic tank systems or lagoons can be used for treatment of sanitary waste.

POWER PLANTS

A modern coal-fired electric generating plant burns coal in a boiler to produce high temperature and high-pressure steam, which passes through a turbine where the thermal energy of the steam is converted to rotating mechanical energy. The turbine transfers energy to the generator, which produces electrical energy. After turning the turbine, the steam enters the condenser, where energy is transferred to the cooling fluid, and the steam reverts to the liquid phase. This last step produces very low pressure on the outlet side of the turbine, necessary for efficient operation of the plant. The lower the outlet pressure, the higher the efficiency; the more heat absorbed by the cooling fluid, the lower the pressure will be; and the lower the temperature of the cooling fluid, the more heat will be absorbed.

Due to inefficiencies in the conversion processes, energy is lost at each step in the process. The laws of thermodynamics limit the overall efficiency of a coal-fired plant to approximately 40 percent. Hence, each kilowatt hour (KWH) of electricity (one KWH is 3,413 BTU's) requires a "heat rate" of 3,413 ÷ .40, or 8,533 BTU's. Some energy, approximately ten percent, enters the atmosphere through the smokestacks. Another five percent is lost within the plant. So the heat that must be rejected to the cooling system is equal to .85 x 8,533 - 3,413, or 3,840 BTU/KWH, which represents 45 percent of the energy obtained from burning the coal. Thus, for each 100 units of energy introduced into the plant, 40 leave as electricity, ten go up the smokestack, five are lost within the plant, and 45 are rejected to the cooling system.

Two fluids are used to absorb the heat rejected in the condenser: water and air. Presently, only one plant in the United States--the 30 MW Wyodak unit in northeastern Wyoming--uses air as the cooling medium in dry cooling towers. All others require water. Although power plants use water for other purposes such as boiler feedwater to supply the stream, in ash handling and stack gas cleaning, and service water for drinking, cleaning, and sanitary purposes, more than 95 percent of the water requirement in a wet system is for cooling.

The advantages and disadvantages of various cooling devices are discussed by Thomas (1975) and Moseley (1974). For the northern Great Plains, estimated net consumption would range from approximately seven af/y per megawatt capacity for once-through cooling to up to twenty-one af/y per megawatt capacity for spray ponds. Dry or hybrid systems (devices which use both air and water as cooling mediums) theoretically could be designed to use little or no water. However, no such systems have been built in the United States for large power plants.

Closed-cycle wet cooling systems are designed to alleviate thermal pollution associated with once-through cooling. However, use of these devices does not entirely eliminate environmental problems. Fogging, drift, icing, and steam plumes may occur downwind. In addition to cooling, water is used for several other important functions in a coal-fired power plant. Each of these functions can contribute its own characteristic waste. Sanitary wastes are not unique to a power plant so they will not be discussed. More important are the wastes from: (1) the condenser cooling system, (2) boiler feedwater treatment operations, (3) plant system cleaning water, (4) exhaust gas treatment system, and (5) solid waste handling system.

Where once-through cooling is not possible, auxiliary offstream cooling devices such as cooling towers and ponds are required. Since these devices, with the exception of dry towers, rely primarily on evaporation for cooling, total dissolved solids gradually become more concentrated and can lead to precipitation of solids inside the condenser. Calcium sulfate and calcium carbonate are often the controlling compounds; thus, recirculating water must stay below their solubility limits. Clogging also may result from silica, iron, and silt in the cooling water.

Therefore, chemicals routinely are added to recirculating water cooling systems to prevent clogging, scaling, and biological growth in the condenser. Boies et al. (1973) discuss the various methods employed to control these potential problems. Chemicals used include alum, ferric chloride, or sodium aluminate (for coagulation), lime (for softening), acid (to control pH), zinc-chromate-phosphate inhibitors (for corrosion prevention), phosphonate compounds and various polymers (for scale prevention), and chlorine and biocides (for control of biological growth). Water treated with these chemicals is flushed periodically through the condenser and subsequently removed from the cooling system. This "blowdown" can be heavily contaminated with TDS and suspended solids, plus residues of the chemicals added to the water. Similar wastes are released from the boiler feedwater treatment system and from boiler blowdown.

Without extensive treatment, blowdown could not be discharged into Montana streams. It is likely that blowdown would be placed in ponds constructed to prevent outflows and seepage. Water would evaporate, theoretically leaving the impurities in permanent storage.

Flue gas desulfurization systems based on the use of lime or limestone necessitate the disposal of large quantities of sludge. Ponding and landfilling currently provide the major means for disposal of these sludges. This sludge is a potential source of both surface and groundwater pollution, depending upon the characteristics of the waste and the disposal site. Potential water pollution problems are the following:

1) soluble toxic species; e.g., heavy metals;
2) chemical oxygen demand;
3) excessive total dissolved solids;
4) excessive levels of specific species; e.g., sulfate and chloride; and
5) excessive suspended solids.

Bottom ash is usually transported by water to settling ponds. The water can evaporate, seep into the groundwater, or be discharged into a stream. The decantate has a high pH and a high concentration of TDS (approximately 5,000 mg/l). In addition, it is expected that trace quantities of arsenic, barium, copper, iron, mercury, lead, and other elements will be present in solution or in suspension in the decanted water.

It is anticipated that the sludge generated from wet scrubbing processes and the bottom ash will be stored in ponds or used in landfill. For coal of one percent sulfur content and ten percent ash (typical Montana coal), the volumes of sludge and ash will be approximately 85 and 215 tons of dry solids per megawatt per year (Casper 1975). With average dry densities of 42 pounds per cubic foot (pcf) for scrubber sludge and 85 pcf for ash, a 1,000 MW plant would produce more than 200 af of dry solids per year. Ash is relatively easy to dewater but sludge is not. Therefore, the solids probably would require a volume of 400-500 af/y for storage.

Waters used to transport this material, as well as other wastewater from a power plant, obviously have the potential to degrade receiving waters and disrupt aquatic life. Under Montana regulations, discharges of sludges and water from sludges to waters of the state generally would not be allowed. It is likely that such waste, as well as blowdown, will be stored in large ponds from which the water will evaporate. The solids would be stored in the ponds or buried in the stripmine pits during reclamation.

Although it is relatively easy to prevent surface outflow from storage ponds, seepage into the groundwater can be eliminated only by careful construction of concrete or membrane linings. The cost would be substantial. Evidence to support a zero-seepage requirement is lacking at present. Colstrip Unit 1 will be intensively monitored to detect undesirable seepage from storage ponds. If seepage threatens to contaminate the groundwater, remedial measures can be required by the Montana DHES.

Possible adverse effects of stack emissions from large coal-fired power plants in the northern Great Plains have yet to be monitored and quantified. The environmental impact statement on Colstrip Units 3 and 4 (Montana DNRC 1974) concluded that stack emissions probably would damage vegetation but that ". . . acid production from sulfur dioxide emitted from Colstrip Units 1, 2, 3, and 4 would not create significant pH changes in nearby streams. . ." and that, with respect to lead, mercury, and fluoride, ". . . there appears to be no reason to assume that adverse concentrations of these elements will occur in streams of the area."

The cumulative effect of numerous power plants the size of the Colstrip units and synthetic fuel facilities may not be negligible, however. Trace elements from many coal-conversion installations could lead to the accumulation of toxic materials in the watershed and adversely affect water quality, particularly in lakes and reservoirs. As with pollutants from ashes, blowdown, and overburden, the logical approach is to systematically monitor affected waters near existing installations in order to detect significant changes in important trace elements before concentrations reach unacceptable levels. Such information also will provide data that can be used to predict the effects of future projects on water quality.

SYNTHETIC FUEL PLANTS

Basically, the conversion of coal into oil or gas consists of adding hydrogen to coal. Water (as steam) is the source of hydrogen. Every conversion process, of which there are several (Mudge et al. 1974, Battella 1974, Chopey 1974, Probstein et al. 1974), must involve a gasification step in which coal reacts with steam to produce a synthesis gas that can be modified with more steam to obtain more of the hydrogen needed to convert coal into oil and hydrocarbon gas (Cochran 1976).

In addition to processing, water is used for cooling, generating steam energy, ash handling, sanitary purposes, and flushing of the cooling system. Water requirements are expected to range from 5,000 to 10,000 af/y for a 250 million standard cubic-foot-per-day gasification plant (Thomas 1975) up to 29,000 af/y for a 100,000-barrel-per-day synthetic crude oil facility (Dickinson 1974). The synthetic crude plant would consume 18 million tons of coal per year; the gasification plant, 7.6 million. A coal conversion complex could produce a combination of pipeline quality gas, synthetic, crude oil, low-sulfur fuel oils, solid char, solvent refined coal, and various byproducts. Water requirements of a specific facility would depend on many factors, including the processes used in converting coal to other products, the mix of oils and gas produced, moisture content of the raw coal, degree of water recycling, and type of cooling system used.

Synthetic fuel facilities ideally will recycle all water until it is consumed (Beychok 1975, SERNCO 1974, USDI 1974). Thus, there should be no wastewater discharge. Rubin and McMichael (1975), however, believe that it "is often technically or economically infeasible to recycle all wastewaters consumptively." Table 21 identifies the quantity and nature of major wastewater streams within a 270 million standard cubic-foot-per-day gasification plant proposed for Wyoming (SERNCO 1974). Because of water's great solvent ability, the composition of process waters will be complex and contain small amounts of practically all compounds in the coal, in addition to the contaminants shown in table 21. Liquefaction processes will produce wastes of similar quality.

Such wastewaters could not be discharged to Montana streams under existing statutes and rules. Therefore, water not evaporated or incorporated into fuel products will accompany solid wastes and brines leaving the plant. The liquid portion will eventually evaporate or seep into the ground. The remaining solid material--ashes, sludges, and other wastes--will be permanently stored in sealed ponds or buried. The pollution potential of these wastes is similar to that of power plant wastes.

TABLE 21. Quantity and nature of major wastewater streams from 270 x 10^6 SCF/day plant proposed for Wyoming.

Source	Design Quantity gpm[a]	Nature
Major phenosolvan effluent	2,947	Rich in NH_3, H_2S, and low-boiling organics
Minor phenosolvan effluent	1,097	Rich in high-boiling organics, fatty acids, ammonia, coal dust, and total dissolved solids
Oily sewer	180	Oily with suspended solids
Sanitary waste	19	Like municipal sewage
Storm and fire	67	Oily with suspended solids
Selected blowdowns	327	Clean with moderate total dissolved solids

SOURCE: SERNCO (1974).

[a]Gallons per minute.

CONTROL OF WASTEWATERS FROM COAL-CONVERSION FACILITIES

The conversion of coal into electricity, substitute natural gas, synthetic crude oil, and other gaseous and liquid products results in a variety of pollutants detrimental to water quality. Potential problem areas are: (1) heat from cooling devices, (2) blowdown, (3) process wastewaters, and (4) solid waste. Methods of controlling these wastes to prevent water pollution are described below.

Heat From Cooling Devices

Approximately two-thirds of the energy content of coal is rejected to the environment in a coal-fired power plant; a synthetic fuel plant rejects approximately one-third. This lost energy is ultimately transferred to the atmosphere, directly or through evaporation of cooling water. Under current Montana regulations, little heated water could be discharged into a stream. Therefore, closed-cycle wet cooling devices; e.g., cooling ponds or evaporative towers, dry (air-cooled) towers, or hybrid (wet-dry) devices would be required for energy conversion facilities in Montana. Consequently, no direct thermal addition to streams should occur.

Blowdown

The following methods have been used to handle blowdown from large cooling towers (Boico et al. 1973): (1) discharge directly to receiving waters, (2) treatment and discharge, and (3) evaporation or treatment for reuse (zero-discharge).

The quality of blowdown can be controlled somewhat through the use of corrosion resistant pipes, pretreatment of recirculating water, the use of physical (brushes or balls to mechanically scrape the interior of pipes) rather than chemical means to remove scale, and other methods. It is highly unlikely that any blowdown, however, could be legally discharged directly into Montana streams. Consequently, treatment of blowdown before discharge or complete use (zero-discharge) are more probable solutions.

Treatment would have to remove suspended sediment, chlorine residual, and any other objectionable constituent, and cool the blowdown to approximately the temperature of the receiving streams. Settling ponds can achieve much of the required treatment, but the effluent still may contain traces of pollutants. Therefore, to avoid expensive additional treatment and in order to utilize water fully in semiarid areas, it is probable that blowdown ultimately will be stored in ponds, perhaps with ashes and sludges, where the water will evaporate, leaving only a solid residue to be handled. The blowdown could be recycled several times or combined with other waste streams or cooling water before final storage.

Process Wastewaters

Characteristics of wastewater streams in a gasification plant are given in table 21. Rubin and McMichael (1975) list similar waste for other coal conversion processes and state that ". . . coal process waters have an inorganic composition as saline as seawater with the addition of small amounts of practically all the organic compounds found in coal." Since there are more than two dozen technically feasible gasification systems and more than a dozen liquefaction processes, the mix of pollutants in wastewater streams from a synthetic fuel plant depends upon the process employed, as well as the composition of the coal and the quality of the raw water supply.

Effluent standards for synthetic fuel plants have not been established because no commercial plants are operating in the United States. In view of the goal of no discharge of pollutants by 1985, the need for water conservation in semiarid regions, and the difficulty of treating wastewaters from coal conversion facilities, it is probable that energy plants proposed for Montana will have no discharge of effluent wastewater. Water not evaporated or converted to fuel ultimately will be buried with wet ash and sludge in the strip mine pits or stored in ponds. Ramifications of subsurface disposal of such wastes are discussed in the section entitled "Impacts of Water Withdrawals."

Solid Waste

Solid waste from coal conversion processes consists of bottom ash from the boiler, fly ash, ash from gasifiers, refuse from coal preparation, sludges from scrubber systems, sludges from water treatment, organic waste from domestic sewage, and dissolved and suspended solids contained in the various wastewater streams that transport or are combined with the ashes and sludges. Solid waste production, including the moisture contained in the material, will range from less than 1,000 tons per day from a 1,000 MW power plant up to 3,500-6,000 tons per day from a 250 MM SCFD gasification complex (SERNCO 1974, Beychak 1975). Liquefaction wastes should be comparable to those from gasification. The following methods can be used to handle these solid wastes:

1) burial of coarse wastes (principally ashes) in strip mine pits under six to ten feet of overburden; and

2) storage of fine materials in storage ponds which would be buried permanently after completion of the project, or periodic removal and burial of the solids in the pits.

There is legitimate concern that seepage from ponds or infiltration of water through the buried wastes will contaminate the groundwater reservoir. Although according to Persse (1975), "To date, there is no evidence to substantiate this concept," table 22 indicates that the wastewaters from the power plant at Colstrip contain trace elements which could adversely affect groundwater quality. Consequently, it would be advisable to permanently isolate these wastes from the groundwater. Isolation could be accomplished by burial above the water table, on top of an impervious layer of clay or other lining, and under several feet of overburden. Only additional field monitoring can determine if the threat to groundwater quality is sufficient to justify the extra cost of providing permanent segregation where natural geologic formations fail to do so.

The EPA (1976) points out that permanent storage of solid and initially liquid wastes in holding ponds is not without peril. Effluents are concentrated substantially during storage. Accidental release, perhaps as a result of earthquakes, flash floods, or structural failure, would produce acute effects, as opposed to chronic effects of a small continuous discharge. The fate of storage sites after termination of the project requires attention also. Perhaps imbankments and impermeable membranes can be maintained during the active life of an energy-conversion facility, but there remains the question of who will be responsible for them when the plant is abandoned after producing 30 to 40 years' volume of wastes.

MUNICIPAL AND INDUSTRIAL WASTES

MUNICIPAL WASTEWATER

Increased mining and transportation of coal and the construction and operation of coal-conversion complexes and other facilities related to mining will initiate an influx of people into eastern Montana. This increase in population will burden the region with additional domestic waste. The chief pollutants in domestic wastewater are pathogens, organic matter, and nutrients. The organic material--dissolved, suspended, and settleable--can become foodstuff for the complex interdependent system of plant and animal life in receiving waters. If sufficient oxygen is present, the end products will be stable forms of carbon, nitrogen, sulfur, and phosphorus.

TABLE 22. Physical parameters of waters from Armells Creek and Montana Power Company ponds in and near Colstrip.

	Source of Water								
	Flyash Pond A 2/10/76	Bottom Ash Pond 2/10/76	Bottom Ash Pond 5/13/76	Dead Storage-Pond B 5/13/76	Cooling Tower Blowdown 2/10/76	Cooling Tower Blowdown 5/13/76	Fishing Pond 2/10/76	East Fork Armells Creek above Colstrip 2/10/76	East Fork Armells Creek below Colstrip 2/10/76
Temp	0.0	0.0						0.0	6.5
pH	4.6	10.22	9.79	8.09	7.77	8.37	7.96	7.79	7.72
SC	7007	2813	3806	3494	4605	3214	4464	2986	2508
TDS	7337	2375			4080		4315	2784	1988
Turb	14	21			105		32	11	44
TH	5596	1306			1822		2802	1764	1090
TA	2	43			102		355	448	307
NO_3-N	10.3	1.5			2.8		.06	.38	.15
PO_4-P	.015	.002			1.32		.015	.054	1.62
SAR	0.5	2.5			5.1		2.0	1.6	2.2
Ca	494	449			433		162	217	150
Mg	1060	45			180		582	297	174
Na	91	210			544		240	150	165
K	6.2	5.8			34		22	12	22
Co	.10	.03			.02		.04	<.01	<.01
Ni	.37	.08			.06		.06	.01	<.01
SiO_2	200	.50			83		2.2	12	25
Cd	.025	.005			.007		.007	.005	.003
Ba	.20	.10			.30		<.10	.10	.10
V	.65	<.10			0.1		<.1	<.1	<.1
Al	17	.65			2.3		.70	.15	1.4
Sn	<.50	<.50			.50		<.50	<.50	<.50
Hg	.0076	.0018			.0002		.0014	<.0002	<.0002
Cr	.07	.01			.05		.01	.01	.01
OH		1.2							
Se	.18	.051	.018	.008		.007	.009	.001	.007
As	.001	.004			.035		.004	.004	.004
Li	.35	.07			.09		.03	.02	.05
HNO_3	2	0			124		433	547	375
CO_3	0	23			0		0	0	0
Cl	15.8	18.8			78		25	0.7	61
SO_4	5650	1620			2720		2850	1560	1040
Fe	.63	.11			1.7		.45	.56	2.2
Mn	5.5	.02			.13		.35	1.2	.89
Zn	.23	.56	<.01	<.01	.56	<.01	<.01	.27	.03
Cn	.24	.01	.02	.03	1.1	.06	.02	.01	.04
B	32	24.8			.74		.50	.27	.50
Pb	.12	.05			.08		.07	.05	<.05
Sr	6.9	5.0			8.4		4.8	9.3	8.5
F	8.4	.46			2.6		.15	.22	1.2
Sb	.64	.10			.10		.10	<.01	<.01
Ag	<.01	<.01			<.01		.01	<.01	<.01
Be	.01	<.01			<.01		<.01	<.01	<.01
Mo	<.05	<.05			<.05		<.05	<.05	<.05

NOTE: All measurements expressed in mg/l.

In the absence of oxygen, on the other hand, decomposition will be accompanied by unsightly scum, sludge, and offensive odors. Since natural streams contain a limited quantity of dissolved oxygen (about 5-12 mg/l) and untreated domestic wastes usually require 200 mg/l or more of oxygen for decomposition, a large dilution factor or extensive treatment before discharge is required to prevent depletion of a stream's oxygen supply and the resultant destruction of fish. The goal of modern treatment processes is to provide a favorable environment for the growth of organisms which will perform most of the decomposition before the wastewater is discharged to the receiving waters.

Even with normal (secondary) treatment, however, the effluent will contain nutrients, principally compounds of nitrogen and phosphorus, which can overfertilize plants in the water and cause unsightly algae blooms. Unchecked, the result is premature aging of lakes and streams--a process called eutrophication. It brings changes in water quality, depletion of oxygen, and replacement of desirable fish species with less desirable species. If eutrophication is a serious threat, advanced treatment processes may be required to remove the nutrients from wastewater.

Karp and Botz (1975) and Karp et al. (1975, 1976) have described thoroughly the 46 existing wastewater treatment facilities in the Yellowstone Basin. The low population density, availability of land, and the minimal maintenance requirement have made lagoons the favored type of domestic wastewater treatment facility. Most towns use multicell lagoon systems to treat their domestic wastewater, although Billings has a complete mix activated sludge system and Livingston and Laurel have primary treatment plants. All towns that discharge from their treatment systems are under the Montana Pollutant Discharge Elimination System (MPDES) permit program that placed them on a compliance schedule to meet requirements of federal laws for secondary treatment by July 1, 1977. However, the degradation of streams by municipal wastewater discharges is decreasing as communities upgrade their treatment processes (Karp et al. 1975). The 208 plans will identify treatment systems that may require upgrading and expansion as a result of anticipated population increases.

Localized problems may occur where: (1) population increases are so rapid that existing facilities become overloaded before the community can expand its treatment facilities, or (2) domestic waste from individual or clustered dwellings (such as mobile home courts in unincorporated areas) may, because of overloaded or improperly designed treatment systems, reach a watercourse. Septic tank effluents also may have a significant impact on groundwater systems. Soil has a natural renovative capacity for septic tank effluent, but where the density of septic tanks is high, this capacity may be exceeded, polluting the groundwater system. Advance planning and strict enforcement of existing zoning and sanitation laws can minimize these problems.

INDUSTRIAL WASTEWATER

Karp and Botz (1975) and Karp et al. (1976) identified 25 industrial dischargers in the basin, including three oil refineries, two coal-fired power plants, two sugar refineries, and several miscellaneous industries such as meat packing plants, oil well fields, and coal mines. All are under the MPDES permit program and are following schedules to comply with requirements of the 1972 Federal Water Pollution Control Act Amendments (FWPCAA), which call for use of the "best practical control technology" by 1977, "best available control technology" by 1983, and "no discharge of pollutants" by 1985.

At present, industrial wastewaters are a decreasing or stable problem. Water quality in the Laurel-Billings reach of the river, which receives wastes from three oil refineries, one steam generating plant, two municipal wastewater treatment plants, two water treatment plants, a sugar beet factory, two meat packing plants (that pretreat wastewaters before discharging to the Billings wastewater treatment plant), and several storm drains, has improved markedly in recent years as modern pollution control techniques have been adopted by industries and by the City of Billings (Klarich 1976). Improvement should continue in the future as industries further reduce their waste discharges in response to deadlines established by the 1972 FWPCAA. Problems of new coal-energy industries are described in previous sections.

CONTROL OF MUNICIPAL AND INDUSTRIAL WASTEWATERS

Under existing federal law all publically owned treatment works must have employed the equivalent of secondary treatment by July 1, 1977, best practicable waste treatment technology by 1983, and eliminate discharges of waste by 1985. Karp et al. (1975, 1976) and Karp and Botz (1975) reviewed the performance of all community-owned treatment works in the basin and concluded that: (1) the degradation of streams by municipal wastewater is decreasing as treatment processes are upgraded, and (2) the potential for correction of problem areas is good; the principal need is for additional federal grant funding.

Several techniques are available to upgrade the effectiveness of the lagoons serving the majority of communities in the basin. Methods include:

1) construction of sufficient capacity so that no discharge occurs and all influent evaporates;

2) mechanical aeration to add oxygen to a system;

3) use of rock or intermittent sand filters to "polish" the effluent;

4) application of effluent to land;

5) addition of chemicals to aid in treatment; and

6) biological harvesting to control effluent solids and nutrients.

Further descriptions of these and other methods are given by Lewis and Smith (1973) and Middlebrooks et al. (1974). Thus, municipalities in the basin should be able to achieve secondary treatment as grant funds become available.

Industries, like municipalities, are under schedules established by the 1972 FWPCAA to reduce and eventually eliminate discharges of pollutants into state waters. Substantial progress has been made through combinations of the following practices:

1) modification of industrial processes to reduce the volume and nature of wastewaters; e.g., recycling and inline treatment;

2) installation of more refined treatment processes to reduce pollutants in the effluent; and

3) rerouting of industrial wastewaters, perhaps after pretreatment, into municipal treatment systems.

The Yellowstone River's water quality has improved significantly in recent years as municipalities and industries have adopted better methods of handling wastewaters.

IRRIGATION RETURN FLOW

Salt is a product of geologic weathering. Precipitation and drainage transport salt into streams and rivers and maintain the quantity of dissolved minerals in the soil at levels which allow plant growth. Thus, through the ages, salt from the watershed has been carried to the ocean by rivers. In changing from natural vegetation to irrigated croplands, dissolved salts as well as water are diverted to the land. If the salt is not removed the land eventually will become too saline for continued agriculture. Therefore, sound agricultural practices dictate that a salt balance be maintained: all salt in the diverted water must be returned to the stream. Since the river will have less water (some having been consumed by evapotranspiration), the concentration of salt will be increased downstream of the irrigated area. Where excess water is applied to the land or the soils contain excessive soluble salts, irrigation return flows may dissolve additional salt and carry it into the stream, thereby forcing the river to carry more salt with less water. Each successive diversion and irrigation cycle on a stream further increases the salt concentration. Irrigation return flows also may deteriorate in quality through the presence of fertilizers, pesticides, and suspended solids acquired during the irrigation cycle.

The effects of irrigation return flows on water quality have been well-studied in many parts of the western United States (Utah State University Foundation 1969, Scofield 1936, Pillsbury and Bloney 1966, Sylvester and Seabloom 1963, Eldridge 1960). Generally, research was directed at areas with the greatest water quality problems, such as Imperial Valley, California and the Colorado River Basin. Regions endowed with abundant high water quality, such as the Yellowstone River, have received little attention from researchers; consequently, possible effects of irrigation on water quality in the Yellowstone River have not been documented. The United States Bureau of Reclamation (USBR) has completed some unpublished studies on irrigation return flow in the Wyoming portion of the basin (Madsen 1975). Another USBR project has collected extensive data on quantity and quality of diversions and return flows in the Yellowstone Basin in both Wyoming and Montana, but final results are not yet available (Manfredi 1976). The state WQB (1975) has collected and analyzed water quality samples from miscellaneous irrigation return flows in the Yellowstone Valley below Billings.

Data from the USBR projects and the state WQB indicate that salt concentration in the irrigation return flow may be several times higher than that of the applied water. The USBR data, for example, revealed concentration factors (salt concentration in irrigation return flow divided by salt concentration in applied water) ranging from 1.8 to 3.1 (Manfredi 1976) in surface return flows. Returns identified as subsurface concentrated salts by a factor of 4.9.

These concentration factors result from two processes: (1) the extraction of essentially pure (nearly distilled) water by plants in their growth processes, which concentrates the dissolved salts in the water remaining in the soil, and (2) the leaching of additional salts ("salt pickup") by water as it percolates through the soil. By measuring the volumes and TDS of diversions and return flows on an irrigated area, it is possible to compute the salt pickup. Data from Madsen (1975) indicate that salt pickup ranged from 0.84 to 8.73 tons per acre per year in several USBR projects in Wyoming. Incomplete data from Manfredi (1976) reveal gross estimates of less than 0 (indicating that salt is accumulating in the soil) up to one-half ton per acre per year salt pickup in various portions of the Yellowstone Basin in Montana. These estimates are somewhat low because: (1) most measurements were made on surface return flows which have less opportunity to leach salts from the soil profile than subsurface return flows, and (2) measurements were terminated in early fall, whereas subsurface returns may continue for several months after irrigation and surface returns cease.

Gross estimates of salt pickup between Billings and Sidney can be obtained from table 23, which summarizes water and TDS discharges of the Yellowstone River and major tributaries. For example, if the contributions from the Bighorn, Tongue, and Powder rivers are subtracted, table 23 reveals that the area along the mainstem of the Yellowstone between Billings and Sidney contributed 892,986 tons of salt and 228,010 net acre-feet of water to the river. These

TABLE 23. Summary of salt and water discharges in the Yellowstone River Basin, 1944-1973.

Station	Water Discharge (acre-feet)	Total Dissolved Solids (Tons)	(mg/l)
Yellowstone River & Billings	5,276,494	1,306,038	182
Bighorn River near Bighorn	2,596,214	2,076,140	588
Yellowstone River near Miles City	8,240,640	4,169,105	372
Tongue River at Miles City	289,151	178,533	454
Powder River near Locate	335,067	518,121	1,137
Yellowstone River near Sidney	8,724,936	4,971,818	419

NOTE: Values were measured or simulated based upon relationships developed from measured data.

data suggest that the additional inflow (228,010) contained an average of 3.92 tons per acre-foot, or 2,880 mg/l. However, records of streams in eastern Montana indicate that the TDS of surface runoff is about 1,200-1,300 mg/l. Therefore, surface runoff could account for only 40 percent to 50 percent of the salt increase. Assuming that 45 percent of the 892,986 tons result from surface runoff, 491,142 tons can be attributed to other sources: groundwater discharge, seeps, springs, and irrigation return flows. If all of it were attributed to the 291,985 acres of irrigated land along the mainstem of the Yellowstone, salt pickup would be 2.12 tons per acre.

Such a gross estimate, however, is somewhat misleading. Table 23 shows that most of the increase in salt load occurs between Billings and Miles City. Between Miles City and Sidney (adjusting for the higher salt loads contributed by the Tongue and Powder rivers), the Yellowstone gains only 106,000 tons of salt per year, but loses 140,000 acre-feet of water. Therefore, salt pickup cannot be estimated for the Miles City-to-Sidney reach. One can conclude only that: (1) the salt load generally increases between Billings and Sidney, (2) irrigation along the mainstem of the Yellowstone contributes an average salt pickup of no more than two tons per acre per year, and (3) the salt pickup varies between different parts of the basin; some irrigated lands may contribute several tons per acre and others may remove salt and store it in the soil.

Irrigation may also change the concentration of suspended solids, depending upon TSS levels in the applied water, the method of applying the water, type of soil, tillage methods, slope, type of drainage system, and similar factors. Preliminary data from Manfredi (1976) indicate that TSS may be increased or decreased by the irrigation cycle. In some reaches of the Yellowstone, TSS of surface return flow increased by a factor ranging from 1.1 to 4.9; in other reaches or tributaries, TSS was actually lower in the surface return flow than in the applied water. In subsurface returns, TSS should be low because of the filtering action of the soil. Subsurface drainage in the lower Yellowstone Basin averaged only 6 mg/l TSS and 254 mg/l in the applied water.

If it is assumed that new irrigation systems will be more efficient than existing systems, surface return flow should be minimal. Most return flow will reach the stream by deep percolation through the soil. Consequently, such return flows should be characterized by low concentrations of TSS but high concentrations of TDS. Sprinkler irrigation on slopes, however, could have the opposite effect--significant surface return flows high in TSS and little subsurface return flow.

CONTROL OF WASTEWATER FROM IRRIGATION

The principal method employed to reduce salt pickup is to reduce the volume of subsurface return flows. Seepage losses can be reduced by lining canals and laterals. Deep percolation losses can be reduced by improved irrigation methods that minimize over-irrigation and uneven applications of water. Tile drainage can be installed immediately below the root zone, thus intercepting percolating waters before they have the opportunity to seep through subsurface soils and dissolve additional salts. Highly mineralized return flows can be conveyed to evaporation ponds. Similarly, silt-laden return flows could be stored temporarily in a sediment basin to allow some of the silt to settle out before the water is discharged. In an extreme case, irrigation return flows could be treated with coagulants in holding ponds to remove suspended solids or by desalinization facilities to reduce TDS. Treatment is expensive, however, and is not usually practical. The practices most likely to reduce the adverse effects of irrigation return flows in the Yellowstone Basin are those involving better water management: lining of ditches, land leveling, converting to sprinkler irrigation, avoiding the over-application of water, and monitoring of soil moisture.

NONPOINT SOURCES OF POLLUTION

The Montana DHES discussed problems of nonpoint pollution in the Yellowstone River Basin in its Water Quality Inventory and Management Plans (Karp and Botz 1975, Karp et al. 1975, 1976). Agriculture, runoff from urban areas, construction projects, inadvertent spills, and natural phenomena were identified as activities which contribute nonpoint pollution (table 24).

TABLE 24. Nonpoint waste sources and characteristics in the Yellowstone River Basin.

Activity	Waste Characteristics
Irrigation return flows	Dissolved and suspended solids, pesticides, nutrients, heat
Runoff from pasture lands	Animal wastes, sediment
Runoff from saline seep areas	Salts, sediment
Runoff from cultivated land	Fertilizers, pesticides, dissolved salts, sediment
Storm drains and urban runoff	Oil and grease, coliforms, biological oxidizable material, suspended solids, toxicants
Construction projects, streambank riprapping	Sediment, equipment wastes
Coal mining	Dissolved and suspended solids, trace elements, equipment waste

SOURCE: Karp and Botz (1975), Karp et al. (1975, 1976).

According to the Montana DHES, agricultural nonpoint discharge is the most serious problem in the basin, followed by storm drains and urban runoff, construction projects, accidental discharges, and natural nonpoint sources. Agricultural runoff and runoff from saline seep areas are the most significant problems in the lower portion of the basin, particularly below Glendive.

Unfortunately, available data are not sufficient to quantify nonpoint pollution from the individual sources. The cumulative effect, however, is reflected in the gradual deterioration in water quality between Corwin Springs and Cartwright, North Dakota. Several recent and on-going projects will provide further information on the nature and magnitude of nonpoint pollution problems in Montana. Kaiser et al. (1975), in the first comprehensive report on saline seep in Montana, listed 28,000 acres in the Yellowstone Basin affected by saline seep and 24,700 additional acres with irrigation salinity problems. One of their conclusions was that "some current land uses are creating salinity problems, and, if left unaltered, will pose economic and environmental problems to future generations." The environmental problems include salinization of groundwater and streams.

Another report by the state WQB (Karp et al., in preparation) identifies and quantifies nonpoint sources in the Billings area. In addition, the 208 planning efforts by the mid-Yellowstone and Yellowstone-Tongue area planning organizations (APO's) and by the state WQB on areas not covered by the regional APO's are including nonpoint pollution as a major study item.

CONTROL OF POLLUTION FROM NONPOINT SOURCES

Water pollution from nonpoint sources can be controlled by the use of appropriate management practices. Some sections in this report describe techniques applicable to irrigation return flows and surface mining of coal--two major sources of nonpoint pollution. According to the EPA (1973), goals of reducing water pollution from agricultural land may be achieved by containing erosion at the source by means of effective conservation practices applied to the land, and by applying fertilizers and pesticides in appropriate amounts at the proper times and in the proper places.

Methods used to control wastes from livestock are described by Manges et al. (1975) and Horton et al. (1976). More difficult to control than livestock wastes will be the management of polluted runoff from urban areas--"runoff generated by precipitation which washes and cleanses an urban environment, and then transports the dirt, filth, etc. to the nearest natural or man-made watercourse" (Colston 1974). Urban runoff can be: (1) treated in municipal wastewater treatment plants (but a high volume of runoff during a short time interval may overload treatment facilities and result in ineffectual treatment), or (2) stored temporarily in retention basins before being released to a stream or to wastewater treatment facilities. Both methods are relatively expensive and not entirely satisfactory.

It is hoped that the 208 plans will identify nonpoint pollution problems in the Yellowstone River Basin and recommend feasible control techniques.

SLURRY PIPELINES

Slurry pipelines would transport a mixture of approximately one-half fine coal and one-half water, by weight. An economically sized facility would require 7,500 acre-feet to transport ten million tons of coal per year. The initial terminal would require storage facilities for large volumes of both coal and water. Water storage should present no pollution problem. If treatment of the water is required, various chemicals, solids, and sludges may have to be handled. Water may leach through coal piles and contribute suspended and dissolved contaminants to local water supplies. One remedy involves storing the coal on impermeable sites with a settling basin downstream to collect surface runoff. Currently, the export of coal via slurry pipelines is not a beneficial use under Montana water law.

Existing situation

YELLOWSTONE RIVER MAINSTEM ABOVE THE MOUTH OF THE CLARKS FORK YELLOWSTONE RIVER

The Yellowstone River drainage above the confluence of the Clarks Fork River has been defined as the secondary study area, and only the mainstem of the region has been inventoried in this survey. Water quality data are available from the USGS, which has maintained three monitoring stations on this reach of the stream; however, these data are not extensive, particularly for certain parameters, because the USGS stations have been in operation for only a short period of time (table 2). Supplemental data, collected as a part of water quality runs on the mainstem (Peterman and Knudson 1975) and from other programs (Karp et al. 1976a) are available from the state WQB for several locations on this segment of the river (table 4). Data from the two agencies were combined for this inventory to provide information for four stations or reaches of the Yellowstone from Corwin Springs to Laurel, Montana: at Corwin Springs, near Livingston, between Big Timber and Columbus, and at Laurel (above the Clarks Fork), in downstream order. Statistical summaries of the major parameters are included in tables 25-28 for these locations. In some cases, data obtained by the state WQB from closely related sites were combined in order to expand the data base. Thurston et al. (1975) also present some water quality information for the upper Yellowstone, but these data were not reviewed for the current survey.

As indicated in table 25, the Yellowstone River at Corwin Springs has a sodium-bicarbonate water through most seasons. The waters are generally soft and would be classified as ideal for municipal supply (Bean 1972). The ionic composition is probably a reflection of the river's proximity to its mountainous headwaters. Yellowstone National Park streams are often quite sodic (Klarich and Wright 1974, Rasmussen 1968, USEPA 1972, Wright and Mills no date) as a result of the park's thermal discharges that flow over rhyolite bedrock composed of sodium feldspars; calcium-containing rocks are relatively rare (Boyd 1961, Roeder 1966). The sodic nature of the Yellowstone at Corwin Springs is most distinct during low-flow periods when a large portion of the discharge in the river below Gardiner (north park entrance) is due to the inflow from Yellowstone Park with reduced flows in Montana's tributary streams. The high concentrations of fluoride and phosphorus in the river at Corwin Springs and the purported arsenic problem of the upper Yellowstone River (Montana DHES 1975, Montana DHES 1976) are also probably related to influences originating within Yellowstone Park, e.g., from geyser activity.

During the spring high-flow period of the Yellowstone at Corwin Springs, the waters have a higher ratio of calcium to sodium than at other seasons (table 25), probably related to the greater flows and increased influence of the tributary streams at this time. Yellowstone tributaries in Montana are largely calcium bicarbonate above the confluence of the Clarks Fork River (Karp et al. 1976). The effects of these tributary streams, e.g., the Shields, Boulder, and Stillwater rivers which drain the Crazy, Absaroka, and Beartooth mountains, are also evident in the mainstem in a downstream direction below Corwin Springs through the increased flows of the river; in addition, calcium

TABLE 25. Summary of the physical parameters measured in the Yellowstone River at Corwin Springs.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	13	1320	4910	1920	12	854	3650	1045	6	978	1560	1095	12	3610	22,400	8190
Temp	11	5.5	17.2	8.0	12	0.0	5.0	1.8	6	4.5	9.0	7.3	12	4.5	17.0	10.8
pH	12	6.8	8.6	7.85	12	7.0	8.2	7.75	6	6.9	8.7	8.4	12	6.1	8.0	7.5
SC	14	154	255	220	12	230	300	280	6	240	300	283	13	80	161	130
TDS	13	108	178	151	12	156	218	190	6	93	220	186	12	60	130	86
Turb	4	1.0	3.8	3.2	5	2.0	5	3.0	2	4.0	6.0	5.0	6	8.0	50	11
TSS	1	--	--	9.4	1	--	--	2.0	0	--	--	--	3	17	48.5	38.9
DO	12	8.4	11.8	10.1	12	10.6	13.2	12.0	6	10.7	12.2	11.4	12	8.1	11	9.7
BOD	11	0.6	1.6	1.0	12	0.6	3.0	1.4	6	0.9	1.5	1.2	12	0.6	2.6	1.1
FC	7	4	88	30	7	0	42	11	4	2	7	5	8	2	30	<10
Ca	10	12	18	15	8	15	23	18	4	17	20	19	9	7.9	20	10
Mg	10	3.4	6.0	5.0	8	4.7	7.1	5.6	4	5.8	6.4	6.1	9	1.2	3.9	2.9
TH	13	46	68	58	12	58	87	73	6	66	76	73	12	28	44	35
Na	10	12	22	19	8	13	28	24	4	15	26	23	9	6.0	14	10
K	1	--	--	2.5	1	--	--	5.5	0	--	--	--	2	1.6	2.5	2.1
SAR	2	0.7	1.1	0.9	1	--	--	1.5	0	--	--	--	3	0.5	0.6	0.5
HCO_3	2	59	70	65	1	--	--	79	0	--	--	--	3	43	72	61
TA	11	47	114	58	10	59	83	72	4	68	72	71	10	17	59	39
SO_4	13	17	36	30	12	30	48	40	6	32	46	36	12	7.5	60	12
Cl	10	6.5	11	9.8	8	9.9	18	13	4	12	14	13	9	2.1	7.0	4.0
F	9	0.5	0.9	0.8	8	0.9	1.1	1.0	4	0.7	1.1	1.0	9	0.3	0.6	0.4
N	9	0.02	0.20	0.09	9	0.18	0.40	0.27	5	0.10	0.30	0.20	10	0.03	1.9	0.08
P	10	0.01	0.12	0.06	8	0.02	0.39	0.07	5	0.03	0.08	0.06	9	0.03	0.48	0.07

NOTE: Measurements given in mg/l.

TABLE 26. Summary of the physical parameters measured in the Yellowstone River near Livingston.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	32	1920	6190	3020	36	961	2350	1525	20	1240	2950	1630	44	1820	27,700	9090
Temp	6	5.0	15.3	7.0	5	0.0	3.5	1.5	5	6.5	11.0	8.5	10	4.5	17.0	13.0
pH	24	7.2	8.3	7.85	32	7.3	8.5	7.9	18	7.4	8.6	7.9	39	6.4	8.2	7.6
SC	29	160	273	213	32	232	334	284	18	219	329	278	42	93	272	141
TDS	29	105	189	145	32	154	216	185	18	143	205	181	42	68	176	92
Turb	1	--	--	2.6	1	--	--	2	0	--	--	--	3	8.6	18	15
TSS	1	--	--	9.7	1	--	--	2.0	0	--	--	--	3	26	83.8	66
DO	3	8.5	11.9	10.0	1	--	--	12.3	0	--	--	--	5	8.5	11.0	10.0
BOD	1	--	--	1.30	1	--	--	1.9	0	--	--	--	3	2.0	3.0	2.3
FC	1	--	--	0	1	--	--	7	0	--	--	--	3	5	80	10
Ca	29	14	23	19	32	21	30	24	18	19	27	23	42	9.2	24	12
Mg	33	4.0	8.2	5.6	32	5.9	8.9	7.7	18	5.7	8.5	7.4	48	1.7	7.1	3.8
TH	29	51	87	71	32	77	110	93	18	71	100	87	42	33	89	48
Na	29	11	21	16	32	17	25	20	18	15	24	21	42	4.9	18	8.6
K	27	2.1	5.3	3.3	32	3.6	6.7	5.0	18	3.6	6.4	5.0	39	1.2	6.3	2.1
SAR	29	0.6	1.0	0.8	32	0.8	1.0	0.9	18	0.8	1.1	0.9	42	0.3	0.8	0.5
HCO_3	29	70	116	94	32	98	131	110	18	83	120	107	42	44	111	63
TA	3	60	85	83	1	--	--	83	0	--	--	--	5	53	41	63
SO_4	29	10	34	25	32	24	50	35	18	26	47	35	42	5.8	34	12
Cl	29	3.8	8.8	7.1	32	7.6	14	11	18	6.6	12	11	42	1.0	11	3.4
F	27	0.5	0.8	0.6	32	0.7	1.3	0.8	18	0.5	0.9	0.8	40	0.2	0.7	0.4
N	27	0.0	0.09	0.01	29	0.0	0.39	0.13	18	0.0	0.13	0.03	42	0.0	1.2	0.01
P	15	0.0	0.19	0.05	17	0.0	0.15	0.03	8	0.01	0.08	0.04	15	0.01	0.06	0.04

NOTE: Measurements expressed in mg/l.

TABLE 27. Summary of the physical parameters measured on miscellaneous sites on the Yellowstone River between Big Timber and Columbus.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	2	2870E	5460E	4165E	1	--	--	1760E	No data available				3	4990E	15,200E	7890E
Temp	2	17.6	20.2	18.9	2	0.0	0.8	0.4					7	5.0	10.0	9.1
pH	5	8.30	8.39	8.30	2	8.14	8.23	8.19					7	7.63	8.02	7.89
SC	5	189	292	278	2	320	345	333					7	131	281	201
TDS	5	150	219	207	2	246	267	257					7	112	232	166
Turb	2	2.1	3.5	2.8	2	2	3	2.5					7	31	47	36
TSS	2	4.2	9.5	6.9	2	2	4	3.0					7	103	197	134
DO	5	9.0	11.2	10.1	2	12.4	12.9	12.7					7	9.7	10.9	10.0
BOD	2	1.0	1.1	1.1	2	2.6	2.9	2.8					7	1.7	4.1	3.1
FC	2	0	50	25	2	3	12	8					7	<10	150	50
Ca	5	19	29	27	2	32	35	34					7	16	39	27
Mg	5	5.1	9.6	7.3	2	7.1	9.3	8.2					7	1.9	8.0	4.8
TH	5	69	108	98	2	108	125	117					7	56	115	91
Na	5	12	17	15	2	23	23	23					7	6.0	16	9.7
K	2	2.5	2.7	2.6	2	4.1	4.3	4.2					5	1.7	2.1	1.9
SAR	5	0.6	0.7	0.6	2	0.9	1.0	1.0					7	0.3	0.6	0.4
HCO_3	5	91	129	115	2	126	143	135					7	70	143	104
TA	5	75	106	94	2	103	117	110					7	58	118	85
SO_4	5	13	34	29	2	42	42	42					7	11	27	16
Cl	5	5.3	6.9	5.7	2	9.9	11.6	10.8					7	1.0	3.1	2.5
F	2	0.5	0.5	0.5	2	0.6	0.8	0.7					7	0.2	0.2	0.2
N	5	<.01	0.04	0.01	2	0.20	0.21	0.21					7	0.05	0.78	0.23
P	5	0.01	0.04	0.02	2	0.01	0.02	0.02					7	0.03	0.22	0.04

NOTE: Measurements expressed in mg/l.

TABLE 28. Summary of the physical parameters measured in the Yellowstone River at Laurel above the Clarks Fork Yellowstone River.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	5	4030	713	5310	2	2500	3400E	2950E	5	2460	6500	3190	6	5510	50,900	16,150
Temp	6	14.5	20.8	15.3	3	0.1	4.5	1.0	5	1.5	13.5	8.0	9	6.5	19.5	14.5
pH	6	7.6	8.52	8.15	3	8.1	8.50	8.16	5	7.5	8.5	7.9	9	7.4	8.6	7.8
SC	7	204	315	245	3	324	410	342	5	238	337	310	9	115	443	170
TDS	6	128	199	151	3	206	309	247	5	128	201	183	9	60	291	123
Turb	5	1.3	4	3	2	5	5	5	5	3	70	30	9	2	100	30
TSS	5	1	16	12	2	8	9	8.5	5	8	169	89	9	9	472	106
DO	5	8.6	9.4	8.9	2	12.8	12.9	12.9	5	9.8	12.8	10.8	9	8.0	11.0	9.6
BOD	5	1.1	1.6	1.5	1	--	--	2.4	4	1.9	6.1	3.8	7	0.7	3.0	1.5
FC	5	3	86	50	2	2	10	6	5	0	57	30	8	0	660	24
Ca	2	18	21	20	3	32	39	33	2	32	32	32	5	12	37	26
Mg	2	5.9	13	9.7	3	9.5	12	10	2	9.1	9.2	9.2	5	2.9	14	5.2
TH	2	77	100	89	3	118	147	120	2	120	120	120	5	42	150	83
Na	2	12	15	14	3	21	26	22	2	19	21	20	5	5.1	13	11
K	1	--	--	2.3	2	3.8	3.9	3.9	2	3.5	4.0	3.8	4	1.7	2.3	2.1
SAR	2	0.6	0.6	0.6	3	0.8	0.9	0.9	2	0.8	0.8	0.8	5	0.3	0.8	0.5
HCO_3	2	96	117	107	3	134	155	144	3	134	142	141	5	58	143	97
TA	2	81	97	89	3	115	127	118	2	116	117	117	5	48	117	85
SO_4	2	15	29	22	2	43	63	53	3	35	42	39	5	7.9	69	17
Cl	2	4.7	5.5	5.1	2	8.0	8.6	8.3	3	7.1	8.7	7.8	5	1.0	4.2	2.9
F	1	--	--	0.4	1	--	--	0.7	0	--	--	--	3	0.2	0.2	0.2
N	6	0.0	0.13	0.04	3	0.04	0.42	0.06	5	0.01	0.38	0.07	9	0.0	0.36	0.01
P	6	0.01	0.06	0.03	3	0.02	0.05	0.03	5	0.0	0.28	0.14	9	0.03	1.8	0.12

NOTE: Measurements expressed in mg/l.

concentrations increase downstream while sodium levels in the river remain fairly constant from Corwin Springs to Laurel. As a result, the Yellowstone at Laurel is moderately hard with a calcium bicarbonate composition in all seasons (table 28). A gradual decrease in fluoride and phosphorus concentrations is also evident in the mainstem to Laurel due to a dilution by tributary streams which have relatively low concentrations of these constituents (Karp et al. 1976). Similarly, there is a small but consistent increase in magnesium levels downstream, accompanied by a decline in chloride concentrations from Corwin Springs to Laurel. This further suggests the gradual decrease of Yellowstone National Park influences by progressive inputs of tributary water. However, in all segments of the river above the Clarks Fork River, magnesium, potassium, and chloride are minor constituents of the water, with sulfate being the secondary anion.

A small downstream increase in median salinity of 10 percent to 45 percent, as expressed in terms of dissolved solids and specific conductance, is evident for the 158-mile segment of the upper Yellowstone between Corwin Springs and Laurel; however, this increase is not totally consistent between all sites or for all seasons. The increase in salinity is greatest during the May-July period (between 30 percent and 45 percent), lowest during the summer and spring (less than 15 percent), and intermediate during the winter (between 20 percent and 30 percent). In addition, dissolved constituent concentrations in the upper river are definitely flow-related, with higher levels generally obtained during the low-flow periods. The four sampling stations on the upper segment demonstrate a median difference in dissolved solids concentration between the May-July, high-flow period and the low flows of winter. However, none of the common ions have markedly high concentrations during any of the seasons or at any of the locations. Thus, the water in the upper Yellowstone River can be characterized as distinctively non-saline with maximum dissolved solid and specific conductance levels of 309 mg/l and 443 µmhos/cm (at Laurel); minimum values are 60 mg/l and 80 µmhos at Corwin Springs. On the basis of salinity and the common ions, the waters in the upper reach appear to be suitable for application to all major beneficial uses, including agricultural, municipal supply, and aquatic life.

As indicated in tables 15 and 16, SAR and specific conductance levels in water from the upper Yellowstone, along with the river's chloride, sulfate, and dissolved solids concentrations, indicate that the stream has a low salinity hazard and a low sodium or alkali hazard for irrigation. As a result, the Yellowstone in this reach has a Class I water suitable for application to all crop and forage plants, including the salinity-intolerant species (table 17). These waters may also be classified as good in relation to livestock, as they are excellent for the watering of all farm and domestic animals (tables 10-14). Common constituent concentrations in the upper river were well below the threshold levels established by the California State Water Quality Control Board (California WQCB 1963). Of the ionic constituents, only fluoride occasionally exceeded the California WQCB threshold levels for stock in a few samples from the river at Corwin Springs. This was generally not true at Livingston and further downstream due to the subsequent dilutions of fluoride by inputs from tributary streams. Even the occasionally high values of fluoride did not approach levels that would be limiting (a maximum of 1.3 mg/l versus the 6.0 mg/l standard), and fluoride concentrations in all samples were well below the criteria for livestock recommended by the EPA (USEPA 1973). As a result, fluoride and dissolved solids concentrations of the upper river are well within the prescribed limits for freshwater aquatic life.

Fluorides in the Yellowstone River above Laurel are below the recommended upper limits for human consumption and are well below concentrations that would constitute a rejection of public supply (table 9). Similarly, concentrations of dissolved solids and common constituents such as chloride and sulfate are considerably below the standards, criteria, and recommendations established by various agencies for drinking water and surface water, and municipal supply (USEPA 1973, USDI 1968, USDHEW 1962). In fact, the concentrations of these constituents and the soft water would make the river desirable as a water supply, according to the NTAC's recommendation (USDI 1968). The relatively high level of fluoride in the river at Corwin Springs is actually within the optimum range (USDHEW 1962) and may be advantageous in eliminating the need for accessory fluoridation. Thus, the occurrence of high fluorides in the upper Yellowstone, stemming from thermal activity in Yellowstone National Park, may not be as degrading to the river or to its beneficial use as has been suggested in other water quality surveys (Montana DHES 1975, Montana DHES 1976).

Turbidity and total suspended sediment (TSS) levels in the upper Yellowstone at Corwin Springs are low in comparison with other streams of the inventory area (table 25), even during the spring runoff period when the turbidity and TSS are highest (Karp and Botz 1975, Karp et al. 1975). This is also true of the river near Livingston (table 26) although there is a slight downstream increase in TSS between the two sites during high-flow periods. The low turbidity and relatively uncolored waters (color ranging between one and four units) indicate that the extreme upper reach of the Yellowstone is aesthetically pleasing during a large part of the year. In turn, the low TSS and TDS concentrations and the low turbidity of the Corwin Springs-Livingston reach describe a water potentially excellent for a freshwater fishery (Ellis 1944, European Inland Fisheries Advisory Commission 1965). Furthermore, the maximum temperatures of the Corwin Springs-Livingston reach (tables 25 and 26) and the temperatures recorded by the USGS for the stream at Livingston are typically below the critical maximum temperatures designated for $B\text{-}D_1$ and $B\text{-}D_2$ class streams (table 8). For example, since 1970, only 9.7 percent of the once-daily temperature measurements at Livingston exceeded 19.5°C for the June-to-September, warm-weather period; 4.8 percent equalled or exceeded 20.0°C (USDI 1966-1974a). As a result, the upper Yellowstone fishery should be salmonid and cold-water, in accordance with the river's classification as a blue ribbon trout stream above Big Timber (Berg 1977).

Turbidity and TSS concentrations are also low during periods of reduced flow through the lower segment of the upper river (tables 27 and 28), but there is a distinct downstream increase in these parameters during the spring and at high flows. This does not detract, however, from the value of the river as a water supply for municipalities, as the stream's turbidities, with only a few exceptions, are below the permissible criteria for surface supply throughout the year at all locations. The major effect, therefore, of the increased TSS levels may contribute to a degradation and alteration of the river's fishery, as turbidity-TSS levels at Laurel would classify the stream as only fair through the March-to-July period (European Inland Fisheries Advisory Commission 1965). In addition, the river tends to warm below Big Timber.

This, in turn, may also reduce the potential of the river as a cold-water fishery. Median temperatures were usually higher at Laurel than at Corwin Springs (except in the winter), and temperatures greater than 19.5°C were more common in the Laurel segment. Since 1970, 16.7 percent of the minimum daily temperatures in the Yellowstone at Billings, about 36 river miles below Laurel, were in excess of 19.5°C with 11.5 percent equal to or greater than 20.0°C (USDI 1966-1974b); this contrasts with the smaller, once-daily percentages obtained for the Yellowstone at Livingston. These varying observations correspond to the classifications of the river between Big Timber and Laurel to Custer as a transition zone fishery, changing from a cold-water stream above Big Timber to a warm-water stream below the confluence of the Bighorn River (Peterman 1977).

The Yellowstone River above Laurel appears to be non-eutrophic as concentrations of phosphorus and nitrogen were usually below the designated critical levels (0.05 mg P/l and 0.35 mg N/l). For the most part, nutrient concentrations, particularly nitrogen, were well below the reference levels specified by the EPA (USEPA 1974b)--0.1 mg P/l and 0.9 mg N/l. On the basis of nutrient concentrations, the river at Corwin Springs makes the closest approach to eutrophy, particularly during the winter-to-spring (table 25). Due to Yellowstone National Park influences, median phosphorus concentrations in the river at this upper station exceeded the reference criteria; however, median nitrogen concentrations were below this value, apparently preventing eutrophication. Below Corwin Springs, phosphorus levels generally tended to decline downstream with the exception of a marked increase at Laurel during the March-to-July period (table 28). These high phosphorus concentrations at Laurel might have been derived from confluences to the river below Columbus, possibly in association with high flows and sediment inputs, as TSS levels were also high during this period. However, extremely low nitrogen concentrations again apparently precluded the development of eutrophic conditions. Other than this spring-summer pulse of phosphorus at Laurel, no seasonal trends were evident in this variable at any of the stations.

Nitrogen concentrations also tended to decline downstream from Corwin Springs, and they were noticeably low in the river at Laurel. Nitrogen levels were consistently low during the summer period when the river's flora would be in full bloom. There appeared to be a nitrogen peak during the dormant winter season when biotic uptake would be at a minimum, and concentrations were high in the spring. The general declines in phosphorus and nitrogen downstream might have been due to tributary dilutions below Corwin Springs or to the progressive use of these nutrients by the stream's periphyton. The upper river appears to be more nitrogen- than phosphorus-limited. The average median concentration of phosphorus equalled 109 percent of its reference level in contrast to 28 percent for nitrogen. These observations of nitrogen limitation and non-eutrophy in the upper Yellowstone are in accordance with Klarich's (1976) conclusions concerning the Yellowstone between Laurel and Huntley.

Due to the low total alkalinities of the upper Yellowstone (the state average is 134 mg/l $CaCO_3$) (Botz and Peterson 1976), the river would be sensitive to acid discharges. However, the river does not appear to be affected in this manner since the ranges of pH in the stream are closely coincidental with the range that is typical of most natural waters: 6.0 to 8.5 units (Hem 1970). Median pH's for all locations and seasons are well within the standards established for $B\text{-}D_1$ streams (table 8); thus, pH should not detract from the river's beneficial use as a sport fishery or for livestock and municipal supply. Seasonal trends in pH are not obvious, although relatively low pH values were obtained during the high flows in association with the reduced alkalinities at this time. In addition, median pH tended to decline upstream in correspondence with the decrease in total alkalinity and bicarbonate.

Dissolved oxygen (DO) levels in the upper Yellowstone are also in accord with the stream's value as a fishery and municipal supply. Minimum DO concentrations at all stations, even during the warm-weather periods, were well above the critical value specified by the state's water quality standards for $B\text{-}D_1$ streams (Montana DHES undated). Median DO concentrations were very near saturation in the upper Yellowstone (table 29); individual samples varied between 92 percent and 124 percent of saturation. This aspect and the generally low five-day BOD's of the river samples indicate no extensive organic pollution in the upper Yellowstone drainage. For example, about 90 percent of the samples had BOD_5 values less than or equal to 3.0 mg/l, while 98 percent had BOD_5 values less than 5.0 mg/l. The general absence of allochthonous organic matter in the upper river is confirmed by the low total organic carbon (TOC) and chemical oxygen demand (COD) concentrations of the samples (table 29). Median TOC levels in the upper Yellowstone were actually less than an average value (10 mg/l) obtained from unpolluted waters (Lee and Hoodley 1967).

In addition to the data available for the major parameters summarized in tables 25-28 for the upper Yellowstone River, some data are also available for various trace elements, such as metals, and for other constituents such as color, TOC, COD, and MBAS (methylene blue active substances). Since these data are generally not abundant, stations were combined to expand the data base of these parameters into two reaches of the upper river--a reach above Livingston to Corwin Springs, and one extending from Livingston to Laurel. The total recoverable and the dissolved concentrations of the trace elements were compiled separately, as applicable, because a metal's dissolved component represents a subset of its total recoverable concentrations, i.e., total recoverable should exceed dissolved. A summary of the trace element concentrations and the other minor constituent levels for the two reaches are presented in table 29.

None of the miscellaneous, non-metal constituent concentrations in the upper Yellowstone suggest pollution problems. Silica concentrations were high above Livingston, which is probably accounted for by the alumino-silicate type of rock in the stream's drainage in Yellowstone National Park (Boyd 1961). However, silica concentrations declined below Livingston, and the median value in this reach was equal to the median value for the nation's surface waters (Davis 1964). Cyanide (CN) was not detected in any of the samples examined for this constituent, and the general lack of MBAS reactions in the samples indicates an absence of synthetic detergents in the river (USDI 1966-1974b). The median oil and grease value was below state standards (table 8), although one of the samples collected for this analysis exceeded this criteria. Fecal coliforms were low at all stations for most of the year, indicating a general absence of marked municipal pollution reaching the river. Fecal levels were below state criteria, and fecal coliforms, along with boron, were well beneath the recommended levels of the NTAC and the EPA for public (and livestock) water supplies (table 9). In addition, boron concentrations in the upper

TABLE 29. Summary of trace element and miscellaneous constituent concentrations measured in the Yellowstone River above the confluence of the Clarks Fork Yellowstone River.

	Yellowstone River above Livingston								Yellowstone River between Livingston and Laurel			
	Total Recoverable Metals and Miscellaneous Constituents				Dissolved Metals				Total Recoverable Metals and Miscellaneous Constituents			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
COD									16	1	40	11
Color	5	1	4	3								
CN	7	0.0	0.0	0.0								
DO[a]									16	92	124	102
MBAS	12	0.0	0.1	0.0								
NH_3-N	20	0.0	0.29	0.06					15	0.02	0.43	0.07
O&G									2	3	13	8
Si	26	17	24	20					5	0.0	16	14
TOC	2	3	6	4.5					18	2.1	14	5.7
Ag					12	0.0	.001	0.0				
As	4	<.01	.031	.020	11	0.0	.030	.012	10	<.01	.022	.011
B	18	<.1	.34	0.1	46	.054	.630	.316	19	<.10	0.29	0.12
Ba					4	0.0	0.0	0.0				
Be					10	0.0	0.0	0.0				
Cd	19	<.001	<.01	<.001	12	0.0	.001	0.0	23	<.001	<.01	<.001
Co					4	0.0	0.0	0.0				
Cr	8	0.0	<.01	0.0	6	0.0	.001	0.0	6	<.01	<.01	<.01
Cu	19	<.01	0.01	<.01	12	0.0	.056	.008	27	<.004	0.040	<.01
Fe	19	.10	1.8	.42	95	0.0	.326	.020	27	.05	9.8	.55
Hg	12	<.0002	0.0003	<.0002	7	0.0	.0018	.0001	13	<.0002	0.0012	<.0002 (0.15?)
Mn	18	<.01	0.26	0.04	23	0.0	.760	.013	26	<.01	0.32	0.11
Mo					12	0.0	.009	.003				
Ni					12	0.0	.023	.001				
Pb	19	<.01	<.05	<.05	12	0.0	.005	0.0	26	<.05	0.04	<.05
Se					7	0.0	.006	.004	4	0.0	.002	.001
Sr	15	<.10	0.25	0.08	4	.148	.224	.208	16	<.03	0.87	0.19
V	15	<.05	<.5	<.5	4	.001	.002	.001	16	<.05	<.5	<.1
Zn	19	<.01	0.03	<.01 (1.1?)	12	0.0	.050	.010	27	<.01	0.58	<.01

NOTE: Measurements expressed in mg/l.

[a]DO expressed as percentage of saturation.

Yellowstone are in accordance with the classification of the stream as a Class I water for irrigation, suitable for application to boron-sensitive crops (tables 15-17).

Ammonia concentrations were similar in both reaches of the upper river; ammonia levels were well below the permissible criteria and recommendations of the NTAC and the EPA for domestic use. At the median pH levels of the river, between 7.5 and 8.4 units, about two percent to twelve percent of the ammonia concentrations listed in table 29 would be in an un-ionized form and potentially toxic to aquatic life (USEPA 1973); this would afford median concentrations of un-ionized ammonia in the stream between 0.001 mg N/l and 0.008 mg N/l and a maximum concentration of 0.05 mg N/l. However, these median values are less than the criteria listed by the EPA for this constituent in relation to freshwater aquatic life (table 19), and they afford a minimal risk to the river's biota.

In addition to its potential toxicity, ammonia can be used by aquatic plants as a nutrient and is a potential eutrophicant, as it may add to a water's nitrogen concentration. However, this does not appear to be true in the upper Yellowstone as median ammonia concentrations in the river would be at levels inadequate to increase inorganic nitrogen to the point of causing eutrophy. For example, the median $(NO_2 + NO_3)$-N concentrations of the river at Corwin Springs in the winter (maximum eutrophic potential) plus the median NH_3-N value equalled only 0.33 mg N/l, below the critical reference levels.

The generally greater total recoverable (TR) levels of a trace element over its dissolved component are illustrated in table 29 for the As, Fe, and Mn data. High TR concentrations may indicate a water quality problem, but not the specific problem because a large portion of the metal may be associated with particulate matter and therefore not free in the water. High dissolved concentrations of a metal would afford a more accurate diagnosis. However, low TR (and dissolved) levels of a trace element would definitely indicate the absence of those problems in a water associated with that particular constituent. On this basis, even though many of the trace elements were detected in low levels at least in some of the samples from the upper Yellowstone, most do not appear to be at concentrations sufficient to detract from the water's use. As indicated in table 29, this would include most notably: Ag, Ba, Be, Cd, Co, Cr, Cu, Pb, and Zn; concentrations were usually well below the various reference criteria for aquatic life, for drinking water and public supply, and for livestock water and irrigation.

Of the various metals, iron and manganese were most commonly found in high concentrations in the upper Yellowstone samples; the high TR levels were generally obtained in conjunction with high river flows and in association with the larger sediment concentrations. Total recoverable Fe and Mn concentrations often exceeded the criteria for drinking water and public supply, and the former parameter often exceeded the recommended maximum concentration for freshwater aquatic life. As noted previously, however, TR concentrations are suggestive of potential problems only; the median dissolved concentrations of these two constituents would indicate that Fe and Mn, for the most part, do not detract from the beneficial uses of the upper river. This also applies to most of the other trace elements that were commonly found in detectable concentrations--B, Mo, Ni, Se, Sr, and V, and possibly As. Arsenic levels were also relatively high in the upper river, corresponding to the designation of this parameter as a potential nonpoint water-quality problem originating from Yellowstone National Park and adjacent areas (Montana DHES 1975, Montana DHES 1976). Although median concentrations were above the American Public Health Service standard for drinking water (USDHEW 1962), they were below the permissible level designated by NTAC and below the recommendation of the EPA for public water supplies (table 9). In addition, arsenic concentrations tended to decline downstream, posing a less critical problem for the river at Laurel, and this parameter does not appear to be at hazardous levels for the river's biota.

Of more immediate interest are the occasionally high TR levels obtained for mercury in excess of the criteria for aquatic life and public supply. Particularly notable is the fact that the high median dissolved concentrations of mercury are greater than the average level recommended for freshwater life by the EPA (table 19). Thus, high mercury levels may actually represent a greater water quality problem for the upper drainage than arsenic, and this parameter definitely merits further consideration in future monitoring programs.

Some pesticide and herbicide data are also available for the Laurel and Corwin Springs stations on the Yellowstone River. In contrast to mercury, however, these potential pollutants apparently have no effect on the water quality in the stream. Of the 332 analyses for these various chemical constituents (14 parameters including lindane; DDT; endrin; 2,4,5-T; and silvex), only one parameter in one sample (0.3 percent of the analyses) was found in detectable concentrations--2,4-D at 0.04 μg/l (USDI 1966-1974b).

In summary, it may be easily concluded that an excellent water quality generally enters the primary survey area from the upper reaches of the Yellowstone River.

YELLOWSTONE RIVER--CLARKS FORK RIVER TO BIGHORN RIVER

YELLOWSTONE MAINSTEM

Several tributary streams of varying flow magnitudes enter the mainstem through this reach. These can be classified into three groups: (1) the large streams, the Clarks Fork Yellowstone River, and Pryor Creek, which have a distinct loading potential and thereby a potential to affect water quality in the mainstem; (2) various intermediate streams, such as Fly Creek; and (3) numerous streams with small flows, such as Duck Creek, Blue Creek, and Alkali Creek; these creeks probably exert minor individual effects on the mainstem but may have cumulative influences on the river's quality as the Yellowstone passes through this study reach. The Clarks Fork River is the largest of these tributaries and was defined as occupying the eastern segment of the secondary study area. As a result, the quality of water in this river will not be directly inventoried in this survey. However, several reports are available that have considered the quality of water in the Clarks Fork River in detail (Karp et al. 1976a, Karp et al. 1976b, Klarich 1976), and this information will be used as a reference point for assessing the potential effects of the Clarks Fork on the mainstem.

Considerable amounts of USGS water quality data are available for the Yellowstone River at Billings (table 3). In addition, lesser amounts of data have been collected by this agency for three other locations on this reach as supplemented by state WQB data (table 6)--near Laurel (below the Clarks Fork), at Billings, at Huntley, and at Custer. This information is summarized in tables 30-33 for the major parameters. The data in table 31 for the Yellowstone River at Billings is probably most representative of the river's overall quality in this segment due to the greater period of collection.

The Yellowstone in the Laurel-to-Custer reach has a calcium-bicarbonate type of water, and sodium and sulfate are secondary ionic constituents. Magnesium, potassium, and chloride are again minor components of the water and have no major effect on the river's quality in terms of its various beneficial uses. This is also true of fluoride with concentrations at low levels in this downstream segment in comparison to the river at Corwin Springs. The concentrations of these four minor constituents varied inversely with flow and are at the same levels observed for the river at Laurel (table 29). In contrast to the downstream increase in magnesium and the downstream decrease in fluoride and chloride noted for the upper river, the concentrations of these four minor constituents remained remarkably constant throughout the Laurel-to-Custer segment of the stream. The primary and secondary ions also varied inversely with flow, but in contrast to the minor constituents, these components tended to increase downstream in relation to the Yellowstone at Laurel as a reference point. As a result, the increase in salinity (total dissolved solids or specific conductance) observed for the upper river continues to occur through the Billings segment of the mainstem. On the basis of these dissolved constituents, the quality of water in the Yellowstone is best at upstream sites during the periods of higher flow.

In contrast to the upper river, the downstream increase of salinity in the Laurel-to-Custer reach was greatest during the August-to-October period (rather than at high flows) and ranged between 50 percent and 68 percent in the vicinity of Laurel, and from 91 percent to 113 percent for the entire segment. The increase near Laurel was probably a reflection of the confluence of the Clarks Fork Yellowstone River which has high specific conductances in comparison to the mainstem (Karp et al. 1976a, Karp et al. 1976b, Klarich 1976). Through the remainder of the year, the increase in salinity was lowest during the winter (7 percent to 23 percent near Laurel and 40 percent to 47 percent for the segment) and somewhat higher during the spring-to-summer period (23 percent to 49 percent near Laurel and 55 percent to 82 percent overall). The overall increase in salinity was much greater through the 91-mile Laurel-to-Custer segment of the stream than for the 158-mile stretch of the upper river--a maximum increase of about 1.1 percent per river-mile and a minimum of 0.5 percent per mile below Laurel versus a maximum salinity increase of 0.2 percent per mile and a minimum of about 0.05 percent per river-mile above Laurel. For the entire reach of the river from Corwin Springs to Custer, salinity increased between 70 percent and 122 percent during low-flow periods and between 122 percent and 150 percent during the high-flow period, indicating a definite downstream degradation in mainstem water quality.

Regardless of the marked increases in salinity, the entire Laurel-to-Custer segment of the river remains non-saline in character (Robinove et al. 1958); however, it becomes more typically hard in nature in this reach,

TABLE 30. Summary of the physical parameters measured in the Yellowstone River near Laurel below the confluence of the Clarks Fork Yellowstone River (Duck Creek Bridge).

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	13	1300	8980	4100	13	1300	4620	2930	7	1330	5340	3590	10	1200	41,800	14,100
Temp	11	3.0	22.0	12.0	13	0.0	4.0	0.0	6	2.0	10.5	7.3	11	10.0	20.0	13.5
pH	12	7.1	8.6	8.2	13	7.2	8.3	8.0	5	7.8	8.4	8.2	10	7.2	8.2	7.8
SC	12	238	430	368	11	240	580	420	6	360	610	460	11	140	490	215
TDS	12	160	295	253	13	207	337	264	6	222	304	273	11	90	197	150
Turb	4	2.0	14	4.4	5	4.0	20	4.0	2	10	70	40	5	13	300	58
TSS	1	--	--	14.4	1	--	--	10	0	--	--	--	2	214	226	220
DO	11	7.8	11.6	9.6	12	10.2	13.1	12.3	6	7.2	12.6	10.8	11	8.0	9.5	8.6
BOD	10	0.4	2.4	1.6	13	0.5	2.6	1.3	5	1.3	2.7	1.8	11	1.0	5.2	1.5
FC	6	27	420	70	6	6	390	13	7	4	70	30	7	70	1800	390
Ca	9	22	41	32	9	37	47	42	4	33	42	40	8	12	28	19
Mg	9	7.1	15	12	9	9.7	14	14	4	11	14	13	8	3.3	8.8	4.7
TH	12	84	186	137	13	125	180	159	6	130	184	159	11	44	114	76
Na	5	14	27	21	3	21	29	24	2	23	25	24	4	7.0	21	8.2
K	1	--	--	2.4	1	--	--	3.2	0	--	--	--	1	--	--	1.4
SAR	3	0.6	0.8	0.8	1	--	--	1.0	0	--	--	--	2	0.3	0.4	0.4
HCO_3	3	106	147	128	1	--	--	160	0	--	--	--	2	79	106	93
TA	6	89	159	122	5	121	186	134	2	127	190	159	5	65	102	87
SO_4	9	29	85	56	12	51	90	72	6	55	91	77	10	11	53	24
Cl	8	4.3	7.0	4.8	9	4.7	17	7.3	4	4.6	6.8	5.8	7	1.4	3.1	2.6
F	4	0.3	0.6	0.4	4	0.4	0.7	0.6	2	0.6	0.6	0.6	4	0.1	0.3	0.2
N	11	0.01	0.61	0.04	11	0.10	0.50	0.30	6	0.0	0.20	0.11	11	0.03	0.40	0.10
P	12	0.01	0.19	0.04	11	0.0	0.49	0.02	6	0.04	0.15	0.11	11	0.0	1.2	0.20

NOTE: Measurements expressed in mg/l.

TABLE 31. Summary of the physical parameters measured in the Yellowstone River at Billings.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	44	2600	20,000	5880	59	1330	5370	3330	27	2550	7610	3680	52	3390	62,800	18,060
Temp	25	3.5	22.5	19.0	30	0.0	6.3	0.5	15	0.5	12.8	6.0	30	8.5	21.9	15.4
pH	41	6.8	8.7	7.8	57	7.2	8.5	8.0	27	7.4	8.6	7.8	57	7.0	8.2	7.7
SC	43	252	582	348	57	340	602	439	27	265	483	422	57	118	549	193
TDS	37	157	381	232	54	210	415	276	27	159	306	260	52	78	352	132
Turb	5	7.7	76	15	1	--	--	9	0	--	--	--	10	22	88	49
TSS	12	6	222	26	14	2	110	7	4	7	130	64	20	19	430	153
DO	1	--	--	8.3	1	--	--	12.1	0	--	--	--	3	8.7	9.4	9.4
BOD	1	--	--	1.9	1	--	--	9.3	0	--	--	--	3	2.4	3.2	2.5
FC	1	--	--	56,000	1	--	--	2230	1	--	--	20	3	40	2210	745
Ca	21	22	41	34	31	34	51	43	16	34	47	40	24	14	46	19
Mg	21	8.1	17	12	33	10	20	14	18	12	16	14	25	3.1	18	6.3
TH	38	89	211	137	56	130	207	168	27	104	180	155	52	28	190	83
Na	39	16	41	24	57	21	40	27	27	16	35	27	51	5.8	46	11
K	18	2.4	4.2	2.7	34	2.5	7.1	3.4	15	2.8	4.6	3.5	19	1.2	7.7	1.8
SAR	38	0.7	1.2	0.8	56	0.8	1.2	0.9	27	0.7	1.2	1.0	52	0.3	1.5	0.6
HCO_3	38	103	187	143	55	128	202	163	27	117	172	153	52	56	197	92
TA	1	--	--	99	1	--	--	151	0	--	--	--	4	55	98	67
SO_4	39	39	136	60	57	49	118	81	27	36	103	77	51	12	120	24
Cl	21	3.5	6.6	5.2	33	3.5	10	6.6	18	6.4	10	7.8	25	1.1	8.8	2.9
F	18	0.3	0.8	0.5	32	0.3	0.7	0.5	15	0.3	1.1	0.6	21	0.1	0.6	0.3
N	26	0.0	1.2	0.08	39	0.0	0.64	0.25	20	0.0	0.64	0.10	29	0.01	0.95	0.08
P	14	0.0	0.12	0.04	19	0.01	0.12	0.03	10	0.0	0.11	0.06	14	0.0	0.19	0.03

NOTE: Measurements expressed in mg/l.

TABLE 32. Summary of the physical parameters measured in the Yellowstone River at Huntley.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	11	3800	9420	7230	6	2700	5400	3190	8	2790	8530	3930	11	6700	63,300	14,400
Temp	10	8.0	24.5	17.3	9	0.0	5.5	1.0	9	2.0	14.0	8.0	12	8.0	21.0	15.5
pH	11	7.6	8.6	8.2	7	7.3	8.3	7.7	8	7.4	8.5	7.9	12	6.9	8.3	7.85
SC	11	290	470	380	8	400	540	494	8	269	523	440	12	145	480	210
TDS	11	166	316	239	8	254	412	302	8	163	332	295	12	89	297	145
Turb	5	5	80	7	2	8	20	14	6	1	90	55	8	2	100	45
TSS	5	8	190	20	2	30.5	82	56.3	6	10	254	146	8	21	518	124
DO	11	7.4	12.0	8.4	7	8.2	12.9	12.3	8	8.9	11.4	10.3	12	7.5	10.7	8.7
BOD	10	1.4	3.2	2.0	6	2.0	3.3	2.4	5	2.5	7.0	2.6	10	1.0	5.0	2.2
FC	11	91	2000	560	7	8	2300	220	10	24	570	290	11	120	530	2400
Ca	6	28	43	36	8	36	52	44	5	37	44	42	7	15	43	19
Mg	7	9.6	16	12	8	13	19	16	5	11	17	15	7	3.6	15	6.9
TH	7	67	170	132	8	140	204	175	5	136	180	170	7	57	170	76
Na	7	19	33	22	8	25	35	33	5	22	35	31	7	6.8	35	13
K	2	2.5	2.8	2.7	2	3.1	4.3	3.6	2	3.8	4.1	4.0	3	1.4	2.1	2.0
SAR	7	0.8	1.1	0.9	8	0.9	1.1	1.1	5	0.8	1.1	1.1	7	0.4	1.2	0.7
HCO_3	2	123	148	136	3	169	174	174	3	137	170	164	3	69	128	81
TA	7	92	129	116	7	120	166	139	5	112	139	135	7	50	152	71
SO_4	7	55	96	68	8	73	122	100	5	64	110	91	7	13	93	33
Cl	7	4.3	6.8	5.2	8	5.9	9.9	8.2	5	4.6	9.7	7.7	7	1.5	5.7	3.0
F	6	0.4	0.6	0.5	5	0.4	0.6	0.6	2	0.5	0.6	0.6	6	0.2	0.5	0.3
N	8	0.05	0.31	0.09	6	0.17	0.38	0.29	7	0.13	0.42	0.15	11	0.0	0.30	0.08
P	8	0.01	0.17	0.06	6	0.04	0.28	0.07	7	0.05	0.29	0.15	11	0.03	0.54	0.11

NOTE: Measurements expressed in mg/l.

TABLE 33. Summary of the physical parameters measured in the Yellowstone River at Custer.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	4	3550	8890	3850	7	2900	4200	3400	3	3000	5700	3200	5	11,400	42,000	17,000
Temp	4	3.5	21.3	18.7	6	0.0	1.5	0.0	3	3.5	15.2	4.5	6	13.0	22.0	14.3
pH	5	6.8	8.6	8.29	6	7.8	8.3	8.1	2	7.9	8.0	8.0	6	7.5	8.08	7.75
SC	4	328	557	468	4	430	562	504	3	397	590	480	6	185	361	288
TDS	5	255	366	321	6	308	437	345	3	287	360	333	6	149	279	215
Turb	4	7	10	9.5	6	3.0	10	9	3	30	60	55	6	41	300	113
TSS	1	--	--	26.8	2	22	73	48	1	--	--	73	3	240	514	292
DO	5	7.6	12.4	10.2	6	9.8	13.6	12.4	3	8.9	11.4	10.2	6	8.2	10.6	9.3
BOD	4	0.4	2.4	2.0	6	1.7	8.1	2.2	3	2.6	4.1	2.8	6	0.2	5.5	4.2
FC	1	--	--	3315	2	40	148	94	1	--	--	66	3	<10	9200	230
Ca	2	29	39	34	2	51	53	52	1	--	--	39	3	22	34	32
Mg	2	11	18	15	2	8.4	23	16	1	--	--	11	3	6.0	12	9.1
TH	5	116	207	172	6	165	222	180	3	143	198	161	6	79	134	103
Na	3	23	31	30	4	33	37	37	1	--	--	25	4	10	25	20
K	3	2.6	3.6	2.8	3	3.1	4.2	4.1	0	--	--	--	3	1.6	2.5	2.4
SAR	2	0.9	1.0	1.0	2	1.1	1.1	1.1	1	--	--	0.9	3	0.5	0.9	0.6
HCO_3	2	127	147	137	2	154	185	170	1	--	--	141	3	87	134	128
TA	5	103	172	131	6	127	167	148	2	116	154	135	6	71	110	97
SO_4	5	58	96	91	6	95	129	104	3	46	108	64	6	21	68	47
Cl	2	4.6	6.1	5.4	2	7.0	8.2	7.6	1	--	--	6.0	3	1.8	3.6	3.5
F	3	0.3	0.8	0.4	3	0.3	0.6	0.5	0	--	--	--	4	0.2	0.4	0.2
N	5	0.0	0.61	0.02	5	0.20	0.75	0.39	3	0.10	0.28	0.17	6	0.0	0.61	0.28
P	5	0.02	0.55	0.11	6	0.02	0.24	0.08	3	0.05	0.28	0.15	6	0.0	0.88	0.33

NOTE: Measurements expressed in mg/l.

rather than soft or moderately hard, and therefore it is not an ideal public supply (Bean 1972). In addition, this reach is not as desirable a source for municipal water as it is upstream due to the increases in sulfate and total dissolved solids. Nevertheless, on the basis of the dissolved common constituents, the water in the Laurel-to-Custer reach of the Yellowstone is suitable for this use and has an excellent quality for the watering of all livestock, as sulfate, chloride, and total dissolved solids concentrations (and bicarbonate, calcium, magnesium, and sodium levels) were well below the recommended maximum criteria for these applications (tables 9-14). Given these aspects plus the low SAR values of the samples, the river between Laurel and Custer possesses a low sodium hazard and a medium salinity hazard for irrigation (Richards 1954) and a Class I type of water that may be successfully applied to most crop and forage species (tables 15-17). In addition, this reach of the river should also be suitable for the support of viable freshwater communities. As described previously, 400 mg/l of total dissolved solids represents a general threshold guideline for distinguishing the possible effects of salinity on the aquatic biota. Although total dissolved solids occasionally exceeded 400 mg/l below Billings during low-flow periods, these occurrences were quite rare and would not be expected to adversely influence the river's biota on a long-term basis.

In addition to the increase in total dissolved solids concentrations to Custer, a downstream change in chemical composition is also evident in the Laurel-to-Custer reach of the Yellowstone River. This alteration represents a general reversal of the trends described for the upper river. In the upper segment, the water tends to become more calcium bicarbonate towards Laurel with tributary inputs generally negating the water quality characteristics originating in Yellowstone National Park. Below Laurel, the proportions of sodium and sulfate in the river tend to increase to Custer. These changes can be illustrated by Ca/Na and HCO_3/SO_4 ratios as follows in table 34.

TABLE 34. Proportions of sodium and sulfate in the Yellowstone River below Laurel.

	Ca/Na		HCO_3/SO_4	
	Low Flows	High Flows	Low Flows	High Flows
at Corwin Springs	0.79	1.00	2.18	5.08
at Laurel above the Clarks Fork	1.51	2.36	3.73	5.71
near Laurel below the Clarks Fork	1.65	2.31	2.33	3.87
at Billings	1.49	1.72	2.12	3.83
at Huntley	1.44	1.46	1.88	2.45
at Custer	1.37	1.60	1.78	2.72

NOTE: Measurements expressed in mg/l.

Both ratios tend to increase from Corwin Springs to Laurel above the Clarks Fork, but then tend to decline downstream in the mainstem below Laurel. This is a probable reflection of the more sodium sulfate type of streams with prairie drainages that join the river below Laurel in contrast to the calcium bicarbonate type of tributaries that drain the mountainous areas of the upper reach. The influences of the Clarks Fork Yellowstone River (above Laurel versus the point near Laurel below the Clarks Fork) in increasing the proportion of sulfate in the mainstem while not affecting its sodium levels are quite distinct. This tributary tends to have a calcium sulfate type of water (Karp et al. 1976a In addition, the two ratios are highest during the high-flow periods when influences from the upstream calcium bicarbonate tributaries would be most pronounced in relation to the magnitude of the downstream inputs with their sodium sulfate types of waters.

In contrast to total dissolved solids, suspended solids-turbidity concentrations are directly related to the magnitude of flow. As a result, turbidity-TSS levels in the river below Laurel were low during the low-flow seasons and markedly increased during runoff periods. Thus, these physical factors tended to detract from the better water quality that occurs during the high flows as a result of the reduced total dissolved solids concentrations. In general, turbidity-TSS levels tended to be higher in the reach of the river below Laurel than for the mainstem above the Clarks Fork River at Laurel (tables 28 and 30). However, given the purported sediment load of the Clarks Fork Yellowstone River (Beartooth Resource Conservation Development Project et al. 1973), this increase was not as distinctive as might be expected, averaging 20 percent and 23 percent for turbidity and TSS, respectively, at low flows, and averaging 93 percent and 108 percent at high flows. In addition, although not totally consistent from site to site through all seasons, these parameters also continued to increase downstream through the Laurel-to-Custer segment.

For the most part, turbidity was not at adequate levels in the Laurel-to-Custer segment to preclude the use of this water as a public supply. Only a few samples had turbidities in excess of 75 JTU (table 9), and these were most commonly collected during high flows, although occasionally high turbidities were also obtained during most seasons through the stations. The occurrences of high turbidity were much more frequent in this reach of the river than upstream; this is suggestive of a less suitable source for municipal use in terms of water treatment costs. The sporadic collections of high turbidity samples were probably associated with runoff events in the surrounding drainage below Laurel, e.g., from the Clarks Fork Yellowstone River and from Pryor Creek (Karp et al. 1975b). The turbidity problem was most pronounced in the Yellowstone at Custer, particularly during the May-to-July period when median levels were in excess of the 75 JTU reference value.

The major effect of TSS in this reach of the Yellowstone appears to be related to aesthetics and to a potential degradation of the Yellowstone salmonid fishery. Bishop (1974) suggests that the high spring sediment loads of the Clarks Fork River and the Yellowstone near and below Laurel generally eliminate these stretches of water as spawning grounds for trout; the salmonids require gravel bars that are relatively free of sediment for the successful incubation of redds (Peters 1962). This then may account for the general decline of the trout fishery between Laurel and Huntley (Karp et al. 1976b, Marcuson and Bishop 1973), although temperature may also play an instrumental role.

However, other fish species are not as sensitive to sediment as trout in terms of their spawning activities, and these, therefore, could establish a resident population within this reach if sediment levels are not delimiting for other reasons. As noted, this fishery would probably be warm-water in character; a downstream increase in the proportion of warm-water species along with a corresponding decline in the salmonid forms has been observed for the Laurel-to-Custer segment of the river (Karp et al. 1976b).

Sediment levels during low-flow periods enable the Yellowstone to serve as an excellent fishery immediately below Laurel, and good-to-moderate below Billings. However, at high flows the fishery would be fair-to-poor at all locations (European Inland Fisheries Advisory Commission 1965). As described previously, fish may be able to survive temporary slugs of high sediment concentrations (e.g., during a high-flow period) but not sustained applications at high levels. As a result, the yearly median sediment concentration at a location may provide an index to assess the overall intensity of sediment exposure according to the classification scheme of the European Inland Fisheries Advisory Committee (1965). Using this index, the Yellowstone River should provide a good-to-moderate fishery in the Laurel-to-Huntley segment with annual median TSS levels ranging between 58 and 88 mg/l, while providing a fair fishery in the vicinity of Custer with a yearly median on the order of 108 mg/l. Potential pollutive influences from the Billings area on this Laurel-to-Custer fishery are considered in another report (Karp et al. 1976b).

A major portion of the Yellowstone reach below Laurel has been classified a $B\text{-}D_3$ stream, i.e., a warm-water fishery (Montana DHES undated). This is in accord with the temperature characteristics of the stream at Billings described previously and in accord with the high maximum, warm-weather temperatures obtained throughout the reach (tables 30-33). Oxygen concentrations are also appropriate for this designation and for a $B\text{-}D_1$ stream (table 8), as minimum DO's were well above 5.0 mg/l and always in excess of 7.0 mg/l. Median DO's were very near saturation (96 percent) and varied between 85 percent and 111 percent. Similarly, pH values were in accord with the criteria for a $B\text{-}D_3$ stream. Thus, neither extremely high pH's nor extremely low pH's (i.e., >9.0 or <6.0) would negate any beneficial river uses. During high-flow periods, pH tended to be lowest, in association with the low total alkalinities at these times.

Median phosphorus concentrations in the Laurel-to-Custer segment of the Yellowstone were higher in the spring and during the high-flow period than in the summer and winter. With the exception of the Billings station (table 31), the March-July pulse of phosphorus first observed in the river at Laurel (table 28) was also evident downstream to Custer. During the summer high-growth period and during winter, phosphorus levels generally increased downstream below Laurel. At Laurel and Billings during these two seasons, phosphorus concentrations in the river were less than the reference criteria diagnostic of eutrophic conditions (tables 30 and 31); however, phosphorus exceeded this value (0.05 mg P/l) at Huntley and at Custer (tables 32 and 33), although lower than the criteria established by the EPA (USEPA 1974b). In terms of nuisance algal blooms, the development of high phosphorus levels would be more critical during the summer months than during the dormant winter season. Median phosphorus concentrations were generally in excess of the EPA's (1974b) reference criteria (0.1 mg P/l) during the March-to-July period at all stations.

These aspects suggest eutrophic conditions in the Yellowstone below Laurel at most stations during most seasons. However, median nitrogen concentrations were typically below the reference value for this parameter, possibly preventing the development of nuisance plant growths. Nitrogen did not exhibit any distinct downstream trends, although concentrations appeared to be highest in the mainstem at Custer. Nitrogen levels were lowest during the summer period of high biological activity and nutrient uptake, and highest during the cold weather period. The Laurel-to-Custer segment appears to be nitrogen-limited and non-eutrophic at present, but this reach is much closer to eutrophy than the stretch of water above Laurel. The Laurel-to-Custer reach appears to be particularly vulnerable to eventual eutrophication if nitrogen inputs to the river are increased. Of the eight sites considered so far, the Yellowstone at Custer is the most representative of eutrophic conditions.

In association with the high percentage of DO saturations, the low BOD_5 values of the Laurel-to-Custer segment indicate the general absence of extensive organic pollution. This is confirmed by the generally low median TOC (less than average) and COD concentrations (table 36). However, this effect appears to be slightly more prominent in this reach than in the upper river, possibly in response to influences emanating from the more urbanized Laurel-Billings areas (e.g., wastewater treatment plant discharges). These aspects can be illustrated as follows in table 35.

TABLE 35. BOD_5 values and median TOC and COD concentrations above Laurel and in the Laurel-to-Custer reach.

River Reach	Average BOD_5	Number Samples BOD_5>5 mg/l	Uniquely High BOD_5 Values	Median TOC	Median COD
Above Laurel	1.9 mg/l	2	6.1 mg/l	5.6 mg/l	11 mg/l
Laurel-to-Custer	2.2 mg/l	6 to 8	7.0, 8.1, and 9.3 mg/l	6.4 mg/l	19 mg/l

The problem of organic pollution is discussed more fully in a report prepared by the state WQB (Karp et al. 1976b).

Trace element and minor constituent concentrations in the Yellowstone between Laurel and Custer are presented in table 36. This summary involves an amalgamation of sites as described for the upper river in order to increase the data base of each parameter. The data in table 36 indicate the absence of several potential water quality problems from the stream:

1) synthetic detergents (MBAS values very low);
2) cyanide (generally undetectable);
3) oil and grease (values typically near zero and less than state standards;
4) organic pollution (TOC and COD concentrations low);
5) aesthetics-color (color usually unnoticeable to the human eye); and
6) ammonia (low levels of the non-ionic toxic form).

TABLE 36. Summary of trace element and miscellaneous constituent concentration measured in the Yellowstone River between Laurel and Custer.

	Yellowstone River near Laurel (Duck Creek Bridge) and at Billings								Yellowstone River at Huntley and at Custer							
	Total Recoverable Metals and Miscellaneous Constituents				Dissolved Metals				Total Recoverable Metals[b] and Miscellaneous Constituents				Dissolved Metals[c]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Cn	9	0.0	0.01	0.0												
COD									16	4	68	19				
Color	27	0	27	3					5	1	6	4				
DO[a]									18	85	111	96				
MBAS	12	0.0	0.03	0.0					12	0.0	0.02	0.0				
NH_3-N	56	0.0	2.4	0.05					28	0.0	0.58	0.12				
O&G									12	0	7	0				
Phenols	4	<.001	0.002	0.002					2	0.002	0.003	0.003				
Si	86	8.7	20	14					4	10	14	13				
TOC	2	2	8	5					17	2.2	16	6.6				
Ag					14	0.0	.002	0.0					4	0.0	.001	.0005
Al					3	.096	.200	.200								
As	3	<.001	0.016	0.010	15	0.0	.060	.007	4	.001	.022	.010	4	.003	.010	.009
B	10	<.10	0.17	<.10	64	0.009	0.504	0.170	12	<.10	0.30	0.14	4	.106	.228	.137
Ba					6	0.0	0.0	0.0					4	0.0	0.0	0.0
Be	1	--	--	<.01	12	0.0	.007	0.0								
Cd	11	<.001	<.01	<.001	17	0.0	.001	0.0	14	<.001	<.01	<.001	4	0.0	.001	0.0
Co	1	--	--	<.01	9	0.0	.001	0.0					4	0.0	0.0	0.0
Cr	13	0.0	<.01	0.0	7	0.0	0.0	0.0	8	0.0	<.01	<.01				
Cu	11	<.01	<.01	<.01	16	0.0	.042	.004	20	<.01	0.05	<.01	4	.007	.025	.012
Fe	11	0.14	4.9	0.62	71	0.0	0.374	0.04	19	0.24	9.3	1.5	4	.040	.211	.084
Hg	8	<.0002	<.001	<.0002 (.33?)	8	0.0	.0003	.0001	9	0.0	0.001	<.0002				
Li	3	0.03	0.75	.050					1	--	--	<.01				
Mn	11	<.01	0.21	0.05	15	0.0	.060	.011	19	.10	.03	.39	4	.011	.063	.029
Mo					16	0.0	.008	0.0					4	.002	.011	.004
Ni					16	0.0	.008	.002					4	0.0	.015	.002
Pb	9	<.01	<.05	<.05	17	0.0	.014	0.0	16	<.01	<.1	<.05	4	0.0	0.0	0.0
Se	1	--	--	<.001	4	.006	.040	.009	5	<.001	0.003	0.002				
Sr	7	<.03	0.28	0.23	8	.140	.530	.408	9	0.03	0.70	0.30	4	.336	.510	.455
V	9	<.05	<.5	<.10	6	.001	.006	.001	10	<.05	0.27	<.1	4	.0009	.003	.0016
Zn	11	<.01	0.02	<.01	17	0.0	.047	.017	19	<.01	0.11	<.01	4	.021	.052	.037

NOTE: Measurements expressed in mg/l.

[a]DO expressed as percentage of saturation.

[b]Be:<.01,N=1; Co:<.01,N=1.

[c]Be:<.001,N=2.

However, ammonia-N may contribute more significantly to the eutrophic potential of the Laurel-to-Custer reach than upstream as inorganic $(NO_2 + NO_3)$-N concentrations were close to the critical reference criteria in the downstream segment. In addition, the TR levels of several metals indicate that these trace elements pose no problems to any of the water uses. This includes boron (irrigation), Be, Cd, Co, Cr, Cu, Pb, V, and Zn. This is substantiated by the low dissolved concentrations of these constituents, and on this basis, Ag, Ba, Li, Mo, Ni, and Se might also be eliminated from consideration as possible water quality problems.

Median silica concentrations in the Laurel-to-Custer segment were similar to those observed in the river at Laurel and about equal to the national average for surface waters (Davis 1964). Strontium levels, on the other hand, tended to increase downstream from Corwin Springs. Median Sr concentrations were somewhat higher than the average levels in major North American rivers (0.06 mg/l) (Durum and Haffty 1963), and higher than the median content of the larger public water supplies (0.11 mg/l) (Hem 1970). However, strontium has not generally been known to be toxic (McKee and Wolf 1974); the major interest in this element lies in its chemical similarity to calcium and in its radioactive Sr-90 isotope which can replace calcium in various biochemical reactions. However, the concentrations of strontium in the Yellowstone do not appear to be at adequate levels to allow its Sr-90 proportion to constitute a water quality hazard. For example, Sr-90 is a beta emitter, and dissolved gross beta levels in the Yellowstone at Billings (ranging between 2.5 PC/l and 7.8 PC/l with a median of 4.3 PC/l) were below the criteria established for the State of Montana (table 8) and well below the desirable level established by the NTAC (1968) for surface water-public supply (table 9). In addition, Sr levels in the Yellowstone were much lower than concentrations in some natural waters that have been utilized as a domestic supply (e.g., 52 mg/l) (Hem 1970). McKee and Wolf (1974) point out that the major hazard of Sr-90 ". . . lies not in direct consumption but in plants and fish that accumulate this element."

The high arsenic and mercury levels described for the upper Yellowstone are apparently carried into the Laurel-to-Custer reach of the river (table 36). However, arsenic does not appear to be a water quality problem in this section as its dissolved concentrations were generally below the Public Health Service (1962) drinking water standard and far below the criteria for freshwater aquatic life (USEPA 1973). In contrast, the median dissolved concentration of mercury was again above the average level recommended for the aquatic biota (as observed for the upper river), and grab sample concentrations also occasionally exceeded this criteria as well as the standard for surface-municipal supply. A review of the water quality data from the Yellowstone below Custer indicates that detectable mercury levels are also present in the lower river. As a result, mercury, along with the phenols and fecal coliforms, appear to represent the major water quality problems in the Laurel-to-Custer segment of the river.

As indicated in tables 30-33, median fecal coliform levels were often in excess of the state's criteria for the average number of organisms that should be present at any B-D stream location, and grab samples were also often in excess of the maximum criteria for this parameter (Montana DHES undated), particularly at high flows. But median fecal concentrations were generally less than the more lenient NTAC and EPA criteria (table 9) for surface water and municipal supply. In comparison to the upper river, markedly high fecal levels were occasionally obtained (>2000 colonies per 100 ml) that exceeded even these latter standards. These violations become progressively more common in a downstream direction as the river passes through the urbanized areas of Laurel and Billings.

In addition to the coliform problem, early water quality surveys of the Yellowstone revealed a flavoring of fish flesh and drinking water in this segment, attributed to high concentrations of phenolic compounds (Montana Board of Health et al. 1956, Spindler undated). With the recent development of better wastewater treatment systems at oil refineries in the Laurel-Billings area (Montana DHES 1972), the concentrations of phenols now appear to be at borderline levels in the river in relation to these taste and odor problems (table 19). However, phenol levels in the Laurel-to-Custer reach are still in excess of drinking water and public supply criteria (USEPA 1973, USDI 1968, USDHEW 1962) and are also in excess of the EPA's (1974b) national inventory, reference criteria (USEPA 1974b). In consideration of fecal coliform and phenol violations, the state WQB is completing a waste load investigation of the Yellowstone between Laurel and Huntley where these parameters form the focal point of the allocation (Karp et al. 1976b). With the operation of a new secondary sewage treatment plant at Billings, and with the continued improvement of oil refinery effluents, the fecal coliform and phenol problems may ultimately decline to noncritical levels. For the time being, however, these parameters are real problems in the Yellowstone River.

Overall concentrations of trace elements tended to increase downstream below Corwin Springs. This can be illustrated by the median TR and dissolved (Dis) concentrations of Sr, Fe, and Mn as follows in table 37.

TABLE 37. Median TR and dissolved concentrations of Sr, Fe, and Mn below Corwin Springs.

	Total Recoverable				Dissolved Concentrations			
	A	B	C	D	A	B	C	D
Strontium	0.08	0.19	0.23	0.30	0.208	--	0.408	0.455
Iron	0.42	0.55	0.62	1.5	0.020	--	0.04	0.084
Manganese	0.04	0.11	0.05	0.39	0.013	--	0.05	0.029

NOTE: A, B, C, and D represent sequential downstream reaches of the river.

Regardless of such increases, most of the trace elements do not appear to present a water quality problem to the lower sections. The greater TR over dissolved concentrations in a sample are illustrated by the Fe and Mn data; however, this does not apply to Sr for some unknown reason. Downstream increases in TR (and thereby dissolved levels) are possibly related to the downstream increases in suspended sediment. In turn, the high maximum TR concentrations of Fe and Mn were generally obtained in conjunction with the occurrence of high sediment loads. Of the various metals, the concentrations of Fe and Mn were typically the highest, affording the greatest probability of exceeding water quality criteria. A comparison of the above TR concentrations to various standards suggests that Fe and Mn levels did exceed many of the reference values; this is not borne out by their dissolved concentrations, which were typically less than the criteria for municipal supply, stockwater, irrigation, and aquatic life. Thus, these trace elements do not appear to detract from the river's quality, even though they can exhibit high TR levels. This is illustrative of the fact that high TR concentrations are only suggestive of possible water quality problems, meriting careful consideration and interpretation.

As indicated previously, radiochemical data from the Yellowstone River at Billings (USDI 1966-1974b) point to a general absence of this type of problem in the stream. This is also the case for the herbicides and pesticides. Similar to the gross beta concentrations, dissolved radium concentrations were well below the state and NTAC criteria for this parameter (tables 8 and 9); Ra-226 ranged between 0.01 PC/l and 0.11 PC/l with a median of 0.055 PC/l. Dissolved uranium concentrations ranged between 0.16 μg/l and 3.2 μg/l with median of 1.7 μg/l. Of the 761 individual pesticide and herbicide analyses (fourteen parameters) on samples from the Yellowstone near Laurel and at Billings, only 1.05 percent demonstrated detectable levels, about 3.5 times greater than the detection success at Corwin Springs. The parameter most commonly detected was 2,4-D (with a range of 0.02 μg/l to 0.42 μg/l and a median of 0.045 μg/l at N=6). Also detected were 2,4,5-T (0.01 μg/l) and DDT (0.01 μg/l) in single samples. All of these concentrations are well below levels that have been shown to directly affect rainbow trout (McKee and Wolf 1974), e.g., 2.2 mg/l for 2,4-D and 24 to 74 μg/l for DDT.

MISCELLANEOUS TRIBUTARIES

A number of small streams join the Yellowstone River between Laurel and Custer. Some partial chemical data are available for most of these creeks as a result of the state WQB's waste load allocation investigation of the mainstem (Karp et al. 1976b), but this information was not reviewed for this inventory. Complete chemical analyses were performed on single grab samples from three of these streams as summarized in table 38, which also includes data from a small tributary to Pryor Creek. These data should provide some insight into the type of water that enters the mainstem via these small streams. Of the four streams, Canyon Creek is unique, as it receives irrigation return flows originating from the Yellowstone River. As evident in table 38, this factor probably produces a dilution of its natural quality. For example, total dissolved solids levels in Canyon Creek are only slightly higher than those in the Yellowstone near Laurel.

Temperature, pH, turbidity-TSS, DO, and BOD_5 values of single samples from each stream are not suggestive of pollutive conditions in their drainages. In addition, phosphorus and nitrogen concentrations did not indicate eutrophic conditions. In contrast, the few data that are available consistently indicate the occurrence of high fecal coliform concentrations in these streams in excess of state standards; this may produce a cumulative fecal loading on the mainstem which corresponds to the downstream increase in this variable. Most noticeable in these tributaries, except in Canyon Creek, are the high dissolved solids-specific conductance levels, suggestive of a generally poor water quality. However, the small flows of these streams probably preclude most water uses other than stock watering. On the basis of TDS, these streams might be rated generally good for stock watering. However, East Fork Creek is unsuitable, and Duck and Spring creeks may also be unsuitable as sulfate concentrations were in

TABLE 38. Summary of the physical parameters measured in Spring, Duck, and Canyon creeks (minor Yellowstone tributaries), and in East Fork Creek (a minor tributary to Pryor Creek).

	Spring Creek	Duck Creek	Canyon Creek	East Fork Creek
Flow	1.39	1.58	260	2.0
Temp	16.0	171	--	10.5
pH	8.17	8.38	7.80	8.30
SC	2410	2903	494	5030
TDS	1895	2298	366	4567
Turb	--	--	--	4
TSS	9	1.5	73	16
DO	12.1	12.1	10.9	9.9
BOD	3.1	2.5	--	2.3
FC	800	3450	--	>1000
Ca	104	164	40	228
Mg	58	95	18	243
TH	500	800	172	1570
Na	380	390	35	800
K	--	--	--	--
SAR	7.4	6.0	1.2	8.8
HCO_3	293	283	156	430
TA	241	236	128	363
SO_4	1053	1358	109	2820
CI	2.5	6.0	7.7	40
F	--	--	--	--
N	0.79	0.02	0.04	0.0
P	0.01	<.01	0.06	0.01

NOTE: Measurements expressed in mg/l.

excess of the limiting level for stock (tables 10-14). In turn, these waters would be unfit for human consumption and would be Class II type waters for irrigation given their high SAR values and TDS concentrations.

The potential cumulative effect of these small streams on the mainstem is most obvious in terms of high TDS and specific conductance levels. Several such sequential inputs would act to increase the TDS levels of the Yellowstone. For example, ten tributaries having the flow and chemical characteristics of Duck Creek in table 38 could increase the TDS concentration of the mainstem about three percent to four percent from that in the river near Laurel. In addition, the sodium sulfate nature of these small streams is in accord with the gradual increase in the proportion of these parameters from Laurel to Custer in the mainstem.

PRYOR, ARROW, AND FLY CREEKS

These streams also join the Yellowstone in its Laurel-to-Custer segment. Next to the Clarks Fork Yellowstone River, Pryor Creek is the major tributary through this reach, and, therefore, it could have a significant effect on mainstem water quality. However, very little water-quality information is available on Pryor Creek other than that collected by the state WQB as part of its water-quality management plans (Karp and Botz 1975). Samples were collected from the stream's upper drainage and from a station near its mouth at Huntley; however, data from these samples were insufficient to allow for a seasonal or flow-based classification of the creek's quality.

Fly and Arrow creeks have lower discharges than Pryor Creek and may be considered intermediate tributaries in the Laurel-to-Custer segment, as they have higher flows than such streams as Duck and Spring creeks. Adequate data are available on Arrow Creek through a state WQB irrigation return flow sampling program to allow for a flow classification of the stream's quality, but detail is insufficient for a seasonal separation. Most water quality information for these Laurel-to-Custer tributaries is available on Fly Creek since the USGS has maintained a monitoring station on this stream for several years (table 3). This allowed for a seasonal classification of the water quality data from Fly Creek as applied to the Yellowstone River.

Data on the minor constituents and trace elements in these tributaries were relatively sparse, both in the number of parameters analyzed and in the number of analyses per parameter. As a result, these data from the streams were combin to provide one statistical summary (table 39). With the exception of a few occasionally high readings for some of the metals (e.g., zinc), most of the trace elements do not appear to be at levels sufficient to suggest water quality problems. As observed on the mainstem, median iron and manganese concentrations were high, but it should be noted that these were TR levels and should be considered in that context. For example, dissolved iron concentrations in Fly Creek were well below the various water quality criteria, but dissolved manganese concentrations were high and exceeded the standards for drinking water and surface water supply (although they were at levels safe for other uses). Silica concentrations in Fly Creek equalled the national average for surface waters, and the water in this creek was generally uncolored. However, TOC levels in Fly Creek were higher than in the mainstem, indicating a greater than average concentration of organic matter, but this was not reflected in the BOD levels of the creek. Therefore, although the high manganese concentrations may degrade water quality, major water-quality problems in these tributaries are apparently related to the high concentrations of certain major parameters (tables 40 and 41

Fecal coliform concentrations in Pryor Creek and the intermediate streams were high and occasionally in excess of state standards; pH and DO levels in the streams were within state criteria and did not indicate pollution. Median BOD_5 levels were probably higher overall than those in the mainstem, but they were less than 5.0 mg/l in all cases and did not suggest extensive organic pollution. With the exception of Arrow Creek at high-flow periods, these tributary streams were generally non-eutrophic with phosphorus levels below the critical reference criteria. Nitrogen levels were occasionally high in the streams (in Arrow Creek and in Fly Creek during the winter), but for the most part, the concentrations of this parameter were well below the levels that indicate eutrophic conditions. Grab sample temperatures usually did not reveal any conspicuous values, although high warm-weather readings were obtained from Pryor Creek on a few occasions; this is not consistent with the stream's $B\text{-}D_1$ designation (Montana DHES, undated

TABLE 39. Summary of trace element and miscellaneous constituent concentrations measured in various secondary streams in the Yellowstone drainage between Laurel and Custer.

	Fly Creek				Fly Creek plus other streams			
	Miscellaneous Constituents and Dissolved Metals				Total Recoverable Metals			
	N	Min	Max	Med	N	Min	Max	Med
Color	38	2	40	6				
Si	175	5.0	18	14				
TOC					3	37	50	37
As					18	<.001	0.02	<.01
B	79	0.010	0.530	0.277	4	<.10	0.56	0.13
Cd					22	<.001	0.001	<.001
Cr					2	<.01	<.01	<.01
Cu					22	<.01	0.02	0.01
Fe	112	0.0	0.70	0.02	21	.10	21	.55
Hg					7	<.001	<.001	<.001 (.007?)
Mn	11	0.0	0.190	0.080	18	<.01	1.7	0.18
Pb					9	<.01	<.01	<.01 (.04?)
V					2	<.05	<.05	<.05
Zn					20	<.01	0.14	0.01

NOTE: Measurements expressed in mg/l.

In addition, the consistently high turbidity-TSS levels in Pryor Creek suggest a poor fishery (European Inland Fisheries Advisory Commission 1965) which is also contrary to its B-D_1 designation. Although most obvious in Pryor Creek, turbidity-TSS levels could also be high in Fly and Arrow creeks (particularly at high flows), and this may partially account for the downstream increase in suspended sediment that occurs in the mainstem towards Custer.

Probably the most obvious water quality attribute of these tributary streams is their high TDS-specific conductance levels which were two to seven times higher than those in the mainstem at Huntley (table 32) during low-flow periods. Sequential inputs of such waters to the Yellowstone probably accounts for at least part of the downstream increase in TDS between Laurel and Custer. However, these particular streams would have a greater effect on the mainstem than Duck Creek, for example, due to their higher flows and greater TDS loads. The median data for Pryor Creek indicate that this tributary could increase the winter TDS level in the Yellowstone about nine percent below their confluence at Huntley. Although these tributaries are non-saline or only slightly saline (Arrow and Fly creeks at low flows), their waters were very hard and their TDS concentrations consistently exceeded the recommendations for drinking water and public supply (table 9). In addition, sulfate concentrations often exceeded these criteria (particularly at low flows), and turbidities in Pryor Creek were generally greater than that deemed desirable for this use. As a result, the waters in these three tributaries are probably not suitable for municipal supply

TABLE 40. Summary of the physical parameters measured in the Pryor Creek drainage and in Arrow Creek near Ballantine-Worden.

	Upper Pryor Creek Drainage near Pryor				Pryor Creek at Huntley				Arrow Creek (<16 cfs)				Arrow Creek (>16 cfs)			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	6	5	72	22	4	106	582	222	11	0.3	15.3	2.0	8	36.3	150	104
Temp	6	0.0	7.2	2.8	8	0.0	29.4	11.3	12	0.0	19.0	11.4	7	13.0	18.5	16.5
pH	6	7.90	8.40	8.20	8	8.00	8.60	8.30	12	7.98	8.48	8.16	8	7.68	8.40	7.86
SC	6	480	1184	773	9	804	1460	982	12	1353	1850	1565	8	470	894	628
TDS	6	409	898	606	7	666	850	722	3	1078	1317	1130	2	497	651	574
Turb	5	10	175	120	6	39	160	86	12	1	24	6.3	8	8.2	89	36
TSS	6	26	427	122	7	<25	3436	711	11	7.1	61	22	8	19	266	117
DO	6	10.3	13.3	11.8	7	7.8	12.6	10.0	3	11.1	14.1	13.1	0	--	--	--
BOD	4	1.8	3.8	3.3	6	1.8	4.2	3.3	3	2.4	3.2	3.2	0	--	--	--
FC	6	<100	>1000	>100	5	40	1060	140	2	<100	860	--	0	--	--	--
Ca	6	55	93	68	7	60	85	66	3	85	104	88	2	48	54	51
Mg		20	32	25	7	31	45	35	3	65	73	66	2	22	25	24
TH	6	218	361	283	7	279	355	339	3	479	560	490	2	211	238	225
Na	6	7.0	121	67	7	54	128	75	3	126	168	136	2	56	88	72
K	3	12	34	25	1	--	--	4.5	0	--	--	--	2	4.0	4.1	4.1
SAR	6	0.2	2.8	1.8	7	1.3	3.3	1.8	3	2.5	3.1	2.7	2	1.7	2.5	2.1
HCO_3	6	228	382	253	7	203	317	268	3	357	397	363	2	209	255	232
TA	6	187	240	210	7	167	268	226	3	293	326	298	2	171	209	190
SO_4	6	34	419	201	7	162	348	262	3	426	568	469	2	148	215	182
Cl	6	0.0	8.0	2.6	7	6.3	27	8.2	3	4.2	13	12	2	8.6	9.4	9.0
F	3	0.3	0.4	0.4	4	0.4	0.6	0.5	2	0.3	0.3	0.3	2	0.5	0.6	0.6
N	6	0.0	0.14	0.08	7	0.03	0.68	0.11	12	0.02	1.5	0.73 (10?)	8	0.27	0.81	0.67
P	6	0.01	0.11	0.02	7	0.01	0.25	0.04	12	<.01	0.05	0.03	7	0.03	0.25	0.11

NOTE: Measurements expressed in mg/l.

TABLE 41. Summary of the physical parameters measured in Fly Creek at Pompeys Pillar.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	50	10	148	51	44	2.5	767	8.5	30	6.0	2050	11	53	7.8	241	51
Temp	8	12.0	18.5	14.5	7	0.5	2.5	2.0	8	0.0	7.0	2.0	7	10.0	20.0	15.5
pH	43	7.6	8.3	8.0	44	7.5	8.4	8.1	30	7.3	8.4	8.1	52	7.3	8.3	8.0
SC	48	747	2120	1025	44	344	2880	2245	30	312	3020	2355	53	404	2960	942
TDS	48	471	1620	717	44	232	2230	1720	30	204	2370	1775	53	265	2190	640
Turb	0	--	--	--	1	--	--	5	2	5	6.5	5.8	1	--	--	47
TSS	0	--	--	--	0	--	--	--	2	15	21	18	1	--	--	168
DO	0	--	--	--	1	--	--	13.1	2	13.0	13.4	13.2	1	--	--	8.7
BOD	0	--	--	--	1	--	--	2.4	2	3.6	4.8	4.2	1	--	--	3.4
FC	0	--	--	--	0	--	--	--	2	5	<100	--	1	--	--	280
Ca	48	50	101	64	44	27	140	106	30	26	145	110	53	31	120	57
Mg	48	27	91	37	44	9.7	120	91	30	8.8	119	86	53	12	110	34
TH	48	240	660	327	44	110	820	640	30	101	802	655	53	130	750	280
Na	48	66	300	108	44	30	410	304	30	20	468	323	53	31	440	110
K	48	1.5	6.0	4.4	44	4.3	8.3	5.3	30	4.5	7.5	5.6	53	2.0	10	3.6
SAR	48	2.6	1.8	5.2	44	1.3	6.5	5.2	30	0.9	7.5	5.7	53	1.2	7.0	2.8
HCO_3	48	202	441	264	44	80	503	393	30	94	464	363	53	117	357	191
TA	0	--	--	--	1	--	--	380	1	--	--	364	1	--	--	118
SO_4	48	190	890	324	44	110	1300	950	30	67	1390	980	53	93	1300	324
Cl	48	4.2	15	8.3	44	3.1	29	15	30	2.0	37	22	53	19	32	8.1
F	48	0.3	0.8	0.5	44	0.1	0.7	0.5	30	0.2	0.6	0.4	53	0.1	0.9	0.3
N	46	0.0	0.45	0.04	41	0.0	0.68	0.36	32	0.0	0.68	0.08	53	0.0	0.35	0.01
P	39	0.0	0.11	0.03	38	0.0	0.21	0.02	28	0.0	0.11	0.02	44	0.0	0.10	0.03

NOTE: Measurements expressed in mg/l.

if other sources are available. The high TDS concentrations of the streams were due primarily to sodium, calcium, bicarbonate, and sulfate, the major ionic constituents; relative proportions varied depending upon the stream, reach, and flow regime. Magnesium concentrations were somewhat higher in these streams than in the Yellowstone, although fluoride, chloride, and potassium were again minor constituents in the waters.

The water quality in Pryor Creek is apparently somewhat better in its upper drainage where the composition is calcium-sodium-bicarbonate; however, TDS levels were still high even in this creek's headwaters region. TDS concentrations increased downstream to the creek's mouth, accompanied by a shift in ionic proportions so that the stream became, like the Clarks Fork Yellowstone River, more calcium sulfate in nature with almost equal proportions of the major cations and the major anions. This is probably a reflection of the inputs of tributaries such as East Fork Creek (table 38), which have sodium sulfate waters and high specific conductances. Due to the low sodium concentrations, Pryor Creek has a low sodium hazard for irrigation; this, and its medium-to-high salinity hazard and low boron levels indicated that Pryor Creek has a borderline Class I-II water for irrigation. As a result, this water should be applied cautiously to salinity-sensitive forage and crop plants. However, the water in Pryor Creek is excellent for watering stock animals.

Water quality in Arrow Creek is definitely related to flow; the stream shows a 50 percent to 60 percent reduction in salinity with a better water quality during the high-flow periods. With discharge in excess of 16 cfs, the water in Arrow Creek has a calcium bicarbonate composition, but during low flows the stream is sodium sulfate in character. These features may reflect the irrigation return flows that enter the creek. These returns would tend to increase the creek's flow, dilute the stream's initial quality, and alter its ionic character from a sodium sulfate water to one more characteristic of the original source of the irrigation water (e.g., the calcium bicarbonate type of water in the Yellowstone River). Thus, in small prairie streams such as Arrow and Canyon creeks, irrigation return flows probably have a beneficial effect in increasing discharge and in improving an otherwise naturally poor water quality. As a result, although the water quality in Arrow Creek is probably excellent during all seasons for stock, it is more beneficial during the high-flow irrigation return flow periods.

Of the three Laurel-to-Custer tributaries, the more eastern Fly Creek (table 41) has the poorest water quality, but only because of its high salinity levels. Although based on slight evidence, pH, temperature, dissolved oxygen, BOD_5, and most trace element levels (except manganese) did not indicate water quality problems in the drainage. In addition, TSS and fecal coliform concentrations are not at particularly high concentrations in comparison to those observed in other streams, such as Pryor Creek and in the Yellowstone River at Huntley. The major water quality problem in Fly Creek, TDS, is definitely flow-related, with a better quality evident during high-flow periods. Surprisingly, highest flows were obtained during the summer-early fall, perhaps reflecting irrigation returns (Durfor and Becker 1964). The waters in Fly Creek are sodium sulfate in nature during all seasons, although this is most prominent during the low-flow winter-spring seasons when irrigation returns would be at a minimum. The downstream increase in the proportions of sodium and sulfate in the Yellowstone mainstem is probably related to the sequential inputs of tributaries such as Fly Creek. During high flows, the water in Fly Creek is applicable to all stock, but this use may be curtailed during the November-to-March period as sulfate concentrations in the stream approach levels limiting to animals at this time (approaching 1000 mg/l) (tables 10-14). This is another example of the beneficial aspects of irrigation return flows reaching these small prairie streams.

Using only the May-to-October data, Fly Creek has a high salinity hazard for irrigation, but low sodium and boron hazards (tables 15 and 16). However, with the high TDS and sulfate concentrations, this stream is best classified as Class II, which should not be applied to salinity-sensitive plants. As specified by the EPA (1976), TDS concentrations of 500-1000 mg/l indicate ". . . a water which can have detrimental effects on sensitive crops." In addition, the salinity levels in Fly Creek, as well as in Arrow and Pryor creeks, are approaching concentrations which may affect freshwater biota. Median TDS concentrations in Fly Creek during the winter and spring definitely exceed the maximum value that allows for the support of a good mixed fish fauna (Ellis 1944). As a result, the biotic structure and composition of these saline streams might be considerably different from that in streams with much lower TDS concentrations. Along with the high TSS levels (and the possibility of high summer temperatures), the high salinity levels would also operate against the designation of Pryor Creek as a $B\text{-}D_1$ class water.

LITTLE BIGHORN RIVER DRAINAGE

LITTLE BIGHORN RIVER MAINSTEM

The Little Bighorn River is the major tributary of the Bighorn River in Montana. Considerable water quality information on the river is available from the USGS, and this has been supplemented by state WQB collections in the drainage (table 6). The USGS maintains two water quality sampling stations on the Little Bighorn--one near Wyola (near the Montana-Wyoming state border) and one near Hardin near the confluence of the stream with the Bighorn River. A stretch of river about 50 miles long separates the two USGS stations.

As illustrated in table 42, a good-to-excellent water quality enters Montana from Wyoming via this river. The upper Little Bighorn River is classified as a $B\text{-}D_1$ stream; dissolved oxygen, pH, and fecal coliform levels in the stream near Wyola were well within the state standards for this designation. Grab sample temperatures were also generally within this criteria, although a few temperatures during the summer exceeded 19.4°C. These factors, along with the low BOD_5 levels of the water samples, indicate no pollution problems in the river's upper drainage.

Total dissolved solids in the Little Bighorn were inversely related to flow, but TDS concentrations and specific conductance levels in the upper stream were low even during the periods of reduced discharge. For example, TDS concentrations in the upper Little Bighorn River were only about 6.7 percent to 8.7 percent higher than those in the Yellowstone at Custer during the low-flow August-to-February period, and about 18 percent to 29 percent higher during the high-flow period of March-to-July. The waters in the upper Little Bighorn had a predominantly calcium bicarbonate composition during the entire year. Sodium and magnesium, the secondary cations, were found in nearly equal concentrations;

TABLE 42. Summary of the physical parameters measured in the Little Bighorn River near Wyola.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	27	115	281	145	44	58	439	130	26	65	551	187	39	174	1820	611
Temp	19	6.0	22.0	16.0	24	0.0	7.0	0.5	13	0.0	8.0	2.5	17	5.4	18.0	10.5
pH	21	7.6	8.3	8.1	40	7.2	8.5	8.15	24	7.6	8.5	8.1	34	7.3	8.5	8.1
SC	26	482	673	556	44	413	675	596	26	350	759	680	39	314	712	424
TDS	27	306	404	349	43	266	526	368	26	281	566	430	39	193	462	255
Turb	0	--	--	--	2	2	10	6	1	--	--	0	2	6	14	10
TSS	12	21	248	62	13	22	346	49	7	18	799	51	9	9.0	1250	216
DO	0	--	--	--	2	12.3	13.4	12.9	2	12.3	12.5	12.4	2	10.9	11.5	11.2
BOD	0	--	--	--	2	2.5	3.2	2.9	1	--	--	2.8	2	1.5	2.9	2.2
FC	0	--	--	--	2	0	3	2	1	0	9	5	2	12	20	16
Ca	27	55	70	63	43	43	81	67	26	40	78	68	39	37	70	52
Mg	27	21	31	26	43	16	33	27	26	16	38	30	39	13	31	18
TH	27	250	300	260	43	170	330	280	26	180	313	299	39	170	303	210
Na	27	13	27	21	43	17	40	22	26	9.4	50	35	39	1.3	47	10
K	27	0.9	2.2	1.6	42	1.0	4.5	1.6	25	1.3	8	2.3	37	0.7	7.8	1.3
SAR	27	0.4	0.7	0.6	43	0.4	1.1	0.6	26	0.3	1.3	0.9	39	0.0	1.2	0.3
HCO_3	27	229	288	249	43	171	292	248	26	166	279	247	39	170	256	214
TA	3	195	219	216	5	209	231	216	4	136	229	202	5	149	203	189
SO_4	27	81	120	100	43	85	160	120	26	22	190	170	38	13	178	54
Cl	27	0.8	3.0	1.4	43	0.4	3.1	1.5	26	0.2	4	2.0	39	0.2	3.0	1.1
F	27	0.0	0.7	0.2	42	0.1	0.5	0.2	26	0.1	0.5	0.2	37	0.0	0.4	0.2
N	23	0.0	0.10	0.01	39	0.0	0.50	0.10	26	0.0	0.42	0.03	39	0.0	0.4	0.01
P	17	0.0	0.07	0.02	20	0.0	0.09	0.02	10	0.01	0.21	0.03	14	0.0	0.06	0.02

NOTE: Measurements expressed in mg/l.

sulfate was the secondary anion. Although the waters were non-saline, they were very hard (Bean 1962, Durfor and Becker 1964) due to the high calcium and magnesium levels. SAR values were low for this same reason. Chloride, fluoride, and potassium concentrations were insignificant in the samples, and phosphorus and nitrogen levels were also remarkably low in comparison to other streams in the study area and in comparison to their reference criteria. The low phosphorus and nitrogen levels indicate non-eutrophic conditions in the upper river. On the basis of the major parameters, therefore, waters in the upper Little Bighorn River appear to be suitable for the following beneficial uses:

1) stock animals--TDS, common constituents, fluoride, and nitrate-nitrite concentrations were at below-threshold levels (tables 10-14);

2) irrigation--the water has a low sodium, medium salinity hazard, and due to the low SAR, chloride, sulfate, and TDS-specific conductance levels, it is a Class I water suitable for application to most crop and forage plants (tables 15-17);

3) drinking water and surface water public supply--TDS, fecal coliforms, nitrate-nitrite, DO, pH, chloride, sulfate, and fluoride levels were in accord with the permissible criteria, standards, and recommendations given in table 9; and

4) freshwater aquatic life--TDS concentrations were generally less than 400 mg/l and consistently less than 670 mg/l.

The low fluoride concentrations in the Little Bighorn indicate the need for accessory fluoridation in order to reach the optimum level for drinking water (USDHEW 1962).

Of the major parameters summarized in table 42, the high TSS levels may detract from the stream's quality to the greatest degree. As observed on the Yellowstone River, TSS levels were directly related to flow, with highest median concentrations during the May-to-July high runoff period. Through the remainder of the year in the upper river, median seasonal concentrations were generally similar and much lower, although high levels of sediment were obtained sporadically during all seasons in response to meteorological runoff events. The overall sediment levels in the river might have been sufficient to reduce the value of the stream as a fishery. Using the index described previously to assess the Yellowstone River, the upper reach of the Little Bighorn probably has only a fair to moderate fishery, with an annual median TSS concentration of about 94 mg/l. In addition, although not evident in table 42 due to the lack of turbidity data, TSS levels in the upper river appeared to be high enough on some occasions to detrace from its use as a public supply. That is, TSS concentrations in excess of 325 mg/l were obtained during most seasons (e.g., the maximum concentrations in table 42); using the equation in Karp et al. (1976), this converts to a turbidity in excess of 75 JTU. This violates the NTAC permissible criteria for public supply (table 9).

In terms of median flow, the Little Bighorn River is between 1.2 and 2.4 times larger near its mouth than at the state border, probably due to tributary inputs to the river below Wyola. The flow differences between sites varied by factors of 1.3 to 1.6 during the May-to-February period, and it was considerably greater in March-April (a factor of 2.4). This larger flow increase in the early spring was probably a reflection of runoff events in these tributaries because prairie streams have their spring flood phase earlier than streams with a mountainous drainage such as the upper Little Bighorn River. These differences in flow regimes, in turn, would become evident in the greater downstream increases in mainstem flows at this time, as illustrated in table 43. In addition, such relationships should also become evident in the water quality data since the prairie tributaries generally have a lesser water quality than the receiving stream.

A comparison of tables 42 and 43 shows a general degradation of water quality through the 50-mile reach of the Little Bighorn River between Wyola and Hardin. This is probably related to tributary inputs of inferior quality, but was manifested primarily by increases in TDS and TSS rather than in parameters that are more directly descriptive of pollution problems. That is, BOD_5, pH, and DO levels in the lower segment were similar to those in the stream near Wyola, and, although fecal coliforms increased somewhat downstream, their concentrations continued to be less than the state criteria for a B-D stream. The river's lower segment is classified a $B\text{-}D_2$ stream, corresponding with the higher maximum and median temperatures observed there (table 43), along with the greater frequency of grab sample temperatures exceeding 19.4°C. This change of classification corresponds to the increase in yearly median TSS concentrations in the river from Wyola to Hardin (to 154 mg/l), also descriptive of a poorer fishery.

TDS concentrations increased downstream from 27 percent to 43 percent, depending upon season. The increase was smallest during the summer when tributary flows were at their lowest, and the increase was greatest in April-March when the tributaries probably had their high-flow periods. In addition, TSS concentrations in the mainstem near Hardin were lowest during the summer in correspondence to the reduced flows of the tributaries. Although TSS concentrations were highest during the spring runoff stage of the Little Bighorn in May-July, a distinct secondary pulse of sediment was also evident in March-April near Hardin, but absent upstream, also probably related to the earlier high flows of the tributaries. Sodium and sulfate levels were exceptionally high in March-April. As a result, the Little Bighorn River near Hardin, like the upper reach, was a calcium bicarbonate stream from May to February, but it had a calcium-sodium-bicarbonate-sulfate type of water in March-April when these constituents were present on an equivalent basis.

With the exception of fluoride, all of the common constituents tended to increase in concentration below Wyola to some extent during some season, but increases in chloride, potassium, calcium, phosphorus, and nitrogen were small. Thus, the waters in the river remained non-eutrophic throughout its entire length. The downstream increase in TDS was related primarily to the greater concentrations of sodium and sulfate in the lower segment, although magnesium also increased significantly towards Hardin, producing a distinct increase in hardness. Such increases in TDS and changes in chemical composition may detract from the use of the lower river as a surface water public supply; this is related primarily to the high TDS levels, the river's extreme hardness, and the occasionally high turbidity and sulfate levels. The waters still have a low sodium hazard (low SAR's) and a medium salinity hazard for irrigation (Richards 1954), but they are probably less applicable to irrigation than upstream waters due to the higher salinities. The lower river becomes a borderline Class I water which could affect sensitive species (USEPA 1976). However, salinities probably would not affect the river's aquatic biota to a large extent, and the stream is an excellent source of water for all stock animals.

TABLE 43. Summary of the physical parameters measured in the Little Bighorn River near Hardin.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	28	146	494	190	44	82	791	177	29	238	2160	448	41	150	2370	960
Temp	19	6.5	29.0	17.0	25	0.0	6.0	0.0	12	0.0	14.0	3.6	16	11.0	25.0	17.5
pH	21	7.7	8.4	8.1	37	7.3	8.3	8.1	29	7.6	8.4	8.1	38	7.4	8.5	8.1
SC	26	635	819	696	41	503	1450	772	30	637	1290	927	42	407	1240	573
TDS	28	401	509	445	41	331	737	501	29	411	861	614	43	251	867	356
Turb	0	--	--	--	1	--	--	23	2	48	51	50	2	24	41	33
TSS	15	15	280	72	18	30	338	80	11	84	1570	189	13	87	1350	306
DO	0	--	--	--	1	--	--	12.1	2	11.3	12.5	11.9	2	10.7	10.8	10.8
BOD	0	--	--	--	1	--	--	2.3	2	2.6	3.5	3.1	2	2.5	2.6	2.6
FC	0	--	--	--	1	--	--	70	2	10	25	13	2	28	51	35
Ca	28	54	73	59	44	44	100	71	29	48	87	72	43	48	81	58
Mg	28	30	37	34	43	20	52	38	28	25	54	40	43	17	51	26
TH	29	260	330	290	41	190	60	320	29	220	440	348	43	200	410	250
Na	28	33	52	42	41	32	69	49	29	53	130	74	43	13	130	28
K	28	0.9	3.3	2.7	43	2.2	5.7	2.8	28	2.7	5.6	4.4	41	1.4	5.8	2.3
SAR	28	0.9	1.3	1.1	44	1.0	1.7	1.2	29	1.3	2.7	1.7	43	0.4	2.8	0.8
HCO_3	28	220	285	246	44	162	410	284	29	180	323	274	43	206	300	242
TA	4	198	234	207	8	229	313	256	2	249	265	257	5	171	221	209
SO_4	28	140	210	170	41	140	260	200	29	180	410	270	43	50	450	110
Cl	28	1.5	4.3	3.0	44	2.4	7	3.2	29	2.2	8.1	4.4	43	1.0	7	2.0
F	28	0.0	0.3	0.2	43	0.1	0.5	0.2	28	0.1	0.6	0.2	41	0.0	0.7	0.2
N	27	0.01	0.09	0.0	40	0.0	0.43	0.13	29	0.01	0.28	0.06	43	0.0	0.38	0.02
P	18	0.0	0.08	0.02	24	0.0	0.18	0.02	11	0.01	0.27	0.06	17	0.01	0.06	0.02

NOTE: Measurements expressed in mg/l.

Some trace element data are also available for the Little Bighorn River as summarized in table 44. Overall, concentrations were lower than those in the Yellowstone, indicating an excellent water class. For example, the median silica level in the Little Bighorn was about 50 percent of that in the Yellowstone and well below the national average (Davis 1964). As a result, TSS and TDS appear to be the major problems detracting from water quality in the Little Bighorn River, and this appears to be generally true of most streams in the Yellowstone Basin.

TRIBUTARY STREAMS

Some water quality data are available on various tributaries to the Little Bighorn River as a result of a state WQB sampling program in the drainage. These streams are listed in table 44. The data are relatively sparse, however, and not conducive to a seasonal or flow-based water quality classification. As indicated in table 44, trace elements in these tributary streams were found in relatively low concentrations. Many of the TR levels of these constituents were never found in detectable concentrations in the samples; the metals that were detected were only occasionally or never observed in excess of water quality criteria. As examples, boron concentrations were well below the critical levels that would be detrimental to irrigation, and Co and V were always below the criteria for irrigation, stock water, and aquatic life. The few samples with mercury in detectable levels may be the major exceptions, although concentrations were not analyzed to adequately low levels to resolve the status of mercury in relation to the various reference criteria; this applies also to the Little Bighorn River. Of the metals, Fe and Mn were most commonly found in relatively high concentrations, but their median concentrations did not exceed any of the reference criteria. In addition, these were analyzed according to total recoverable components and their dissolved concentrations would probably be relatively low and not indicative of water quality problems.

Levels of pH, BOD, DO, and possibly the fecal coliform levels in most of the tributary streams do not appear to have water quality problems (table 45). In addition, all of these streams were non-eutrophic with low nitrogen and phosphorus concentrations; this in turn corresponds to the lack of downstream change in the eutrophic status of the Little Bighorn. Turbidity-TSS and fecal coliform levels may pose water quality problems for Pass and Owl creeks, but this does not seem to be true for Lodge Grass Creek or for the various minor tributaries such as Reno Creek, where attention focuses primarily on the high TDS concentrations.

The Little Bighorn tributaries had a calcium bicarbonate water (with the exception of a calcium sulfate water in Lodge Grass Creek), and their ionic compositions were quite similar to those in the mainstem near Hardin; i.e., Mg < Na < Ca and $SO_4 < HCO_3$ with F and Cl insignificant. However, TDS concentrations were distinctively higher in the tributaries than in the Little Bighorn, although a wide range of variation (between 10 percent and 257 percent) was evident in these comparisons, depending upon the tributary stream, mainstem reach, and season. On the average, TDS levels in the tributaries were 131 percent higher than those in the upper reach of the mainstem and 68 percent higher than those in the Little Bighorn near Hardin. This in turn corresponds to the downstream increase in mainstem TDS concentrations. The tributary streams were very hard with low SAR values, and they created a high salinity hazard for use in

TABLE 44. Summary of trace element and miscellaneous constituent concentrations measured in the Little Bighorn River drainage.

	Little Bighorn River near Wyola				Little Bighorn River near Hardin				Little Bighorn River near Wyola and near Hardin together				Little Bighorn River tributaries[a]			
	Miscellaneous Constituents and Dissolved Metals								Total Recoverable Metals							
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Si	130	5.2	11	7.2	140	4.5	13	7.6								
As									4	<.001	<.01	<.01	5	<.001	<.01	<.01
B	37	0.0	0.320	0.075	62	0.009	0.151	0.108	2	.05	.18	.115	2	.05	.23	.14
Be									2	<.01	<.01	<.01	2	<.01	<.01	<.01
Cd									8	<.001	<.01	<.01	14	<.001	<.01	<.01
Co									2	<.01	<.01	<.01	2	.01	.03	.02
Cr									3	<.01	0.01	--	2	<.01	<.01	<.01
Cu									8	<.01	0.01	<.01	14	<.01	<.01	<.01
Fe	103	0.0	0.16	0.02	113	0.0	0.20	0.01	8	.13	2.5	.50	14	<.01	2.5	0.33
Hg									7	<.001	0.001	<.001	12	<.001	0.001	<.001
Li									2	.01	.01	.01	2	<.01	0.10	--
Mn	23	0.0	0.07	0.01	26	0.0	0.06	0.01	6	<.01	0.08	0.055	12	<.01	0.15	0.05
Pb									2	<.01	<.01	<.01	2	<.01	<.01	<.01
Se									2	<.001	<.001	<.001	2	<.001	<.001	<.001
V									2	.03	.03	.03	2	.03	.07	.05
Zn									8	<.01	0.02	<.01	14	<.01	0.02	<.01

NOTE: Measurements expressed in mg/l.

[a]Tributaries sampled were the following: Pass Creek (N=2), Spring Creek (N=1), Owl Creek (N=3), Little Owl Creek (N=1), Sioux Pass Creek (N=1), Lodge Grass Creek (N=4), Grey Blanket Creek (N=1), and Reno Creek (N=1).

TABLE 45. Summary of the physical parameters measured in various tributaries to the Little Bighorn River.

	Pass Creek near Wyola				Owl Creek drainage (Little Owl, Owl, and Sioux Pass creeks near Lodge Grass)				Lodge Grass Creek at Lodge Grass				Minor tributaries (Spring, Grey Blanket, and Reno creeks)			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	2	20.8	117	68.9	5	6.5	35.3	17.6	4	6.81	55.4	33.3	3	1.32	5.0	3.0E
Temp	2	0.0	10.0	5.0	5	0.0	10.5	9.3	4	0.0	11.9	2.9	3	8.0	13.3	9.7
pH	2	8.3	8.4	8.35	5	8.3	8.5	8.3	4	8.1	8.5	8.35	3	8.2	8.7	8.5
SC	2	601	1023	812	5	769	1156	970	4	843	1588	1121	3	837	1414	1036
TDS	2	494	856	675	5	648	829	791	4	659	1297	911	3	692	1215	861
Turb	2	30	53	42	5	3	60	34	4	2	13	6	3	<1	7	5
TSS	2	82	226	154	5	8.6	182	87	3	6.0	28.5	7.0	3	2	14.2	6.0
DO	1	--	--	9.7	5	9.3	12.2	10.6	4	10.2	12.9	12.2	3	11.5	12.6	12.4
BOD	1	--	--	1.5	5	1.7	2.5	2.3	4	1.1	2.9	2.2	3	1.2	3.5	2.2
FC	2	4	580	292	5	18	600	30	4	0	30	8	3	0	55	53
Ca	2	67	83	75	5	58	86	68	4	92	119	105	3	45	117	70
Mg	2	27	37	32	5	41	76	57	4	38	75	51	3	40	76	60
TH	2	280	359	320	5	313	507	400	4	385	609	471	3	360	489	458
Na	2	24	85	55	5	20	60	53	4	33	144	81	3	13	208	49
K	1	--	--	27	0	--	--	--	0	--	--	--	0	--	--	--
SAR	2	0.6	2.0	1.3	5	0.4	1.3	1.3	4	0.7	2.5	1.6	3	0.3	4.8	1.0
HCO_3	2	278	298	288	5	406	451	429	4	217	338	288	3	253	637	418
TA	2	234	244	239	5	333	370	357	4	186	287	236	3	208	566	367
SO_4	2	92	325	209	5	87	204	168	4	238	607	400	3	230	268	238
Cl	2	1.0	1.4	1.2	5	2.0	3.6	2.4	4	1.2	6.8	3.2	3	0.2	3.0	0.2
F	1	--	--	0.2	0	--	--	--	1	--	--	0.2	1	--	--	0.1
N	2	0.0	0.13	0.07	5	0.0	0.75	0.11	4	0.0	0.07	0.01	3	0.0	0.06	0.05
P	2	<.01	0.02	--	5	<.01	0.07	0.03	4	<.01	0.17	<.01	3	<.01	0.02	0.01

NOTE: Measurements expressed in mg/l.

irrigation (typically Class II waters, tables 15 and 16). Although these streams apparently have a good-to-excellent water quality for application to all stock animals, they do not appear to be suitable as a source of drinking water or public supply because of their high TDS and total hardness levels. In addition, the salinity levels in these streams were at levels adequate to influence the aquatic biota (i.e., generally greater than 670 mg/l) and to affect salinity-sensitive crop and forage species. Thus, water quality in the Little Bighorn River tributaries would probably be judged as only fair, primarily degraded by salinity factors; this is true of many prairie streams in eastern Montana.

BIGHORN RIVER DRAINAGE

BIGHORN RIVER MAINSTEM

The Bighorn represents a major river system with an extensive drainage in both Wyoming and Montana; it is the largest tributary to the Yellowstone River. As a result of its length, a large portion of the Bighorn's water has traveled considerable distances before it reaches the mainstem. Consequently, it is susceptible to a variety of factors, including reservoirs, tributary inputs, evaporation, and point and nonpoint pollution, which may degrade its initial quality.

The Bighorn River originates in Montana as the outlet from Yellowtail Reservoir, and the potential effect of the reservoir on downstream water quality has been discussed in several papers and reports (Soltero 1971, Soltero et al. 1973). Due to the dam, the current flow regimes and qualities in the river are probably not reflective of its natural condition. A few of these effects are readily apparent in the data summaries prepared for this inventory and will be considered in later sections in this report.

Although the annual average flows in the Yellowstone River at Billings are about 44 percent higher than those in the Bighorn at Bighorn (near the Yellowstone confluence) (USDI 1974), a large part of this excess is due to the spring flood, or the mainstem which is largely absent from the Bighorn due to artificial regulation. Median flows during the May-to-July period, as tabulated for this inventory, were about 222 percent higher in the Yellowstone at Billings than in the Bighorn at its mouth for the same period (a 3.22-fold difference). In turn, during the November-March low-flow periods in the Yellowstone, median Bighorn flows were actually 13 percent to 18 percent higher than those in the mainstem at Billings (table 31). As noted, the Bighorn would tend to have a relatively poor water quality due to its drainage length. Given the high flows of this stream, it therefore has the potential to exert a significant influence on Yellowstone mainstem quality. Due to the flow relationships described above, this influence should be strongest during the late summer, winter, and early spring when Yellowstone flows are at their minimum.

Water quality data are available from three stations on the Bighorn River as a part of USGS monitoring programs in the region (table 3). The three sites are equidistant with an upper station at St. Xavier just below the dam, a middle location near Hardin, and a lower site near the river's mouth at Bighorn. These data have been supplemented by a few WQB collections from various locations on the river. For many of the parameters, the data from the uppermost site (table 46) are representative of quality in the entire length of the stream, as

TABLE 46. Summary of the physical parameters measured in the Bighorn River at St. Xavier.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	51	124	5980	3140	53	1722	5580	3890	28	521	6700	4020	47	1670	20,240	5123
Temp	15	9.5	19.5	14.5	17	2.0	12.5	7.0	11	1.0	4.0	3.0	13	4.5	12.5	6.0
pH	39	7.0	8.2	7.8	46	7.2	8.4	8.0	26	7.3	8.3	8.0	42	6.6	8.5	7.9
SC	47	515	1090	765	51	657	1150	859	28	788	1160	924	47	576	1100	875
TDS	49	322	788	503	50	441	842	570	27	475	831	625	47	362	790	582
Turb	3	1.2	2.0	2.0	5	2.0	4.0	2.0	2	2.0	3.0	2.5	3	1.4	6.0	2.0
TSS	0	--	--	--	1	--	--	8.0	0	--	--	--	1	--	--	8.0
DO	3	9.6	10.8	10.0	5	11.2	12.8	11.4	2	12.8	12.8	12.8	4	10.6	13.2	12.1
BOD	3	0.7	1.5	0.8	5	0.7	2.4	1.2	2	0.6	0.7	0.7	4	0.7	2.7	1.8
FC	0	--	--	--	1	--	--	26	0	--	--	--	1	--	--	26
Ca	48	43	92	65	49	56	99	73	27	62	98	81	46	46	96	75
Mg	48	13	32	21	49	20	36	24	27	21	37	27	46	14	34	26
TH	50	160	360	249	53	220	389	286	28	240	394	316	48	180	380	294
Na	48	40	107	66	49	61	118	78	27	59	113	80	46	49	108	80
K	48	1.3	4.3	3.5	49	2.9	5.6	3.8	27	3.0	5.2	3.9	45	1.7	5.1	3.8
SAR	48	1.4	2.5	1.9	49	1.6	2.6	2.1	27	1.7	2.6	2.0	46	1.5	2.5	2.0
HCO_3	48	130	224	178	49	180	241	197	27	175	263	216	46	130	252	208
TA	8	115	156	140	10	150	180	162	4	181	198	183	7	162	187	182
SO_4	50	140	362	230	53	190	393	270	28	210	394	286	48	160	362	270
Cl	48	3.4	15	8.5	49	8	15	10	27	6.7	16	11	46	6.6	15	12
F	48	0.1	0.5	0.4	49	0.3	0.8	0.4	27	0.4	0.8	0.4	46	0.2	0.8	0.4
N	50	0.0	0.48	0.21	53	0.0	0.6	0.30	30	0.01	0.8	0.29	50	0.02	0.5	0.18
P	25	0.0	0.08	0.03 (.47?)	29	0.0	0.12	0.02	13	0.01	0.08	0.02	21	0.0	0.07	0.02

NOTE: Measurements expressed in mg/l.

downstream water quality changes did not appear to be as great in the larger river as those in the Little Bighorn.

The Bighorn River has a sodium-calcium-sulfate water throughout its length, and magnesium and bicarbonate are secondary ionic constituents. Fluoride, chloride, and potassium were minor constituents (although chloride levels were somewhat higher in the Bighorn River than in the Little Bighorn River). The waters in the river were very hard and non-saline, although TDS concentrations were high in comparison to the Little Bighorn and Yellowstone rivers--on the average, 1.43 times higher than the Little Bighorn, 2.64 times higher than the Yellowstone at Billings, and 1.95 times higher than the Yellowstone at Custer. The upper Bighorn showed a direct linear relationship between flow and TDS; this is generally the opposite of what has been observed in other large streams, and may be a reflection of reservoir influences which were carried downstream to Bighorn. Also, the unusually low TSS and turbidity levels at St. Xavier were probably the result of the reservoir acting as a sediment trap. Dissolved oxygen, BOD, and pH did not indicate water quality problems anyplace on the river, and fecal coliforms and TSS did not indicate water quality problems in the upper reach. All of these parameters were in accord with state criteria and the state's designation of the upper segment as a B-D_1 stream (Montana DHES, undated). Grab sample temperatures were also in accord with this criteria because temperatures were generally less than 19.4°C (table 8). Salinity and potential eutrophication therefore appear to be the major water quality problems in the upper reach. The high salinities approach values (670 mg/l) that could affect the aquatic biota, but the B-D_1 designation of the upper reach and its water quality are reinforced by the purported success of trout fisherman in this segment of the Bighorn River.

The concentrations of dissolved constituents remained constant throughout the extensive reach of the Bighorn in Montana; the greatest downstream increase was in sulfate (tables 47 and 48). As a result, TDS levels increased only slightly from St. Xavier to Bighorn (less than 11 percent). This suggests that due to their low flows or to their nearly equal salinity concentrations, the various Montana tributaries did not affect the river's salinity levels much. On the basis of these major parameters, the water in the Bighorn is expected to be excellent for the watering of all stock but unsuitable for municipal supply as a result of the high TDS and sulfate levels (table 9). Due to the high calcium-magnesium concentrations, the Bighorn has low SAR values and a low sodium hazard for irrigation; however, it has a high salinity hazard and is probably a Class II water that should be used with care in the irrigation of certain plants.

The river's TSS levels increased downstream below St. Xavier. Like the Little Bighorn, a spring sediment pulse is also evident in the Bighorn at Bighorn, probably a reflection of tributary inputs with their early spring runoff periods. As a result of the increase in TSS, the value of the stream's fishery would be expected to decline downstream. Using the index defined previously, the upstream fishery would be excellent (having turbidities less than 8 JTU) but would then become a fair fishery near its mouth, with an annual median TSS concentration of 120 mg/l (European Inland Fisheries Advisory Commission 1965). This is in accord with the state's classification change of the river from a B-D_1 in the upper reach to a B-D_2 stream below Hardin (Karp et al. 1976a). Median and maximum grab sample temperatures increased towards Bighorn during the March-to-October period--also in accord with the classification change.

TABLE 47. Summary of the physical parameters measured in the Bighorn River near Hardin.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	13	1600	5020	2960	16	2900	5200	3850	9	500	6550	4820	14	1500	8000	4420
Temp	13	10.8	21.0	15.3	16	0.0	10.0	3.0	10	0.0	7.0	4.0	14	0.5	18.0	11.8
pH	10	7.6	8.7	8.3	12	6.9	8.4	8.0	7	7.8	8.30	8.0	11	7.1	8.20	8.0
SC	11	560	1000	840	14	740	1160	875	7	770	1100	900	10	750	1110	885
TDS	12	362	722	580	16	514	691	632	9	538	952	689	13	472	787	637
Turb	0	--	--	--	0	--	--	--	1	--	--	4	0	--	--	--
TSS	0	--	--	--	0	--	--	--	1	--	--	14.8	0	--	--	--
DO	10	8.2	12.6	9.2	12	10.4	15.0	12.0	7	11.2	13.2	12.4	11	9.1	12.8	11.0
BOD	10	1.2	3.3	1.8	12	0.7	3.2	1.5	7	0.9	2.5	1.2	11	1.1	2.8	1.5
FC	10	1	490	100	10	0	130	8	7	0	270	12	6	41	7700	142
Ca	13	32	79	64	12	57	79	73	7	71	87	78	11	42	86	69
Mg	10	15	2.7	22	12	20	26	24	7	23	29	27	11	19	31	26
TH	10	140	310	250	12	230	300	280	7	270	340	300	11	180	340	280
Na	4	51	79	65	4	69	77	73	3	76	82	79	5	60	99	80
K	0	--	--	--	0	--	--	--	0	--	--	--	0	--	--	--
SAR	4	1.5	2.0	1.8	4	1.8	2.1	1.9	2	1.9	2.0	2.0	5	1.7	2.3	2.0
HCO_3	0	--	--	--	0	--	--	--	1	--	--	205	0	--	--	--
TA	4	108	166	131	4	152	172	165	3	168	193	176	5	149	185	166
SO_4	10	150	310	239	15	230	332	280	9	260	440	303	13	200	370	276
Cl	12	4.8	12	7.9	16	3.4	12	10	9	9.4	14	12	13	7.0	14	12
F	4	0.4	0.7	0.4	4	0.4	0.6	0.4	2	0.4	0.6	0.5	5	0.3	0.6	0.4
N	11	0.13	0.60	0.30	13	0.10	0.60	0.38	8	0.21	0.50	0.28	11	0.02	0.40	0.18
P	11	0.02	0.25	0.08	12	0.01	0.26	0.06	8	0.04	0.50	0.08	11	0.0	0.21	0.1 (1.0?)

NOTE: Measurements expressed in mg/l.

TABLE 48. Summary of the physical parameters measured in the Bighorn River at Bighorn.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	50	860	5970	3296	64	706	6500	3770	36	685	8520	4325	57	820	23,000	5610
Temp	23	7.0	21.0	16	28	0.0	8.5	2.0	17	1.5	10.5	4.8	29	0.6	21.7	15.5
pH	44	7.1	8.8	7.8	59	7.4	8.6	8.0	34	7.3	8.5	8.1	51	7.4	8.53	7.9
SC	44	580	1160	855	60	740	1180	911	34	555	1210	950	51	599	1090	899
TDS	42	365	836	555	57	516	854	621	33	362	862	666	49	371	848	619
Turb	5	3	20	10	8	3	30	8	4	18	120	62	8	11	260	75
TSS	16	14	288	80	14	15	973	40	15	35	1450	114	28	39.2	6460	342
DO	8	7.6	10.5	8.9	8	10.1	13.2	12.3	6	10.5	11.8	11.0	11	7.8	11.7	9.0
BOD	3	0.9	1.7	1.2	2	2.5	5.1	3.8	4	1.6	2.4	1.8	6	1.0	5.1	2.2
FC	4	30	2520	89	6	21	170	25	4	3	41	16	7	25	310	80
Ca	25	48	96	65	32	64	98	75	21	42	92	82	25	58	91	76
Mg	29	16	34	24	33	16	39	26	24	16	47	31	26	22	41	27
TH	43	190	384	273	59	250	402	300	33	171	415	332	49	224	400	316
Na	44	46	118	74	60	69	120	83	33	52	123	86	49	33	120	81
K	28	2.5	4.7	3.4	31	2.3	4.7	3.6	23	1.4	5.6	4.2	24	2.6	6.1	3.7
SAR	44	1.5	2.6	2.0	59	1.8	2.6	2.0	33	1.6	2.7	2.1	49	0.9	2.7	2.0
HCO_3	44	106	233	186	59	183	256	211	33	132	279	226	49	152	256	217
TA	6	127	161	153	8	157	194	166	3	184	197	189	7	153	210	176
SO_4	44	160	400	264	60	206	397	287	32	164	431	300	49	150	450	285
Cl	28	5.0	15	8	33	8.0	19	11	23	3.5	14	12	26	7.4	14	10
F	28	0.2	1.0	0.4	31	0.3	0.6	0.4	22	0.3	0.8	0.5	25	0.2	0.8	0.4
N	23	0.0	0.53	0.20	30	0.0	0.43	0.3	22	0.07	0.45	0.23	24	0.01	0.41	0.22
P	12	0.0	0.14	0.05	15	0.0	0.07	0.01	11	0.01	0.33	0.02	17	0.0	0.20	0.02

NOTE: Measurements expressed in mg/l.

The warm winter temperatures in the river at St. Xavier (table 46) and the subsequent declines of winter temperatures downstream to Bighorn (tables 47 and 48) probably reflect reservoir influences. Fecal coliform concentrations also tended to be higher in the lower river, but the state's criteria for average and grab sample concentrations in $B\text{-}D_2$ streams were violated in only a few instances.

Eutrophication may be a problem in the Bighorn River, but it is most obvious in the middle segment of the stream near Hardin. Of the various streams inventoried, this type of problem is most likely to occur in the Bighorn River. As observed on the Yellowstone, a distinct seasonal nitrogen cycle also became evident in the Bighorn River wherein nitrogen (N) levels were typically highest during the dormant winter and early spring seasons and lowest during the warmer, late spring-to-fall periods when biological activity would be at its highest. Distinct seasonal alternations were not evident in the phosphorus (P) data. At St. Xavier, both median N and P concentrations were below their reference criteria (table 46). However, eutrophic potential increased to Hardin where median P levels exceeded 0.05 mg/l during all seasons (table 47). In addition, median N concentrations at this location were very close to their reference level, especially during the critical summer period. Since median ammonia concentrations in the Bighorn ranged between 0.05 mg/l and 0.10 mg/l (table 49), total inorganic N concentrations in the stream might have been at levels high enough to exceed the N criteria (0.35 mg/l) for a large percentage of the time during the August-to-April period. Thus, eutrophy would be indicated when both P and N often exceed these nutrient standards, demonstrated by extensive algal growths or "moss" in the middle river near Hardin.

However, eutrophic potential appears to decline downstream below Hardin to Bighorn due to the decline in median P levels (table 48). The river is probably more P- than N-limited at St. Xavier, with a lower probability of eutrophy than near Hardin where the river is most likely nitrogen-limited. Also, the river is probably more P-limited near its mouth with a lower probability of eutrophy than indicated at Hardin. However, median N and P concentrations in the Bighorn were well below the reference criteria used by the EPA (USEPA 1974b).

Data for the minor constituents and trace elements in the Bighorn River are summarized in table 49. Silica concentrations were below the national average for surface waters, and all metal concentrations were generally very low in the upper river and did not indicate water quality problems. This was also true of the river at Bighorn, although the metals tended to increase in concentration downstream. The trace elements would not be expected to detract from any water uses, with the possible exception of mercury, which was observed at levels approaching 7 μg/l in a few samples. The high TR concentrations of iron in the lower river were probably related to the high sediment levels that were occasionally obtained there. High TR levels of Fe were not observed in the upper reach where TSS concentrations were consistently low, and dissolved concentrations of Fe in the river near Bighorn were generally insignificant in all samples. Strontium levels were in excess of the average value for major streams (Durum and Haffty 1963) and did not indicate excessive Sr-90 levels.

Minor constituents on the whole did not cause pollution. In general, there was no extensive organic pollution (dissolved oxygen was near saturation and TOC levels were low), no synthetic detergents (MBAS values were low), and no ammonia

TABLE 49. Summary of trace element and miscellaneous constituent concentrations measured in the Bighorn River.

	Upper river near St. Xavier and near Hardin								Lower river at Bighorn							
	Miscellaneous Constituents and Dissolved Metals				Total Recoverable Metals[a]				Miscellaneous Constituents and Dissolved Metals				Total Recoverable Metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Color	67	1	21	5					10	1	12	4				
DO[b]									22	86	109	100				
Fecal Strep									11	7	1300	66				
MBAS	22	0.0	0.10	0.01												
NH_3-N	56	0.0	0.59	0.05					6	0.04	0.19	0.10				
Si	167	6.0	16	11					91	4.0	21	9.6				
TOC	11	1.0	22	4.0					5	4.8	11	7.6				
Ag	4	0.0	.001	0.0												
Al													1	--	--	.800
As	4	0.0	.006	.001	3	<.001	<.01	<.01	5	0.0	.002	.002	7	<.001	<.01	0.002
B	134	.060	.300	.110	1	--	--	.11	50	.058	.200	.120	6	<.10	0.46	0.13
Ba	4	0.0	0.0	0.0												
Be	2	0.0	0.0	0.0	1	--	--	<.01					1	--	--	<.01
Cd	4	0.0	0.0	0.0	4	<.001	<.01	<.01	5	0.0	.001	0.0	14	0.0	0.02	<.01
Co	4	0.0	.001	0.0	1	--	--	.02	5	0.0	0.0	0.0	6	<.01	0.08	<.05
Cr					6	0.0	<.01	0.0	5	0.0	0.0	0.0	7	0.0	0.05	<.01
Cu	4	.004	.030	.013	4	<.01	<.01	<.01	5	.001	.003	.002	15	<.01	0.05	0.01
Fe	98	0.0	.210	.010	4	.16	.25	.22	71	0.0	.360	.030	14	.07	8.2	.82
Hg					3	<.001	0.007	<.001	5	0.0	0.0	0.0	12	0.0	0.007	<.0002
Li					1	--	--	.05					1	--	--	.04
Mn	31	0.0	.132	.005	2	.01	.07	.04	11	0.0	.020	.010	13	.02	.22	.05
Mo	4	0.0	.020	.004												
Ni	4	0.0	.010	.003												
Pb	4	0.0	0.0	0.0					5	.001	.003	.002	11	<.01	0.100	<.100
Se					1	--	--	<.001	5	.001	.003	.002	7	<.001	0.004	0.002
Sr	4	0.804	1.070	0.910									3	.36	2.1	.52
V	4	0.0	.0014	.0010	1	--	--	.04					3	<.01	<.10	<.10
Zn	4	.017	.051	.022	3	<.01	0.01	<.01	5	.002	.020	.010	14	<.01	0.05	0.02

NOTE: Measurements expressed in mg/l.

[a]Pb: <0.01, N=2).

[b]DO expressed as percentage of saturation.

toxicity (un-ionized ammonia concentrations were low given the median total-NH_3 and pH levels of the stream). In addition, municipal wastewater discharges do not appear to have a major effect on the Bighorn River, as the median annual fecal coliform to fecal strep ratio was less than one (FC:FS=0.80). FC:FS ratios between 0.7 and 1.0 indicate that stream bacteria are derived primarily from animal and soil rather than human sources (Millipore Corporation 1972). As a final point, the waters of the Bighorn River were uncolored--color was typically less than ten units. As a result, the waters in the river should be aesthetically pleasant unless turbidity or eutrophication occur.

BEAUVAIS CREEK

In addition to the Little Bighorn River, several other smaller streams (with median flows about 5 cfs to 50 cfs) join the Bighorn River in Montana or have portions of their drainage areas in the state. The USGS has sampled Beauvais Creek, which drains the west central part of the Bighorn drainage between Yellowtail Reservoir and Hardin, for several years as a hydrologic benchmark station." The USDI (1974) describes this type of station as one that:

> . . . provides hydrologic data for a basin in which the hydrologic regimen will likely be governed solely by natural conditions. Data collected at a benchmark station may be used to separate effects of natural from manmade changes in other basins which have been developed and in which the physiography, climate, and geology are similar to those in the undeveloped benchmark basin.

Beauvais Creek provides insight into the natural quality of water in streams that have a prairie, rather than a mountainous, origin. As indicated in table 50, data were sufficient for a seasonal classification of this stream's water quality.

As might be predicted for a stream that is little affected by man's activities, median BOD_5 levels in Beauvais Creek were consistently low (<1.6 mg/l). However, values in excess of 5 mg/l and approaching 10 mg/l were obtained sporadically, indicating that moderately high background BOD_5 concentrations can occur from natural sources at particular times. Occasionally, high BOD_5 levels have been measured in other streams of the basin in relation to their typically low median concentrations. However, even a BOD_5 of 10 mg/l is not particularly high in comparison to values that have been obtained in organically polluted streams. As a result, DO concentrations in Beauvais Creek were near saturation (with a median DO saturation of 97 percent), and minimum values were consistently above the state's criteria for a B-D stream. Similarly, values of pH were typically within state standards (table 8), and median levels were close to those obtained on other streams possessing an adequate number of readings (approaching a value of 8.0 units for the entire study area). Also, grab sample temperatures from Beauvais Creek were not outstanding, but the relatively high maximum readings in the summer would indicate that this creek is probably a warm-water fishery--a $B\text{-}D_3$ rather than a $B\text{-}D_1$ or $B\text{-}D_2$ stream.

The direct relationship between flow and suspended sediment and the inverse relationship between flow and dissolved solids were not as noticeable

TABLE 50. Summary of the physical parameters measured in Beauvais Creek near St. Xavier (Bighorn River tributary).

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	26	3.0	15.	7.9	31	1.5	182.	8.6	15	8.8	169.	22.	24	6.2	254.	27
Temp	23	3.0	22.0	13.0	28	0.0	6.0	0.0	10	0.0	10.0	3.0	20	9.0	20.0	17.3
pH	26	7.4	8.4	8.0	31	6.8	8.7	7.8	14	7.4	8.5	8.0	23	7.1	8.6	7.8
SC	26	1100	1920	1395	31	600	2150	1530	14	580	1490	1160	23	930	1500	1170
TDS	26	868	1360	1105	31	433	2020	1160	14	418	1120	830	23	655	1240	903
Turb	0	--	--	--	0	--	--	--	0	--	--	--	0	--	--	--
TSS	12	32	2400	122	17	37	3380	286	8	84	5940	634	13	104	9870	322
DO	22	7.2	12.0	8.8	28	10.0	12.6	12.0	11	9.8	12.2	11.6	20	7.2	11.0	9.2
BOD	18	0.3	4.0	1.4	20	0.4	7.7	1.5	10	1.0	10.0	1.5	16	0.2	2.8	1.2
FC	5	29	1600	140	8	13	510	50	3	11	200	100	6	20	1500	145
Ca	26	133	268	225	31	39	380	230	14	45	200	124	23	83	215	170
Mg	26	31	56	48	31	11	84	52	14	11	48	31	23	23	50	43
TH	26	457	893	750	31	140	1290	770	14	158	700	432	23	305	738	610
Na	26	20	79	36 (193?)	31	40	130	67	14	43	172	88	23	13	120	43
K	26	1.8	5.3	3.4	31	2.3	7.4	3.2	14	2.0	5.9	3.3	23	2.0	6.5	2.9
SAR	26	0.3	1.4	0.6 (3.9?)	31	0.6	3.0	1.0	14	0.8	3.8	1.9	23	0.3	3.0	0.8
HCO_3	26	150	273	191	31	92	319	247	14	95	284	204	23	150	270	224
TA	7	136	224	169	9	80	248	218	4	129	189	142	6	173	221	195
SO_4	26	510	778	656	31	240	1160	680	14	200	670	450	23	330	655	510
Cl	26	1.6	6.	2.5	31	1.6	9.	3.8	14	1.6	7.2	3.8	23	1.4	8.0	2.7
F	26	0.0	0.9	0.4	31	0.3	0.7	0.4	14	0.4	1.0	0.5	23	0.0	1.1	0.4
N	24	0.0	0.58	0.02	29	0.0	0.45	0.20	14	0.0	0.72	0.11	23	0.0	0.29	0.07
P	26	0.0	0.21	0.05	31	0.01	1.5	0.05	13	0.02	2.2	0.10	23	<.01	0.52	0.05

NOTE: Measurements expressed in mg/l.

in Beauvais Creek as in some of the other streams of the study area. These contradictions were most obvious in the transition from spring to summer, when flows and dissolved solids concentrations increased, but suspended sediment decreased. Like the lower Little Bighorn River, Beauvais Creek also demonstrated a secondary flow peak in the spring, probably reflective of the earlier prairie runoff period. The stream's proportions of sodium, its SAR ratios, and its TSS levels also increased at this time, although its TDS concentrations declined. However, regardless of runoff events, both TDS and TSS concentrations were high in Veauvais Creek during all seasons, suggesting naturally high background levels of these parameters in the Bighorn drainage and in the prairie-type of stream in general. As a result, and on the basis of the common constituents and TSS, Beauvais Creek apparently has a naturally poor water quality in relation to most beneficial uses.

The waters tended to be slightly saline, and the TDS, sulfate, and probably the turbidity levels of the stream were for the most part above the recommended standards and permissible criteria for drinking water and public supply (table 9). Although TDS concentrations were less than the reference levels for various stock animals, sulfate concentrations were in excess of the threshold level for stock in nearly 70 percent of the samples. The stream has a low sodium hazard for irrigation (SAR values are low) but probably has a high salinity hazard (Richards 1954), Class II water for this use due to the creek's high specific conductance levels and high sulfate concentrations (tables 15 and 16). Furthermore, these salinity features also suggest a potential to adversely affect the aquatic biota (TDS levels were in excess of 670 mg/l). More important, the high suspended sediment levels would probably degrade the creek's fishery, as the annual median TSS concentration (314 mg/l) indicates a poor class of stream (European Inland Fisheries Advisory Commission 1965). TSS concentrations in excess of 2000 mg/l were obtained occasionally from the creek during all seasons; these slugs of sediment may also affect the biota.

As in most Yellowstone drainage streams, chloride, fluoride, and potassium were insignificant constituents in Beauvais Creek. The waters were calcium sulfate; sodium and magnesium were the secondary cations and bicarbonate was the secondary anion. As a result of the high calcium and magnesium concentrations, SAR values were low, but the waters were unusually hard, which would detract from the stream's value as a potential domestic supply. Median phosphorus levels in Beauvais Creek were equal to or in excess of the reference criteria indicating conditions for eutrophication; however, the waters were nitrogen-limited and therefore non-eutrophic. Less than 12 percent of the samples from Beauvais Creek had both P and N in excess of the corresponding criteria, and none of the samples had both P and N in excess of the EPA's nutrient standards for eutrophication (USEPA 1974b). Peak nitrogen levels were again obtained during the dormant winter season, declining considerably during the biologically active summer-fall period. The Beauvais Creek data indicate that high phosphorus concentrations, along with the high TSS and TDS levels, are natural features of this drainage area.

High natural levels of bacteria, both fecal coliform and fecal strep are also evident in the drainage during all seasons (tables 50 and 51). Median fecal concentrations in Beauvais Creek did not exceed the state's average criteria (Montana DHES, undated), but 18 percent of the grab samples had fecal levels in excess of 400 colonies per 100 ml. This violates the state's

TABLE 51. Summary of trace element and miscellaneous constituent concentrations measured in tributaries to the Bighorn River.

	Tributaries to Yellowtail Reservoir				Soap and Rotten Grass creeks				Beauvais Creek							
	Total Recoverable Metals								Miscellaneous Constituents and Dissolved Metals[a]				Total Recoverable Metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Color									21	1	48	4				
CN									1	--	--	0.0				
DO[b]									26	87	133	97				
Fecal Strep									23	34	3100	410				
Si									95	5.8	26	14				
Ag													1	--	--	<.01
Al									8	0.0	.500	0.0	1	--	--	.100
As	1	--	--	.001	3	<.01	<.01	<.01	2	0.0	0.0	0.0	4	.001	.02	.002
B									33	.080	.424	.160				
Ba									1	--	--	0.0	1	--	--	0.0
Be									1	--	--	0.0				
Cd	7	<.001	<.001	<.001	8	<.001	<.01	<.01	13	0.0	.003	0.0	4	<.01	0.02	0.01
Co									13	0.0	.001	0.0				
Cr									8	0.0	0.0	0.0	9	0.0	.04	0.0
Cu	7	<.01	<.01	<.01	8	<.01	0.01	<.01	12	0.0	.024	.006	4	<.01	0.08	0.02
Fe	7	<.01	4.5	0.18	8	.18	9.5	1.5	70	0.0	.75	.31	4	.98	14	4.6
Hg	6	<.001	<.001	<.001	5	<.001	<.001	<.001					4	0.0	0.0002	<.0001
Li									12	0.0	.06	.03				
Mn	7	<.01	0.25	0.01	4	.13	.50	.21	38	0.0	.31	.03	4	.12	2.2	.44
Mo									10	0.0	.018	.002				
Ni									12	0.0	.008	.004				
Pb					4	<.01	<.01	<.01	13	0.0	.017	.002	4	<.100	<.100	<.100
Se									1	--	--	.012	4	.001	.005	.003
Sr									12	.37	3.8	2.25				
V									1	--	--	.0014				
Zn	7	<.01	0.03	0.01	8	<.01	0.07	0.02	14	0.0	.05	.02	4	.07	.31	.20

NOTE: Measurements are expressed in mg/l.

[a]Ag: 0.0, N=1.

[b]DO expressed as percentage of saturation.

standard (table 8). An annual median FC:FS ratio of 0.26 was obtained in the stream, and this ". . . may be taken as strong evidence that pollution derives predominantly or entirely from . . . (animal) wastes" (Millipore Corporation 1972). This would be expected given the isolation of Beavais Creek from man's activities. Most of the fecal loads in the Little Bighorn and Bighorn rivers, the Yellowstone River above Laurel, and Owl and Lodge Grass creeks are probably derived from natural sources. A major exception is the Yellowstone River below Billings which has median fecal concentrations at Huntley (table 32) in excess of the 145 colonies per 100 ml obtained from Beauvais Creek; this is probably a result of the municipal wastewater discharges that reach the Yellowstone through the urbanized Laurel-Billings reach of the river (Karp et al. 1976b).

The water in Beauvais Creek was generally clear and the median silica concentration was equal to the national average for surface waters (Davis 1964). The trace elements, except cyanide, barium, lead, and silver, had detectable TR concentrations in at least some samples, and several of the TR values (Fe, Mn, and Zn, and possibly Cd and Cu) suggested potential water quality problems (table 51). As observed in most of the streams, B, Fe, Mn, and Sr were usually high. However, the high TR concentrations were probably related to the high suspended sediment levels of the stream, and dissolved concentrations indicated non-critical levels of most of the trace elements, particularly B, Cd, Cu, Mn, and Zn. Although dissolved strontium concentrations were high, radiochemical analyses did not indicate a problem (USDI 1966-1974b), as dissolved gross beta concentrations (a median of 6.3 PC/l and a range of 3.5 to 14 PC/l) and dissolved radium-226 concentrations (a median of 0.08 PC/l and a range of 0.05 to 0.15 PC/l) were well below the state and NTAC criteria (tables 8 and 9). Dissolved uranium concentrations ranged from 1.2 µg/l to 4.6 µg/l, within the range (0.1 to 10 µg/l) found in most natural waters (USDI 1970). Of the trace elements, only iron may be a potential water quality problem in Beauvais Creek; concentrations may be too high for the aquatic biota and municipal supply.

The median dissolved concentration of iron exceeded the criteria for freshwater life, and about 68 percent of the samples from Beauvais Creek had dissolved iron levels in excess of the criteria for the aquatic biota (table 19). The median dissolved concentration of iron was almost equal to the reference criteria and standard for surface water public supply and for drinking water; thus, about 50 percent of the samples from Beauvais Creek had dissolved iron concentrations above these specified levels. However, the high levels of iron in Beauvais Creek are apparently not related to pollution inputs, but rather originate from natural sources. This suggests that naturally high iron concentrations may be characteristic of the Yellowstone Basin, particularly in association with high suspended sediment concentrations, with the iron derived primarily from the prairie streams.

Data are also available for various herbicide-pesticide analyses of samples from Beauvais Creek (USDI 1966-1974b). Of the 102 individual analyses for 18 parameters only DDT was detected (0.02 µg/l), and only in a single sample (a detection success of 1.0 percent). Detection of these parameters was more common in the Bighorn River at St. Xavier due to proximity of agricultural activity; 4.2 percent of the analyses provided detectable concentrations. DDT and 2,4-D were detected in single cases with concentrations of 0.08 and 0.04 µg/ However, the low probability of detecting herbicides and pesticides and their generally low concentrations indicate that they do not cause water quality problems in the Bighorn drainage.

OTHER TRIBUTARIES ABOVE HARDIN

Some water quality data are available on several other streams in the Bighorn drainage as a result of state WQB sampling programs in the region (Karp and Botz 1975, Slack et al. 1973). These tributaries can be separated into four groups:

1) streams which drain the same general area as Beauvais Creek between Yellowtail Reservoir and Hardin, but on the opposite (eastern) side of the Bighorn River (Soap and Rotten Grass creeks);

2) creeks which drain the mountainous areas around Bighorn Lake in south central Montana and empty directly into the reservoir;

3) Sage Creek, west of Bighorn Lake and unique in its southerly flow, which joins the Bighorn system in Wyoming; and

4) Tullock Creek, which drains the northeast segment of the Bighorn drainage between Hardin and Bighorn, joining the mainstem very near its mouth.

Statistical summaries of the major water quality parameters for the first two groups listed above are presented in table 52. Tullock Creek is discussed in the next section of this report.

Date from Beauvais Creek indicate that high concentrations of suspended sediment and dissolved solids probably occur naturally in many of the streams in the Bighorn, and, possibly, the Yellowstone drainages. Thus, as in Beauvais Creek, the high levels of TDS and TSS in Soap and Rotten Grass creeks are probably the result of natural features, although they may be amplified by man's activities. Man's activities may also account for the slightly greater BOD_5 levels in Soap and Rotten Grass creeks over those in Beauvais Creek (table 50). However, neither the BOD_5 concentrations nor the levels of pH, DO, and SAR in Soap and Rotten Grass creeks suggested pollution problems, although fecal coliform concentrations were high and occasionally exceeded the state recommendation.

Several other similarities are evident between Beauvais, Soap, and Rotten Grass creeks, possibly due to the closeness of the respective drainage areas. They all have streams with similar flows tending to have slightly saline, calcium sulfate compositions and extremely hard waters. In all three streams sodium, magnesium, and bicarbonate are secondary ions and chloride and fluoride concentrations are apparently insignificant; SAR ratios are low; waters are non-eutrophic and nitrogen-limited with median phosphorus concentrations very near or greater than reference level; and concentrations of metals are low with the possible exceptions of iron, manganese, and zinc (table 51). The calcium sulfate water in these group 1 streams suggests that gypsum ($CaSO_4$) formations may exist in the Yellowtail-Hardin portion of the Bighorn drainage; this is most apparent in Gypsum Creek (table 52).

In general, the water quality in Soap and Rotten Grass creeks is poor and poses the same problems for water use as Beauvais Creek. The high TDS and sulfate (and possibly iron) concentrations and the occasionally high turbidities would detract from using the streams as municipal supplies (USDHEW 1962)

TABLE 52. Summary of the physical parameters measured in various tributaries to the Bighorn River.

	Tributaries to Yellowtail Reservoir near Fort Smith[a]				Soap Creek near St. Xavier				Rotten Grass Creek near St. Xavier			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	8	0.5E[b]	168	23.8	3	12.5	138	15E	4	18	112	20.2
Temp	8	6.5	13.0	9.9	3	0.0	3.0	15.1	5	0.0	11.6	0.5
pH	8	7.90	8.50	8.30	3	7.40	8.50	8.40	5	7.60	8.30	8.20
SC	8	307	2300[b]	388	3	849	1500	1021	5	843	2020	1536
TDS	8	243	2162[b]	302	2	690	822	756	4	726	1318	1237
Turb	7	2	125	7	3	8	80	51	4	19	90	65
TSS	8	6	402	25.5	3	22.8	341	178	4	25	996	183
DO	8	9.5	11.8	10.4	3	9.9	13.2	10.5	5	10.3	13.1	12.2
BOD	7	1.3	2.2	2.0	3	1.6	3.2	2.5	5	1.8	4.1	2.9
FC	7	0	480	0	2	4	610	307	5	20	1980	84
Ca	8	44	483[b]	54	2	84	117	101	4	83	160	142
Mg	8	8.9	84	18	2	42	44	43	4	38	83	67
TH	8	152	1552[b]	205	2	391	467	429	4	362	715	641
Na	8	1.0	21	4.8	2	43	56	50	4	65	124	115
K	1	--	--	18	0	--	--	--	0	--	--	--
SAR	8	0.0	0.3	0.2	2	0.9	1.1	1.0	4	1.5	2.2	1.7
HCO_3	8	148	234	195	2	257	285	271	4	254	314	285
TA	8	121	198	165	2	224	241	233	4	208	257	233
SO_4	8	6.6	1392[b]	34	2	227	334	281	4	283	656	621
Cl	8	0.3	15	1.5	2	2.3	7.0	4.7	4	3.4	7.0	6.0
F	1	--	--	1.2[b]	1	--	--	0.5	1	--	--	0.4
N	8	0.0	0.25	0.06	2	0.03	0.04	0.035	4	0.06	0.79	0.14
P	8	<.01	0.04	<.01	2	0.04	0.04	0.04	4	0.03	0.24	0.10

NOTE: Measurements are expressed in mg/l.

[a]Crooked, Gypsum, Porcupine, Dry Head, Hoodo, Big Bull Elk, Little Bull Elk, and Black Canyon creeks.

[b]Data from Gypsum Creek.

as would the very hard nature of the water. The high TSS-turbidity and TDS levels may also adversely affect the aquatic biota (European Inland Fisheries Advisory Commission 1965, Ellis 1964); consequently, these streams indicate poor water quality for fishery needs.

These creeks have low sodium hazards but high salinity hazards for irrigation (probably a Class II water) that should be used with care in application to certain crop and forage species (tables 15-17). In addition, although TDS concentrations are indicative of a good class of water for stock animals, sulfate concentrations in Rotten Grass Creek exceeded the threshold concentration for stock animals (California WQCB 1963).

The Yellowtail tributaries have the best water quality in the Bighorn drainage. This can be shown by ranking the annual median TDS concentrations of the various streams as follows:

1) Yellowtail tributaries--about 302 mg/l;
2) upper Little Bighorn River--346 mg/l;
3) Sage Creek--about 464 mg/l;
4) lower Little Bighorn River--470 mg/l;
5) upper Bighorn River--566 mg/l;
6) lower Bighorn River--612 mg/l;
7) middle Bighorn River--630 mg/l;
8) Little Bighorn River tributaries--about 810 mg/l;
9) Soap and Rotten Grass creeks--about 1000 mg/l;
10) Beauvais Creek--1026 mg/l; and
11) Tullock Creek--about 1280 mg/l.

Except in the Yellowtail tributaries, Sage Creek, and the Little Bighorn River, water quality in the tributaries is generally poorer than that in the mainstem streams.

The effect of Beauvais, Soap, and Rotten Grass creeks on the Bighorn River is evident in the above listing by the increase in mainstem TDS concentrations from St. Xavier to Hardin. The decline in mainstem TDS from Hardin to Bighorn is probably due to dilution from the Little Bighorn River, which joins the Bighorn below the mainstem-Hardin sampling station.

The low TSS-turbidity values and low TDS and fecal coliform concentrations in the Yellowtail tributaries (excluding Gypsum Creek) probably result from the mountainous drainages of these streams (the Pryor and Bighorn mountains) and the general lack of an extensive prairie system (USDI 1968). The waters were definitely non-saline, although they were very hard as a result of the high calcium concentrations. Pollution problems were not indicated by DO, pH, and BOD_5 values; this is appropriate as the streams are generally removed from man's activities. All of the constituents for which there were data were in accord with state standards (table 8). Consequently, the tributary streams to Yellowtail Reservoir appear to be suitable for all beneficial uses--drinking water and public supply (although softening may be required due to the hard waters), stock water, and the irrigation of all crop and forage plants (a Class I water); however, the unsurveyed, mountainous and remote nature of these streams would probably preclude their extensive use by man (USDI 1968).

The TR concentrations of the metalsin the Yellowtail tributaries were generally low (table 51); thus, the trace elements should not detract from any of the water uses. In addition, these streams should be excellent fisheries, if no physical barriers are present. The tributary fisheries would probably be cold-water due to the orographic locations of the streams; these creeks have been given a B-D_1 designation by the State of Montana (Montana DHES, undated). In contrast to the Bighorn River, the waters in these tributaries were non-eutrophic and probably more phosphorus- than nitrogen-limited.

Concentrations of all ionic constituents, with the exception of calcium and bicarbonate, were relatively low in the group two streams. This was most distinct in terms of their low sodium (and SAR) and sulfate levels in relation to the higher concentrations of these two ions in the other streams of the Bighorn drainage. The presence of such chemical features would indicate extensive limestone formations in the Bighorn-Pryor Mountains.

Although Sage Creek has a different drainage pattern than the other Bighorn tributaries, it originates in the same mountainous area as the western tributaries to Yellowtail Reservoir (Pryor Mountains), and as a result, Sage Creek has a similar type of water as the group two streams (table 53). However, Sage Creek has a more extensive prairie drainage above its sampling location near Warren, contributing to its water quality. Sage Creek also has non-saline and calcium bicarbonate waters which are very hard with low trace element concentrations, but higher concentrations of TDS and most ionic constituents than the Yellowtail tributaries. Concentrations of sodium and sulfate are particularly high. These higher ionic concentrations would not preclude the use of the stream's water for stock or irrigation. That is, Sage Creek may be classified as a Class I water with a low sodium and a medium salinity hazard, although its high TDS levels and hardness might give the water a borderline classification for public supply and drinking water. Relatively high TR iron (and possibly manganese) levels were evident in Sage Creek, as in many streams in the Yellowstone Basin. Iron was found in high concentrations in one sample in association with high suspended sediment concentrations. Such high iron and manganese levels may reduce the water's value as municipal supply, but the data were not adequate for a definite assessment of this nature.

The water in Sage Creek was non-eutrophic, and DO, pH, BOD_5, SAR, fecal coliform, and most ionic constituent levels conformed to state criteria where applicable. The relatively high TSS-turbidity levels, therefore, may be the major detractions from the water quality. The high TSS levels in Sage Creek at Warren may be related to its comparatively long prairie segment, as in Pryor Creek, and in contrast to the orographic drainage of the Yellowtail tributaries.

The Montana fishery in Sage Creek is probably cold-water due to its closeness to the Pryor Mountains. This means that it is classified as a B-D_1 stream, although the stream would probably provide only a fair fishery due to the high TSS concentrations.

TABLE 53. Summary of the physical parameters and total recoverable metals measured in Sage Creek near Warren during the August-October period.

	Physical Parameters N	Min	Max	Med		Total Recoverable Metals N	Min	Max	Med
Flow	2	15	62.0	38.5	As	2	<.001	<.001	<.001
Temp	2	4.0	12.0	8.0	Cd	2	<.001	<.001	<.001
pH	2	8.20	8.40	8.30	Cu	2	<.01	<.01	<.01
SC	2	488	662	575	Fe	2	0.3	4.1	2.2
TDS	2	401	527	464	Hg	1	--	--	<.001
Turb	2	7	44	26	Mn	2	<.01	0.11	--
TSS	2	22	154	88	Zn	2	<.01	0.02	--
DO	2	9.3	10.9	10.1					
BOD	2	1.5	1.7	1.6					
FC	2	<100	115	--					
Ca	2	63	67	65					
Mg	2	22	28	25					
TH	2	260	272	266					
Na	2	1.8	42	22					
K	0	--	--	--					
SAR	2	0.0	1.1	0.6					
HCO_3	2	212	248	230					
TA	2	174	212	193					
SO_4	2	56	173	115					
Cl	2	0.1	9.0	4.6					
F	0	--	--	--					
N	2	0.15	0.01	0.08					
P	2	<.01	0.05	--					

NOTE: Measurements are expressed in mg/l.

TULLOCK CREEK

Tullock Creek is the most northern tributary of the Bighorn River (USDI 1968), and as a result, has an extensive prairie drainage. This is reflected in the type of water in the creek and in its quality. As suggested previously, Tullock Creek probably has the poorest water quality in the Bighorn drainage. Some water quality data are available from the state WQB for an upper site on the stream and for a lower station near its mouth (table 6). The upstream data were insufficient for a seasonal or flow-related classification; data from the lower location were adequate for a separation based on flow, as seen in table 54.

The chemical composition of water in Tullock Creek was generally different from that in other streams in the Bighorn system. Upstream, the waters were sodium bicarbonate in nature, with sulfate the secondary ionic constituent. Downstream at low flows, the waters became sodium sulfate in character, which is characteristic of many prairie streams. However, at high flows the creek in its lower reach retained its sodium bicarbonate type of water--probably a reflection of upstream influences being carried downstream during the periods of high discharge.

Calcium and magnesium are the secondary cations in Tullock Creek. The greater magnesium over calcium concentrations, particularly noticeable on an equivalence basis, differed from the other streams inventoried, which had greater calcium over magnesium concentrations. As in most streams in the Yellowstone Basin, chloride and fluoride concentrations were insignificant in Tullock Creek.

Median values of pH and BOD_5 were slightly higher in Tullock Creek than those established for other streams in the study area--higher than the median pH approaching 8.0 units and higher than the median BOD_5 which was generally less than 3.0 mg/l. However, Tullock Creek is a B-D_2 stream, and its pH values were within the state criteria for this designation (table 8). In addition, its BOD_5 levels, though comparatively high, did not suggest that too much organic pollution was reaching the stream. As suggested by the Beauvais Creek data, sporadically high BOD_5 levels in excess of 4 mg/l and approaching 10 mg/l might be expected as a natural occurrence.

The stream's DO concentrations were greater than the state's minimum criteria for a B-D_2 stream; a few samples, however, demonstrated DO values slightly less than this recommendation (7 mg/l). This fact, and the high maximum summer temperatures obtained from the stream (greater than 19.4°C) indicate that it would be more appropriate to classify Tullock Creek a B-D_3 stream instead of a B-D_2 stream. This is probably true of many of the small lowland streams in the Bighorn drainage.

Fecal coliform concentrations tended to increase downstream in Tullock Creek, and occasional grab sample concentrations at the lower site exceeded the state recommendation; however, the median levels of fecals were less than the state's average criteria. Also, trace element concentrations appeared to be high (except As, Cd, Hg, and Pb) in Tullock Creek (table 54). This was true of iron and manganese, but, after studying the matter, TR concentrations of B, Co, Cr, Li, and V do not appear to be critical levels in relation to

TABLE 54. Summary of the physical parameters and trace elements measured in the Tullock Creek drainage.

	Upper Tullock Creek				Tullock Creek near Bighorn[a]				Tullock Creek near Bighorn[b]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	3	1.8	25.5	24.2	7	0.0	7.8	2.8	7	18	481	30.1
Temp	3	0.0	17.2	0.0	6	0.0	21.6	10.6	7	0.2	19.0	4.5
pH	3	7.90	8.80	8.40	7	7.70	8.69	8.25	7	7.00	8.80	8.38
SC	3	1184	1270	1226	7	692	2884	2107	7	236	2422	911
TDS	3	943	1087	968	6	556	2415	1651	6	196	1971	1221
Turb	3	27	44	35	7	13	42	30	7	21	485	85
TSS	2	38	118	78	6	30.0	97.6	58.4	7	80.5	940	164
DO	3	8.0	11.6	8.5	5	4.8	9.8	8.2	6	7.7	11.9	9.8
BOD	3	4.4	4.9	4.9	5	1.4	5.8	3.1	6	2.1	>11	4.6
FC	2	0	5	3	5	11	500	34	4	0	690	151
Ca	3	32	41	34	7	33	81	54	7	17	57	37
Mg	3	39	62	43	7	20	77	62	7	8.3	73	37
TH	3	245	359	256	6	197	521	380	7	79	433	245
Na	3	170	185	184	7	71	536	345	7	18	450	200
K	0	--	--	--	4	3.0	7.0	6.0	7	4.5	7.7	6.9
SAR	3	4.2	5.1	4.6	6	2.1	11.4	7.6	7	0.9	9.7	5.6
HCO_3	3	382	514	421	7	179	645	566	7	93	686	412
TA	3	313	506	351	6	149	529	462	7	76	589	346
SO_4	3	230	323	267	7	220	1070	640	7	28	735	312
Cl	3	4.0	4.5	4.1	7	3.8	21	10.0	7	0.4	14	4.8
F	0	--	--	--	6	0.3	0.5	0.4	4	0.1	0.3	0.2
N	3	0.02	0.52	0.32	6	0.01	0.62	0.17	7	0.02	0.34	0.10
P	3	0.02	0.13	0.04	7	0.01	0.10	0.02	7	0.02	0.49	0.05

Total recoverable metals[c]	N	Min	Max	Med
As	5	<.01	<.01	<.01 (.007)
B	7	<.10	0.18	0.10
Cd	14	<.001	0.01	<.001
Co	1	--	--	.03
Cr	3	<.01	0.02	0.01
Cu	14	<.01	0.05	0.01
Fe	14	.47	11	1.5
Hg	3	<.001	<.001	<.001
Li	1	--	--	.03
Mn	13	.04	1.4	.11
Pb	3	<.01	<.01	<.01
V	1	--	--	.03
Zn	14	<.01	0.06	0.01

NOTE: Measurements are expressed in mg/l.

[a] Less than 8.0 cfs.

[b] Greater than 8.0 cfs.

[c] Be: <.01, N=1; Se: <.001, N=1.

various reference criteria. Table 51 shows that seven to ten percent of the TR and dissolved concentrations of Fe, Mn, and Zn in Beauvais Creek were present in the dissolved form. Thus, the dissolved metals concentrations, including those of Fe, Mn, and Zn in Tullock Creek (and also in Rotten Grass, Soap, and Sage creeks) do not appear to cause water quality problems because the calculated dissolved concentrations would be lower than the corresponding reference criteria.

Major features that degrade Tullock Creek's quality apparently are its high dissolved and suspended solids concentrations. Suspended sediment levels in Tullock Creek were relatively high throughout the stream and were directly related to flow. Dissolved solids concentrations were also high, but they tended to increase downstream at a level of 26 percent at similar flows, and they were negatively correslated with discharge. The waters were typically slightly saline and very hard; these features together with the high sulfate concentrations would generally eliminate the creek as a source for domestic supply. Turbidities also often exceeded the permissible criteria for surface water public supply. Although the stream may be considered a good source of stock water on the basis of TDS levels, the high sulfate and bicarbonate concentrations of the creek occasionally exceeded the threshold and limiting levels of these parameters (tables 10-14) at all locations and flow regimes. Most common near the stream's mouth during periods of low discharge, this would reduce the value of the creek as a source of water for domestic animals. In turn, the high TDS and TSS concentrations, particularly in the downstream reach at low flows, would be expected to have a detrimental effect on the stream's biota. On the basis of overall TSS concentrations, the stream would probably support a poor fishery.

Tullock Creek appears to have the poorest water quality for irrigation of any of the streams analyzed. It has a high salinity hazard and a medium sodium hazard for this use (USDA 1954) in contrast to the low sodium hazards observed in other streams of the Bighorn drainage. With high sulfate, sodium, SAR, and specific conductance-TDS levels in the stream, Tullock Creek definitely has a Class II water for irrigation (tables 15 and 16) that should be used with caution when applied to some crop and forage species.

YELLOWSTONE RIVER
BIGHORN RIVER TO POWDER RIVER

YELLOWSTONE MAINSTEM

This is an extensive reach of the Yellowstone River that receives water from numerous small prairie tributaries of potentially poor quality and from several large tributaries, including the Bighorn River. The larger tributaries, such as the Bighorn, would be expected to affect the water quality of the Yellowstone mainstem, and cumulative effects would be expected from the smaller streams. Several water quality trends and problems are evident in the mainstem above Custer.

Some water quality trends observed on the Yellowstone River above Custer are summarized as follows:

1) There is an inverse relationship between TDS concentrations and flow, with salinity increasing downstream. This is due primarily to increasing sodium, sulfate, calcium (and total hardness), and bicarbonate levels.

2) Magnesium, potassium, chloride, and fluoride are minor constituents in the river above Custer and lack distinct changes in concentration downstream.

3) The water is calcium bicarbonate with increasing proportions of sodium and sulfate and generally lower Ca:Mg and $HCO_3:SO_4$ ratios downstream.

4) Values of pH tend to be lower at high flows and upstream with the reduced alkalinities.

5) There exists a tendency towards a greater, but apparently non-critical, organic loading in the river below Billings.

6) Temperatures become warmer below Big Timber.

7) A direct relationship has been observed between TSS-turbidity and flow, the levels of which generally increase downstream to Custer.

8) Metals concentrations increase downstream, as shown by the TR and dissolved levels of Fe, Mn, and Sr.

9) A spring-summer, March-July pulse of high phosphorus concentrations occurs with a downstream increase in phosphorus during the winter and summer.

10) Non-eutrophic conditions prevail due to a nitrogen limitation, although the river tends to become more eutrophic downstream.

11) Peak nitrogen concentrations occur during the winter and low levels during the summer.

12) Pesticide-herbicide detection is more successful downstream.

Potential water quality problems in the Yellowstone above Custer might be listed as follows:

1) The river has relatively high fluoride concentrations above Livingston, possibly detracting from the stream's use for stock water and irrigation.

2) High phenol and fecal coliform concentrations occur below Laurel.

3) High TSS-turbidity and TDS concentrations develop downstream.

4) Arsenic and mercury concentrations are potentially high.

5) Eutrophy may occur downstream near Custer.

Ammonia may be a eutrophic element in the Laurel-to-Custer reach of the river, as the stream is nitrogen-limited.

Water quality data on the Bighorn River-to-Powder River reach of the Yellowstone River are available from the USGS for three locations. In downstream order, they are at Myers below the Bighorn River, at Forsyth above Rosebud Creek and at Miles City above the Tongue River. The USGS site at Terry in the subsequent study segment lies below the confluence of the Tongue and Powder rivers and may be expected to show the effects of these tributaries on the mainstem (USDI 1968).

The site at Miles City is probably most representative of the river's quality in the Bighorn-to-Powder reach due to the longer period of collection (table 3). Stations at Billings and near Livingston also gave more accurate information for their reaches for the same reason. Thus, inter-reach water quality comparisons are probably most valid when made between the Livingston, Billings, and Miles City locations. The USGS data for the Bighorn-to-Powder reach were supplemented by information collected by the state WQB as a part of various sampling programs (Karp and Botz 1975, Montana DNRC 1974, Peterman and Knudson 1975). Closely related state WQB sites on the river were combined to correspond to the three USGS locations (Myers, Forsyth, and Miles City); this accounts for the modifications of the USGS site designations in the water quality tables of this report (tables 55-57) for major parameters.

An inverse relationship between flow and TDS concentrations was evident in the Bighorn-to-Powder segment of the Yellowstone River. A two-fold increase in TDS was observed from the May-July runoff period to the low-flow winter-spring seasons. However, this relationship was not as obvious throughout the entire year in the Bighorn-to-Powder reach as it was upstream. Above Custer, median TDS concentrations increased from the May-July period to the winter season, and concentrations in the winter and spring (March-April) were then closely equivalent. Only a 17 mg/l or 6.6 percent difference in TDS was obtained between the May-July-to-winter and the winter-to spring periods (a 6.2 percent average difference in specific conductance). Median flows decreased from the runoff period to the winter with flows during the winter and spring seasons also closely equivalent, i.e., a 338 cfs or 5.5 percent average difference between these seasons. In contrast, in the Yellowstone below Custer, median TDS levels consistently increased from the runoff period through the spring phase, averaging 62 mg/l or 13.1 percent higher in the spring than in the winter. However, median flows also increased dramatically from the winter to the spring, averaging 2917 cfs or 38.5 percent higher during the latter season. This secondary peak in flows during the spring, along with the increase in TDS concentrations, is probably a reflection of inputs to the Bighorn-to-Powder segment from prairie streams which have an earlier runoff period and a relatively poor water quality; this, in turn produces a direct relationship between flow and TDS for a portion of the year in the lower river.

Salinity in the Yellowstone River, as measured by total dissolved solids or specific conductance, was found to increase downstream from Corwin Springs

TABLE 55. Summary of the physical parameters measured in the Yellowstone River at Myers.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	8100	14,500	9620	7	7000	10,000	7680	7	8000	14,700	12,360	9	12,000	57,200	33,500
Temp	7	10.5	21.0	15.0	8	0.0	5.5	1.1	8	2.2	13.1	8.8	10	10.0	23.5	14.3
pH	7	8.0	8.7	8.3	8	7.7	8.4	8.4	8	8.00	8.35	8.2	12	7.78	8.4	7.94
SC	7	431	750	520	8	640	760	727	8	618	789	735	12	265	764	438
TDS	6	279	397	369	7	410	565	470	8	395	616	540	12	156	620	292
Turb	4	5	25	10	4	4	59	12	5	22	340	27	9	24	200	85
TSS	3	13	100	16.8	2	22	94	58	6	50	126	71	7	63	534	348
DO	7	7.6	10.6	9.3	8	11.4	13.0	12.2	8	10.0	12.4	10.8	12	5.8	11.3	8.8
BOD	3	0.8	2.0	1.7	2	2.0	3.8	2.9	7	1.5	4.3	2.5	9	0.9	5.6	2.8
FC	1	--	--	3500	2	58	70	64	4	9	64	26	4	90	>10^4	315
Ca	6	39	53	45	7	55	66	64	8	53	70	65	12	24	65	38
Mg	7	14	21	20	8	19	27	21	8	19	30	25	12	7.2	26	13
TH	6	156	220	180	7	220	269	240	8	210	300	264	12	90	268	146
Na	6	36	51	42	7	50	62	58	8	48	76	65	12	16	70	32
K	6	2.7	3.8	3.1	6	3.2	5.0	3.3	6	1.9	4.2	3.6	10	1.6	3.9	2.5
SAR	6	1.2	1.6	1.4	7	1.4	1.7	1.6	8	1.4	2.0	1.8	12	0.7	1.9	1.1
HCO_3	7	142	188	162	7	174	197	195	8	166	207	194	12	88	209	130
TA	7	116	154	138	7	143	162	160	8	136	170	159	12	72	171	121
SO_4	6	95	160	133	7	170	210	200	8	170	260	224	12	49	237	96
Cl	6	5.6	9	6.5	7	8	10	9.3	8	7.6	12	10	12	2.6	9.5	5.5
F	6	0.3	0.4	0.4	6	0.4	0.4	0.4	6	0.4	0.7	0.5	12	0.2	0.6	0.4
N	6	0.06	0.31	0.1	7	0.2	0.72	0.34	7	0.14	0.7	0.28	10	0.09	0.4	0.22
P	6	0.01	0.07	0.04	7	0.0	0.05	0.03	8	0.02	0.30	0.05	9	0.03	0.54	0.18

NOTE: Measurements expressed in mg/l.

TABLE 56. Summary of the physical parameters measured in the Yellowstone River near Forsyth.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	7900	14,500	9480	8	7000	9970	7550	8	7740	14,800	9980	11	10,800	61,800	33,800
Temp	7	10.5	22.3	15.0	9	0.0	4.5	1.0	9	5.6	14.4	6.5	13	10.0	22.7	16.0
pH	8	8.0	8.5	8.5	9	7.4	8.5	8.3	9	8.1	8.6	8.2	13	7.6	8.5	8.12
SC	8	450	760	565	9	610	755	740	9	580	859	735	13	245	500	435
TDS	7	296	486	367	7	417	548	467	9	362	668	560	13	145	357	254
Turb	4	5	48	9	4	4	66	16	6	3	140	22	10	25	320	111
TSS	3	12	135	32	3	8.8	54	28	7	10	155	38	9	122	992	363
DO	7	7.7	11.0	8.8	9	11.0	13.1	12.4	9	9.3	12.3	10.8	12	7.3	10.6	8.5
BOD	3	0.7	2.4	1.7	3	2.6	4.6	3.8	7	1.8	3.3	2.1	8	0.6	4.8	2.4
FC	1	--	--	7900	3	1	52	20	5	0	130	10	5	9	855	315
Ca	7	39	55	45	7	54	64	62	9	49	74	67	13	23	50	33
Mg	8	14	21	18	8	18	25	22	9	17	29	25	13	4.2	17	11
TH	7	154	220	190	7	208	260	250	9	190	300	270	13	33	180	120
Na	7	37	58	49	7	52	62	55	9	43	81	69	13	16	80	29
K	7	2.7	3.4	3.1	6	3.1	4.8	3.3	4	2.9	4.3	4.2	8	1.7	3.2	2.4
SAR	7	1.3	1.7	1.5	7	1.5	1.7	1.6	9	1.4	2.1	1.9	13	0.8	2.6	1.1
HCO_3	8	138	185	165	7	151	200	195	9	162	203	193	13	87	169	115
TA	8	117	152	141	6	152	164	160	10	124	174	168	13	71	139	95
SO_4	7	110	172	150	7	170	210	190	9	150	273	220	13	44	190	88
Cl	7	5.1	9	6.5	7	7.0	11	9	9	6.8	12	9.6	13	3	7	4.9
F	7	0.3	0.5	0.4	6	0.4	0.4	0.4	6	0.5	0.7	0.5	11	0.2	0.4	0.3
N	7	0.06	0.21	0.1	7	0.3	0.47	0.4	8	0.07	0.4	0.16	13	0.04	0.40	0.19
P	7	0.01	0.16	0.05	7	0.0	0.04	0.03	9	0.02	0.33	0.04	13	0.02	0.55	0.12

NOTE: Measurements expressed in mg/l.

TABLE 57. Summary of the physical parameters measured in the Yellowstone River near Miles City.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	36	6160	19,000	9115	37	4200	33,700	7490	25	5780	22,000	9130	39	9030	66,000	26,200
Temp	19	8.5	23.2	16.5	21	0.0	6.5	1.0	15	0.0	17.0	2.0	23	9.5	24.7	15.0
pH	32	7.2	8.7	8.1	39	7.0	8.5	8.1	26	7.4	8.7	7.9	44	6.8	8.5	7.9
SC	35	430	724	600	39	391	913	740	28	581	926	760	46	245	870	410
TDS	34	272	523	391	37	254	615	482	27	385	638	506	46	150	648	258
Turb	12	2	50	12	15	3	200	9	12	4	200	36	20	24	800	142
TSS	6	13	118	31.7	3	39	180	62	8	10	421	77.5	13	121	1140	456
DO	14	7.6	11.6	9.1	15	11.1	13.8	12.6	11	8.0	12.3	11.1	20	7.4	10.1	8.8
BOD	3	0.9	2.8	1.6	2	3.8	8.3	6.1	6	1.4	4.8	2.3	9	0.5	5.1	1.9
FC	11	0	13,400	9	11	0	1200	7	11	0	300	12	16	7	2100	385
Ca	29	36	59	50	34	37	73	61	24	46	72	65	43	23	58	38
Mg	29	13	23	18	34	10	29	22	24	16	30	25	43	7.0	25	12
TH	30	120	241	201	33	130	286	246	25	182	292	260	43	86	246	140
Na	29	34	71	52	34	37	73	61	24	50	80	66	43	15	75	30
K	27	2.1	4.8	3.4	33	2.8	5.3	3.8	22	2.9	5.5	4.1	38	1.5	4.9	2.6
SAR	30	1.2	2.0	1.6	33	1.1	2.4	1.7	25	1.5	2.1	1.8	43	0.7	2.4	1.1
HCO_3	30	142	196	174	34	138	220	193	24	149	213	196	44	83	204	123
TA	9	117	157	151	10	127	175	157	6	122	169	160	9	88	134	94
SO_4	29	100	210	160	34	100	289	201	24	146	266	224	42	46	200	94
Cl	29	5.3	10	7.9	33	4.3	12	9.6	25	2.9	14	10	43	2.2	9.5	5.5
F	27	0.3	0.9	0.4	33	0.3	0.6	0.4	23	0.3	0.7	0.5	41	0.0	0.9	0.3
N	33	0.0	0.98	0.06	38	0.0	0.71	0.30	29	0.0	0.6	0.23	48	0.0	1.1	0.10
P	26	0.0	0.16	0.04	30	0.0	0.13	0.03	19	0.01	0.40	0.04	28	0.03	1.6	0.11

NOTE: Measurements expressed in mg/l.

to Custer. This trend was also evident in the Bighorn-to-Powder reach of the river, but it was most obvious and consistent between the Custer and Myers sampling locations around the confluence of the Bighorn River. Below Myers, salinity increases downstream were relatively small. This indicates that tributary effects on the river below Myers were not as distinct as those emanating from the Bighorn River. For example, the increase in salinity from Custer to Myers averaged 38.7 percent, and that from Custer to Miles City averaged 38.6 percent. This suggests that the Bighorn River had a significant effect on the Yellowstone with negligible effects developing from the smaller tributaries in the Bighorn-to-Powder segment. The overall increase in salinity from Custer to Miles City ranged from about 22 percent to 58 percent, depending upon season and parameter (i.e., specific conductance or TDS). The total increase in salinity in the river from Corwin Springs to Miles City ranged from 164 percent to 173 percent and from 153 percent to 172 percent during the August-to-April period for specific conductance and TDS, respectively, and it equalled 215 percent and 200 percent during the runoff period. The change in salinity per river mile in the Bighorn-to-Powder segment (to Miles City) was greater than that in the upper river above Laurel but less than that in the Laurel-to-Custer reach. This can be shown in table 58 below.

TABLE 58. Salinity change per river mile in the Bighorn-to-Powder segment.

Reach	Percentage increase in salinity per river mile	
	Maximum	Minimum
above Laurel	0.2	0.05
Laurel to Custer	1.1	0.5
Custer to Miles City	0.5	0.2

In the upper river above Laurel, the downstream increase in salinity was greatest during the May-July runoff phase, intermediate during the winter, and lowest during the August-October and the spring (March-April) periods. A different pattern was evident in the Laurel-to-Custer segment of the Yellowstone--the salinity increase was greatest during the August-October period, intermediate between March and July, and lowest during the winter. On the Bighorn-to-Powder reach of the Yellowstone, the increase was lowest in the August-October period when flows and TDS concentrations in the Bighorn River (table 48), and therefore the tributary's TDS loads, were at their lowest. The salinity increase was greatest during the winter-spring, November-April period when the TDS concentrations in the Bighorn were high and when its median flows were greater than those in the mainstem at Billings. Intermediate increases in salinity were obtained during the runoff period below Custer when the high flows in the Yellowstone would tend to negate the TDS loadings from the Bighorn River. Therefore, on the basis of total dissolved solids, there was a continued downstream degradation of water quality in the Yellowstone below Custer to Miles City; the quality was poorest below Custer in the spring and greatest during the runoff period (ignoring the TSS factor).

Suspended sediment concentrations were generally much greater throughout the Yellowstone River during the May-July period of high flows than during the rest of the year. Although considerable variation was obtained between sampling stations (probably due to the general absence of TSS data), an 18-fold maximum average difference became evident between low and high-flow seasons over the entire river above Miles City.

The direct relationship between flow and TSS was fairly consistent in the river above Huntley, although TSS-turbidity levels in the spring (March-April) tended to be somewhat higher than might be expected on the basis of flow. This discrepancy was more noticeable in the river below Billings, and in the Bighorn-to-Powder segment, the spring increase in TSS corresponded to a secondary, March-April peak in flow below Custer. The spring increase in TSS, like TDS, can be attributed to inputs from prairie tributaries with their earlier runoff periods and relatively high TSS loads. Most sites on the Yellowstone above Huntley demonstrated a slight decline in TSS-turbidity from August-October to the winter period and coincided with a drop in flow. Below Billings, however, TSS-turbidity increased between these seasons regardless of the flow decline, and this continued into the spring season. This might also be attributed to early runoff events from the lowland regions during the winter period.

A general downstream increase in TSS-turbidity occurred during all seasons; this was observed in the river above Custer and was carried into the Bighorn-to-Powder reach of the river to Miles City. As a result, water quality in the Yellowstone River also declined downstream, as measured by the presence of suspended sediment and turbidity; these variables detracted from the better water quality during the runoff period. This in turn may affect various water uses in the Bighorn-to-Powder segment. Most notably, the high turbidities at high flows would detract from the use of the river as a domestic supply during runoff season, as median turbidities exceeded permissible criteria for surface water public supply (table 9). The consistently high turbidities would tend to degrade the river aesthetically regardless of the generally uncolored water (color was typically less than 10 units).

The high TSS concentrations may affect the Yellowstone fishery. Such a condition was observed in the Laurel-to-Custer reach, and any degradation would be more pronounced below Myers because of the greater TSS concentrations. On the basis of annual median TSS levels (156 mg/l), the river at Miles City probably is a fair fishery judging from the observations of the European Inland Fisheries Advisory Commission (1965). This contrasts with the good-to-moderate fishery in the Yellowstone above Huntley to Laurel and blue-ribbon fishery in the river at Corwin Springs (Berg 1977).

With the possible exceptions of fluoride and potassium, the concentrations of most dissolved ionic constituents in the river increased to some extent from Custer to Myers (comparing tables 33 and 55) in response to inputs from the Bighorn River and the increase in total dissolved solids through this segment. However, fluoride, potassium, magnesium, and chloride continued to be secondary or insignificant components of the samples, and sodium, calcium, sulfate, and bicarbonate dominated the chemical composition of the water. This was also true in the segment of the river below Myers where the levels of dissolved constieuents remained constant with small and inconsistent concentration changes in most parameters downstream to Miles City. This is appropriate, as there are no marked increases in TDS levels throughout this reach. Regardless of initial concentration increases in the Bighorn-to-Powder segment, none of the major ionic constituents or the TDS concentrations appeared to be at levels sufficient to consistently and significantly detract from any of the water uses. The water in the Yellowstone between Myers and Miles City was obviously unsuitable as a surface water public supply due to its high TDS levels and low fluoride concentrations, but it probably could be used for public supply if given certain reservations.

The Miles City data (table 57) shows that TDS and sulfate concentrations occasionally exceeded the permissible criteria and standards for public supply and drinking water. About 28 percent of the samples from the Bighorn-to-Powder reach had TDS in excess of 500 mg/l; this was most frequent during the November-to-April period. About 15 percent of the samples had sulfate concentrations in excess of its reference criteria. These findings, and the unusually hard nature of the water, detract from the river's potential value as a municipal supply.

Salinity levels in the Bighorn-to-Powder reach may influence the aquatic biota with TDS concentrations occasionally in excess of 400 mg/l. This effect, however, would probably be mild, as TDS exceeded 400 mg/l in only about 56 percent of the samples and never exceeded the critical 680 mg/l level throughout this reach.

The Bighorn-to-Powder segment may be expected to provide excellent water quality for stock animals, as total dissolved solids and ionic constituents are well below threshold levels. Also, it is qualified to be a Class I water for irrigation, as the boron (<0.35 mg/l), SAR, chloride, sulfate, and TDS-specific conductance levels were well within range of values for this classification (tables 15 and 16). The Yellowstone consistently had a low sodium hazard for irrigation between Custer and Miles City due to the high calcium and low sodium concentrations, and, consequently, the low SAR values. However, it had a medium salinity hazard for irrigation from May to October, and the river tended to have a high salinity hazard during the winter and spring when TDS concentrations were high. A high salinity hazard during the spring could reduce the river's value for irrigation during the March-April period.

Sodium, calcium, and sulfate showed the greatest increases in concentration below Custer, consistent with the calcium-sodium sulfate water in the Bighorn River (table 48). As a result, the trend for the Yellowstone to become more sodium sulfate in character downstream continued through the Bighorn-to-Powder reach of the stream. This can be shown using Ca:Na and HCO_3:SO_4 ratios as seen in table 59. The effect of the Bighorn was less pronounced when the Yellowstone had high flows, which would tend to mask the TDS loading from the tributary to some extent. The effect of the tributary was greatest in terms of the HCO_3:SO_4 ratios due to the high concentrations of sulfate in the Bighorn; this was also observed on the Clarks Fork Yellowstone River. The extremely low HCO_3:SO_4 ratios in the Yellowstone below Custer occurred during the winter and spring periods when TDS concentrations and flows in the tributary were high in comparison to the mainstem. An intermediate HCO_3:SO_4 ration was obtained from August to October when Bighorn TDS levels and flows were low. Due to these features, the Bighorn-to-Powder reach tends to have calcium bicarbonate water during high flows, a calcium-sodium bicarbonate water in the late summer and early fall, and a calcium-sodium sulfate water during the late fall, winter, and spring.

As observed on the Yellowstone above Custer, values of pH in the Bighorn-to-Powder segment tended to be lower during the high-flow periods in association

TABLE 59. Downstream composition changes on the Bighorn-to-Powder reach of the Yellowstone River.

	Ca:Na		$HCO_3:SO_4$	
	Low Flows	High Flows	Low Flows	High Flows
above Laurel	1.51	2.36	3.73[a]	5.71
Billings	1.49	1.72	2.12[a]	3.83
Huntley	1.44	1.46	1.88[a]	2.45
Custer	1.37	1.60	1.78[a]	2.72
Myers	1.06	1.19	1.22[b] 0.93[c]	1.35
near Forsyth	0.98	1.14	1.10[b] 0.96[c]	1.31
Miles City	0.98	1.27	1.08[b] 0.92[c]	1.31

NOTE: Measurements are given in mg/l.
[a]August-April.
[b]August-October.
[c]November-April.

with the reduced alkalinities. Also, pH tended to increase downstream below Custer to Forsyth in accordance with the increase in alkalinity through this segment. However, the ranges of this parameter in all seasons and at all stations were never outside of the state's criteria for pH in a $B-D_3$ stream, and they were not indicative of pollution problems. Although median pH decreased from Forsyth to Miles City, pH levels were generally greater in the river at Miles City (table 57) than at Billings (table 31).

The river tends to change from a cold-water fishery above Big Timber (Berg 1977) to a warm-water fishery downstream, with the Laurel-to-Custer reach of the river in a transition zone (Peterman 1977). A continuation of this trend is evident below Custer, and the Yellowstone is most likely a warm-water stream at that point. With the exception of the winter season when median temperatures were consistently less than 2.0°C throughout the river and maximums were less than 7.0°C, and ignoring inconsistencies between sites due to lack of data, maximum and median grab sample temperatures increased downstream from Corwin Springs to Miles City. This can be demonstrated by averaging the May-October warm-weather data for sequential sites corresponding to a cold-water reach (Corwin Springs to Big Timber), a transition zone reach (Big Timber to Huntley), and a warm-water reach (Huntley to Miles City) as follows in table 60.

TABLE 60. Average May-October warm-weather data for sequential sites.

	Median Temperatures	Maximum Temperatures
Corwin Springs to Big Timber	9.7°C	16.6°C
Big Timber to Huntley	14.7°C	19.6°C
Huntley to Miles City	15.8°C	22.6°C

The different temperature characteristics of the extreme upper Yellowstone and the lower river can also be demonstrated by USGS temperature data taken once daily from the stream near Livingston and at Miles City. Since 1970, only 9.7 percent of the readings from the river near Livingston exceeded 19.4°C during the June-September warm-weather period; only 4.8 percent were equal to or greater than 20°C. In contrast, for the same seasonal and historic intervals, 64.3 percent of the once-daily readings at Miles City exceeded 19.4°C with 60.9 percent greater than or equal to 20°C. None of the readings from the river at Livingston exceeded 22.5°C, and maximum temperatures through the five years ranged between 20.5°C and 21°C. At Miles City, however, 24.1 percent of the once-daily temperatures were greater than 22.5°C, with maximum temperatures ranging between 24°C and 27°C. These data show that the Yellowstone River below Billings is appropriately classified a B-D_3 stream.

High phosphorus concentrations were found in the Yellowstone at Custer in excess of reference criteria as a result of a general downstream increase below Laurel and an accentuation of a May-July (and March-April) pulse which first became evident at Laurel (table 28). This spring-early summer pulse of phosphorus might have been related to the high sediment levels in association with the high flows. Thus, with the high nitrogen concentrations, the Yellowstone at Custer (and Huntley) was potentially eutrophic, although nitrogen-limited. The trend towards eutrophy was apparently negated below Custer with an initial decline in median phosphorus concentrations to Myers, and with a lessening of the March-July pulse of phosphorus. This was probably caused by dilutions from the Bighorn River which had low phosphorus concentrations at its mouth during all seasons, lacking the high-flow pulse. Below Custer, therefore, median phosphorus concentrations were less than or equal to the reference criteria, except during the runoff period, when phosphorus concentrations were constant throughout the Myers-to-Miles City segment of the stream. The river does not appear to be eutrophic below Myers; less than 18 percent of the samples from the Bighorn-to-Powder segment would have both P and N in excess of the nutrient reference criteria, and less than five samples would have both of these nutrients in excess of the EPA's (1974b) criteria.

Nitrogen concentrations remained high below Custer, although median values were typically less than the corresponding standard for eutrophication. This in turn corresponds to the high, but noncritical, nitrogen concentrations in the Bighorn River. High winter and low summer variations of this parameter were observed in the Bighorn-to-Powder reach, as in the upper Yellowstone and the Bighorn rivers. Below Myers, nitrogen tended to decline downstream, although this was not totally consistent between all sites and during all seasons. The decline was greatest during the runoff period. From Custer to Myers, nitrogen either increased or decreased by season, depending on the nitrogen level and flow (or nitrogen loading) relationships between the Bighorn River at Bighorn and the Yellowstone River at Custer. That is, nitrogen concentrations increased between stations from August to October and from March to April when nitrogen levels in the Bighorn were high compared to those in the Yellowstone. When the opposite conditions were in effect, during the winter and high-flow periods, nitrogen concentrations decreased from Custer to Myers.

A slight and noncritical organic loading became evident in the Laurel-to-Custer reach of the river, probably caused by various industrial and municipal discharges from the urbanized Laurel-Billings area. Although sporadically high

BOD_5 levels were obtained below Custer, organic loading did not appear to rise in the Myers-to-Miles City reach, as median BOD_5 levels in this lower segment were generally equal to those upstream; the average BOD_5 level at Huntley and Custer equalled 2.6 mg/l whereas that below Custer equalled 2.7 mg/l. Occasionally high BOD_5 values, but less than 10 mg/l (table 50), might be expected as natural occurrences. BOD_5 values in the Bighorn-to-Powder reach of the Yellowstone never exceeded 9 mg/l, and only 14 percent of the samples had BOD_5 levels in excess of 4 mg/l. In addition, median TOC and median COD concentrations (tables 61 and 62) were equivalent to or less than the average for natural surface waters (Lee and Hoodley 1967).

Organically polluted streams, such as Yegen Drain in Billings (Karp et al. 1976b, Klarich 1976), demonstrate much higher grab sample BOD_5 and TOC concentrations and more frequent high values. In Yegen Drain, for example, a median BOD_5 of 14.5 mg/l and a median TOC of 35 mg/l was obtained with several grab samples having BOD_5 levels in excess of 80 mg/l; 100 percent of the samples had BOD_5 concentrations greater than 4.0 mg/l and TOC concentrations greater than 35 mg/l. Based upon these findings, organic pollution does not appear to be a problem in the Yellowstone River. This was confirmed by the high dissolved oxygen levels in the Bighorn-to-Powder reach--minimum values were well above the state criteria for a B-D_3 stream and median values were very near saturation (tables 61 and 62).

A noticeable fecal coliform problem developed in the river through the Laurel-to-Custer reach as a result of wastewater discharges from the Laurel-Billings area. This was most obvious at Billings and Huntley (tables 31 and 32) where median and grab sample concentrations commonly exceeded Montana's water quality standards (Montana DHES 1973). Concentrations were too high to be attributed to natural occurrences. The fecal problem was also evident in the river at Custer, though it apparently had lessened through the Huntley-Custer reach, as there were fewer violations and generally lower concentrations downstream (table 33). At all stations below Billings, fecal concentrations were greatest at high flows. Fecal levels tended to increase downstream from Custer during the May-July period, but they tended to decline in the river below Custer to Miles City (tables 33 and 55-57) through the rest of the year. Below Custer, median fecal concentrations in the river were within the state's average criteria at all sites and during all seasons. This suggests a further lessening of the fecal problem due to a natural die-off following the upstream inputs; however, occasional grab samples had concentrations still in excess of state criteria. Nevertheless, fecal levels, for the most part, do not appear to restrict the use of water from the Bighorn-to-Powder segment of the Yellowstone for municipal supply. Only 7 percent of the samples from the Bighorn-to-Powder reach had levels in excess of the NTAC (1968) and the EPA (1973) recommendations for surface water public supply. (USEPA 1973, USDI 1968).

The phenol problem that developed in the Laurel-to-Custer segment of the river cannot be assessed in the Bighorn-to-Powder reach because data are unavailable. Similarly, herbicide-pesticide concentrations and detection success cannot be established in the Bighorn-to-Powder reach. However, herbicide-pesticide information is available from the USGS on the river at Sidney (USDI 1966-1974b). The potential upstream fluoride problem is apparently eliminated from the river before it reaches Livingston due to tributary dilution. Fluoride concentrations remained low in the Bighorn-to-Powder reach and did not suggest

TABLE 61. Summary of miscellaneous constituent and trace element concentrations measured in the Yellowstone River at Myers and near Forsyth.

	Yellowstone River at Myers								Yellowstone River near Forsyth							
	Miscellaneous constituents and total recoverable[a] metals				Dissolved metals				Miscellaneous constituents and total recoverable[b] metals				Dissolved metals[c]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[d]	22	60	108	99					22	86	108	95				
NH_3-N	7	0.03	0.14	0.07					7	0.02	0.14	0.10				
Si	20	8.7	13	11					20	8.5	13	11				
TOC	4	2.1	13	8.9					4	4.7	15	10				
Ag					2	0.0	.001	.001								
Al	7	0.4	9.9	0.8	6	0.0	.01	.04	8	0.10	15	1.2	6	0.0	.16	.02
As	4	.005	.055	.018	6	.002	.006	.005	5	<.01	.023	.002	6	.003	.005	.004
B	11	<.10	0.33	0.10	12	.06	.16	.14	11	<.10	0.29	0.10	12	.05	.15	.14
Ba					2	.100	.100	.100					3	0.0	<.1	<.1
Be					5	0.0	0.02	<.01					6	0.0	0.01	<.01
Cd	15	0.0	0.001	<.001 (.02?)	5	0.0	0.001	<.001	20	0.0	<.01	.002	5	<.001	0.001	0.0
Co					2	0.0	.001	.001	2	<.01	0.01	0.01	2	0.0	.002	.001
Cr	2	.01	.02	.02	7	0.0	<.01	0.0	6	0.0	0.09	<.01				
Cu	19	<.01	0.06	<.01	5	.001	.019	.004	24	<.01	0.17	0.01	5	.001	.006	.002
Fe	15	0.13	11	1.6	15	.01	.16	.03	20	.02	19	1.7	15	0.0	.10	.04 (.44?)
Hg	14	0.0	<.001	<.0002 (.002?)	5	0.0	.0002	0.0	19	0.0	<.0029	.0006	5	0.0	0.0030	0.0001
Li					3	.03	.05	.03					5	<.01	0.05	0.02
Mn	15	<.01	0.37	0.11	16	0.0	.03	.01	18	.03	.54	.12	16	0.0	.03	.01 (.3?)
Mo					3	0.0	.003	.002					4	0.0	.002	.002
Ni					5	.001	.073	.002					5	.001	.02	.005
Pb	13	<.05	0.10	<.10	5	0.0	.004	.002	20	<.01	<.10	<.05	5	0.0	.003	.001
Se	8	0.0	.004	.002	6	.001	.002	.002	9	<.001	0.004	0.002	6	.001	.003	.002
Sr	6	.08	1.2	.40	3	.53	.65	.60	6	.06	1.2	.41	3	.55	.64	.60
V					5	.0004	.002	.002	8	<.05	0.18	<.1	6	.0001	.001	.001
Zn	19	<.01	0.07	0.03	6	.01	.04	.02	24	<.01	0.12	0.02	6	0.0	.03	.02

NOTE: Measurements are expressed in mg/l.

[a] V: <.10, N=5.

[b] Be: <.01, N=2.

[c] Ag: 0, N=2; Cr: <.01, N=6.

[d] DO expressed as percentage of saturation.

TABLE 62. Summary of miscellaneous constituent and trace element concentrations measured in the Yellowstone River near Miles City.

	Miscellaneous constituents and dissolved metals				Total recoverable metals			
	N	Min	Max	Med	N	Min	Max	Med
COD	16	6	73	15				
Color	15	1	11	6				
DO[a]	45	66	117	97				
NH_3-N	16	0.01	0.41	0.13				
Si	114	3.8	17	11				
TOC	43	1.4	16	6.0				
Al	3	<.01	0.03	0.01	3	1.9	9.0	2.2
As	3	<.01	0.03	0.01	11	<.001	0.03	0.009
B	53	.016	.224	.150	10	<.10	0.22	0.10
Be	3	<.01	<.01	<.01	1	--	--	<.01
Cd	3	0.0	0.0	0.0	22	<.001	0.003	<.001
Co					1	--	--	.01
Cr	3	0.0	.01	0.0	7	0.0	0.02	<.01
Cu	3	0.0	.002	.002	25	<.01	0.10	0.01
Fe	82	0.0	1.8	.02	24	.02	38	1.8
Hg	3	0.0	.0002	.0001	13	<.0002	0.001	0.0002
Li	4	<.01	0.05	0.03				
Mn	17	0.0	.05	.005	23	.01	1.5	.12
Mo	3	.001	.003	.002				
Ni	3	.002	.006	.003				
Pb	3	.001	.002	.001	14	<.01	<.11	<.05
Se	3	.001	.002	.001	6	<.001	0.002	0.001
Sr					5	.06	1.1	.42
V	3	.001	.002	.002	6	<.05	0.22	<.10
Zn	3	0.0	.02	0.0	25	<.01	0.27	0.02

NOTE: Measurements are expressed in mg/l.

[a]DO expressed as percentage of saturation.

problems other than being below the optimum level for drinking water. In contrast, the high arsenic and mercury levels observed in the upper river were apparently carried into the Bighorn-to-Powder reach of the stream (tables 61 and 62). Upstream, arsenic occasionally violated the Public Health Service (1962) standard for drinking water, although it was not at levels high enough to necessitate a rejection of supply or to violate the NTAC and the EPA criteria (table 9). Dissolved and TR concentrations of arsenic showed an overall decline downstream with a lower frequency of violations in the Bighorn-to-Powder reach. Arsenic was never at levels sufficient in the Yellowstone to exceed the criteria for livestock and the aquatic biota.

Grab sample and median concentrations of mercury, both in its dissolved and TR forms, often exceeded criteria for aquatic life. For example, of the samples analyzed for mercury from the Bighorn-to-Powder reach with a sufficient detection limit (to 1 µg/l), 29 percent had TR concentrations equal to or greater than 2 µg/l, and 10 percent had TR concentrations between 10 µg/l and 20 µg/l; between 45 percent and 81 percent of the samples had TR concentrations equal to or greater than 1 µg/l. In measuring the dissolved concentrations, 46 percent of the samples had detectable levels of mercury (>1 µg/l), and 31 percent of the samples had levels equal to or greater than 2 µg/l. Grab sample mercury concentrations also occasionally exceeded the EPA's criteria for public water supplies, although they were not at levels sufficient to be harmful to stock animals (California WQCB 1963).

Like mercury and arsenic, all of the remaining metals and trace elements were detected in some of the samples from the Bighorn-to-Powder reach of the Yellowstone, at least in their TR forms (tables 61 and 62). Although silica declined downstream below Custer, the overall concentrations of these constituents appeared to be somewhat higher in the Bighorn-to-Powder reach than in the Laurel-to-Custer segment upstream. For example, the mean median TR and mean median dissolved concentrations of nine metals that were consistently analyzed at all sampling stations equalled 0.18-0.19 mg/l and 0.079 mg/l, respectively, the in Laurel-to-Custer reach. Higher levels of 0.26-0.27 mg/l and 0.089-0.090 mg/l were obtained in the Bighorn-to-Powder segment. In both reaches, higher TR concentrations were obtained for the metals; about 43 percent of the TR concentrations in the Laurel-to-Custer reach were in the dissolved form and 34 percent in the dissolved form downstream. Thus, the TR levels of the metals apparently increased more between the Laurel-to-Custer and Bighorn-to-Powder segments than their increased components; this is probably a function of the higher sediment levels in the river below Custer. However, the concentration increases of the TR and dissolved forms of Fe, Mn, and Sr from Custer to Miles City were not as great or as consistent as they were in the river from Corwin Springs to Custer. This can be seen in table 63. Greater TR over dissolved concentrations of Sr and boron were evident in the Bighorn-to-Powder reach, as in the upstream segment.

Several trace elements demonstrated high median and grab sample concentrations, particularly in their TR forms, which may indicate water quality problems. This includes silica, ammonia, Al, As, B, Cr, Cu, Fe, Hg, Mn, Sr, V, and Zn; but especially Al, Fe, Mn, and Sr. The high maximum concentrations of these variables were generally obtained in conjunction with high suspended sediment levels. However, the concentrations of several other trace elements were low even in the TR form, and, as a result, these variables probably would not detract from any water uses. These constituents would include Ag, Be, Se, and Mo, particularly, but also Cd, Co, and Li.

TABLE 63. Concentration increases of TR and dissolved forms of Fe, Mn, and Sr in the Yellowstone River above Custer and at Myers, Forsyth, and Miles City.

	Fe		Mn		Sr	
	TR	Dissolved	TR	Dissolved	TR	Dissolved
Yellowstone above Custer[a]						
A	0.42	0.020	0.04	0.013	0.08	0.208
B	0.55	--	0.11	--	0.19	--
C	0.62	0.04	0.05	0.05	0.23	0.408
D	1.5	0.084	0.39	0.029	0.30	0.455
Yellowstone at Myers	1.6	0.03	0.11	0.01	0.40	0.60
Yellowstone at Forsyth	1.7	0.04	0.12	0.01	0.41	0.60
Yellowstone at Miles City	1.8	0.02	0.12	0.005	0.42	--

[a]Points A, B, C, and D represent sequential downstream reaches of the Yellowstone River above Custer.

Of those trace elements demonstrating occasionally high TR levels, many had low median TR concentrations or low dissolved concentrations. This would indicate that Al, Cr, Cu, and V, and also Ba, Ni, and Pb caused no water quality problems as their median dissolved levels were well below various reference criteria at all stations. Of the trace elements, therefore, ammonia, As, B, Fe, Hg, Mn, Sr, and Zn seem to have the greatest potential for causing water use problems. This would exclude silica with median concentrations in the Bighorn-to-Powder reach below the average for surface waters (Davis 1964).

Arsenic and mercury may cause water quality problems. Strontium concentrations do not appear to be at levels adequate to promote radiochemical problems for the reasons mentioned in the description of Beauvais Creek. Dissolved boron levels were well below the criteria for public supply, stock animals, and aquatic life, and they were well below the irrigation criteria for a Class I water. Maximum and median dissolved manganese concentrations were also less than these reference criteria; this was most obvious in zinc concentrations. Median dissolved iron concentrations were also below the criteria for drinking water and public supply, irrigation, and aquatic life; maximum dissolved values at Myers and near Forsyth were also less than these levels. However, occasionally high maximum levels of iron were obtained in the dissolved and TR components near Miles City, suggesting the development of iron-related water quality problems in the lower reach of the Yellowstone River. For example, about 7 percent of the Yellowstone samples from the Miles City locations had dissolved iron concentrations in excess of 0.2 mg/l, and about 6 percent of the samples had concentrations in excess of 0.3 mg/l.

Median ammonia concentrations were high in the Yellowstone River at Huntley-Custer (table 36) and in the Bighorn River at its mouth (table 48). As a result, high ammonia concentrations were also obtained in the Yellowstone downstream of Custer. Median ammonia levels tended to decline from Custer to

Myers (comparing tables 36 and 61) and then show a steady downstream increase from Myers to Miles City (tables 61 and 62). However, at the median pH levels of the mainstem at Miles City, only about four to five percent of the ammonia would be in the un-ionized and toxic, NH_3 form (<0.01 mg/l). This was also true in the Yellowstone at Myers-Forsyth, and un-ionized ammonia concentrations would be below the critical level established by the EPA (1973). Thus, ammonia would not be present in the river as a toxicant to aquatic life, but it may be a eutrophic factor. That is, if annual median ammonia-nitrogen concentrations are added to the median inorganic nitrogen levels obtained from the various stations below Custer, total soluble inorganic nitrogen (TSIN) concentrations would exceed the nitrogen reference criteria for eutrophication during some seasons, but not the criteria used by the EPA (1974b). However, these higher TSIN levels apparently do not alter the non-eutrophic status of the Yellowstone described previously.

During the critical summer-to-late fall period of high biological activity in the river, the Yellowstone did not appear to be eutrophic as both TSIN and P concentrations were below the corresponding reference levels; the river would be more N- than P-limited during this August-to-October season. During the less critical and biologically dormant seasons of winter and spring, TSIN concentrations generally exceeded the N criteria due to the seasonal nitrogen peak at this time. Phosphorus was generally below its reference levels, establishing the river as non-eutrophic and P-limited during the November-to-April. During the May-to-July period, TSIN concentrations were below the N criteria, but phosphorus exceeded its criteria due to the high-flow pulse of phosphorus described previously. Thus, the river was non-eutrophic and distinctly N-limited during this particular phase of the hydrologic cycle.

SARPY CREEK DRAINAGE

Sarpy Creek is a small intermittent tributary to the Yellowstone River; however, it does have a rather extensive drainage area south of Hysham between the Tullock and Armells Creek systems. During 1974, 35 percent of the measurements taken showed zero flow in the stream and 56 percent of the flow measurements were less than one cfs (USDI 1974). Sarpy Creek, therefore, would not be expected to have a significant effect on the Yellowstone mainstem; its importance lies in the fact that its headwaters are in an active strip mining area. Because of this, considerable water quality data are available on its upper drainage due to sampling programsinitiated for environmental impact statements (USDI 1976). Data are also available from the USGS for a location near the creek's mouth (USDI 1976), and from the state WQB.

The upper Sarpy Creek drainage has unusually poor water quality (table 64). Although occasionally high concentrations of TSS were obtained upstream in the creek, the 38,650 mg/l reading is especially notable. Overall, TSS levels did not significantly detract from the creek's quality; median TSS concentrations were less than those in the Yellowstone River. Rather, the poor quality was caused primarily by the extremely high TDS concentrations of the upper reaches--median TDS levels were 4.5 to 11.6 times greater than those in the Yellowstone River, depending upon season. As in most streams, TDS and flow were for the most part inversely related in upper Sarpy Creek with extremely high concentrations during the low flows of summer and low concentrations during the March-

TABLE 64. Summary of the physical parameters measured in the Upper Sarpy Creek drainage near Westmoreland.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	16	0.1	0.0	0.6	6	0.0	25.9	0.7	138	0.1	78.1	1.2	55	0.0	21.2	0.7
Temp	20	2.5	35	13.5	22	0.0	3.5	0.0	26	0.0	9.0	4	32	6.7	31	18.5
pH	21	7.6	8.7	8.1	26	7.1	8.4	7.65	26	7.26	8.5	8.0	34	7.5	9.1	8.14
SC	3.	3077	5181	4762	10	283	6660	2500	14	275	3300	2795	18	1800	5650	3320
TDS	14	1442	5862	4203	22	101	7002	2303	22	351	3154	2286	29	1565	5462	2987
Turb	21	2	>1000	15	26	2	180	12	25	4	172	10	36	0	62	16
TSS	20	1	38,650	12	26	2	190	16.5	29	1	216	8.5	39	0	209	11
DO	0	--	--	0	2	4.7	11.1	7.9	7	10.2	11.3	10.8	4	8.0	8.6	8.2
BOD	3	9	16	11	10	1.8	>11	4	13	1.0	5.0	4.1	20	<.1	52	6.6
FC	0	--	--	--	5	1	500	11	6	0	86	10	8	<1	1030	175
Ca	3	150	290	190	12	18.8	229	109	12	9	178	129	18	30	210	143
Mg	2	264	342	303	9	9.2	356	203	12	18	238	177	15	209	425	275
TH	3	1607	1881	1812	10	85	1880	906	12	170	1387	1080	15	134	2029	1608
Na	4	235	805	552	11	20	913	194	16	19	370	214	21	218	1077	371
K	0	--	--	--	4	13	54	27	7	6	12	7	9	11.7	29.5	14
SAR	0	--	--	--	6	0.9	9.5	2.5	7	0.7	3.7	2.7	9	2.6	5.8	3.5
HCO_3	3	220	610	610	10	76	1999	598	12	144	641	539	15	529	1002	683
TA	21	180	1900	568	26	50	1638	490	23	116	641	480	34	430	867	555
SO_4	21	224	3687	1817	26	18	3825	1082	26	81	2383	1219	36	718	3480	1650
Cl	3	24	84	24	10	5.0	27	10.5	14	4	26	12.0	15	0	35	19
F	21	0.4	1.4	0.7	25	0.1	0.8	0.4	29	0.1	1.1	0.5	38	<.2	1.2	0.4
N	3	<.02	<.05	<.02	10	0.02	0.57	0.27	12	0.0	0.04	<.02	18	<.02	3.75	0.22
P	3	0.03	0.03	0.03	9	<.01	0.30	<.03	14	<.01	0.07	0.03	18	0.0	0.10	<.03

NOTE: Measurements expressed in mg/l.

April peak flow period. This shows the influence of the earlier runoff period in lowland prairie regions over mountainous drainages which, in turn, is reflected in mainstem discharge (secondary March-April peak) and TDS levels (highest in March-April below Custer).

The waters in upper Sarpy Creek were slightly saline (moderately saline in the summer), extremely hard, and they had a sodium sulfate composition characteristic of many small streamsin eastern Montana. Sulfate concentrations were high--about 50 percent of the TDS weight was sulfate. All dissolved constituents were in greater concentrations in upper Sarpy Creek than in the Yellowstone River, although fluoride, chloride, and potassium were minor ions. Calcium-magnesium and bicarbonate were secondary constituents with magnesium concentrations greater than calcium concentrations. This suggests an extension of the dolomitic formations into the Sarpy Creek drainage. The high TDS and high ionic constituent concentrations preclude many water uses from the stream, including that of surface water public supply--TDS and sulfate concentrations are well above the reference criteria for this use (table 9). In addition, although the overall TSS levels of the stream would not be expected to affect the aquatic biota, TDS concentrations exceeded 1350 mg/l and specific conductances greater than 2000 μmhos/cm would indicate a detrimental influence on freshwater life (Ellis 1944).

Upper Sarpy Creek has a poor Class III water for irrigation due to the high TDS and sulfate concentrations (tables 15 and 16); the water has a very high salinity hazard for this use but a low sodium hazard due to the low SAR values (table 64). As indicated by the EPA (1976), water of this nature " . . . can be used for tolerant plants on permeable soils with careful management practices." Such tolerant crop and forage species are listed in table 17. Regardless of water quality, however, the generally low flows in the upper reach would probably eliminate the possibility for many of these uses. The water quality in upper Sarpy Creek is only fair for application to stock animals (tables 10-14), and, due to the high TDS levels, it should not be used to water poultry. Median sulfate and bicarbonate concentrations were consistently greater than the limiting levels for stock animals, and magnesium concentrations occasionally exceeded threshold levels. Extended consumption of these high sulfate waters could be harmful to animals (California WRCB 1974). However, TDS concentrations decline downstream in Sarpy Creek to its mouth (table 65), suggesting that the waters in lower Sarpy Creek may be more suitable for stock animals.

Sarpy Creek was unusual because it showed a general downstream improvement in water quality and a reduction in TDS concentrations from about 23 percent to 37 percent, depending upon season; the reverse was found to be true in most other streams. Sarpy Creek also showed a slight downstream increase in TSS concentrations, but they were not noticeably high even in the lower reach, and were not expected to significantly affect the aquatic biota.

As in the upper reach, salinity appeared to be the major problem in downstream quality, especially during the lower flows. The lower reach, therefore, probably would not be suitable as a surface water public supply, due again to the high TDS, sulfate, and hardness levels. Salinity may cause problems for the aquatic biota in the lower reach, as median TDS concentrations exceeded

TABLE 65. Summary of the physical parameters measured in Sarpy Creek near Hysham.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	3	0.02	0.3	0.2	9	0.3	193	1	3	3.2	387	15	6	0.4E	30.2	15.5
Temp	3	7.0	18.5	8.2	8	0.0	6.5	0.5	4	0.0	10.5	2.5	6	11.0	23.0	14.9
pH	3	8.20	8.5	8.4	9	7.6	8.5	8.10	4	7.9	8.5	8.25	6	8.2	8.70	8.4
SC	3	2340	4300	3130	9	288	3720	2395	4	215	2800	2203	6	1151	4300	2603
TDS	3	1890	4280	2689	9	182	2610	1650	3	150	2269	1430	5	1570	3578	2300
Turb	3	7	14	8	9	3	30	4	4	10	100	24	5	7	81	48
TSS	0	--	--	--	2	6.0	9.5	7.8	2	14.0	47	30.5	3	12	148	66.2
DO	2	1.8	8.4	5.1	9	8.0	12.5	10.2	4	10.4	11.2	10.9	5	7.8	8.6	8.1
BOD	0	--	--	--	2	2.8	3.0	2.9	2	2.7	3.7	3.2	2	4.9	6.3	5.6
FC	0	--	--	--	2	18	20	19	2	29	79	54	1	--	--	0
Ca	3	59	190	122	9	18	110	86	3	20	91	88	6	48	130	83
Mg	3	92	210	113	9	8.0	130	74	3	10	129	95	6	52	190	130
TH	3	530	1300	770	9	78	810	535	3	91	758	610	6	336	885	715
Na	3	430	880	515	9	27	600	370	3	14	385	240	6	105	770	383
K	2	9.7	12	10.9	7	7.2	14	9.8	2	7.4	9.9	8.4	4	4.4	11	9.3
SAR	3	8.1	10.0	8.2	9	1.3	9.2	7.0	3	0.6	6.1	4.2	5	2.5	6.9	5.6
HCO_3	3	548	886	573	9	89	853	605	3	95	556	425	6	235	704	474
TA	3	470	727	471	9	73	700	496	3	78	456	349	6	193	604	417
SO_4	3	1000	2500	1345	9	64	1300	750	3	40	1096	770	6	340	1841	1131
Cl	3	16	33	17	9	3	21	14	3	4	11.8	11	6	0.2	17	14
F	3	0.3	0.4	0.4	8	0.1	0.5	0.4	2	0.1	0.3	0.2	4	0.3	0.4	0.4
N	3	0.0	0.75	0.01	8	0.0	0.2	0.03	3	0.1	0.24	0.1	6	0.0	0.5	0.04
P	3	0.01	0.05	0.03	9	0.0	0.46	0.02	3	0.02	0.35	0.02	6	0.02	0.11	0.03

NOTE: Measurements expressed in mg/l.

1350 mg/l and specific conductances exceeded 2000 μmhos/cm. Furthermore, the waters would have a high or very high salinity hazard for irrigation. Because of the downstream reduction in TDS concentrations, the lower reach waters would have good quality for stock (Seghetti 1951), although bicarbonate and sulfate concentrations were still greater than the limiting levels for animals (California WQCB 1963).

A change in chemical composition became evident in Sarpy Creek, probably a reflection of intermediate inputs with a different water quality diluting the TDS concentrations. In general, calcium plus magnesium and sulfate concentrations declined downstream, sodium levels increased significantly, and bicarbonate declined slightly. Fluoride, chloride, and potassium continued to be insignificant constituents of the water. The stream near Hysham tended to become more sodium sulfate; the average (Ca + Mg):Na ratio declined from 1.39 to 0.55, and the average $HCO_3:SO_4$ value increased slightly from 0.44 to 0.55. The average Ca:Mg ratio increased to the lower reach from 0.60 to 0.95, indicating that the intermediate inputs to Sarpy Creek were probably sodium sulfate-bicarbonate and not derived from dolomitic regions.

The lower reach's water samples showed higher SAR values (table 65). As a result, the lower reach had a median sodium hazard for irrigation. Overall, the lower segment of Sarpy Creek appears to have a poor quality, borderline Class II/Class III water for irrigation (tables 15 and 16), and the low summer flows may eliminate the use of the stream for irrigation altogether.

Sarpy Creek has been classified a B-D_3 stream by the State of Montana (Montana DHES, undated), although the water-use description for this classification is not very appropriate for the water quality in the stream. Because of the water's high TDS concentrations, Sarpy Creek does not appear to be " . . . suitable for drinking, culinary, and food processing purposes . . ." (Montana DHES, undated), and it does not appear to be suitable for the ". . . propagation of non-salmonid fishes . . ." (Montana DHES, undated). Its value as an agricultural supply is also questionable. High inorganic nitrogen and ammonia concentrations, which might have been derived from explosives used in strip mining activities in the region, were occasionally obtained from the stream. Also, ammonia levels appeared to be sufficiently high at times (table 66) to be potentially toxic to the aquatic biota through the pH levels of the water--un-ionized, gaseous ammonia was sometimes in excess of 0.02 mg/l (USEPA 1973).

Other physical characteristics indicate, however, that Sarpy Creek's B-D_3 classification is appropriate. For example, the pH and dissolved oxygen levels were in accord with the criteria for a B-D_3 water, and the high maximum temperatures were also normal for this classification. Also, fecal coliform concentrations declined downstream and did not generally suggest water quality problems in either the upper or the lower segment (tables 8 and 9). The creek was definitely non-eutrophic as both median nitrogen and phosphorus concentrations were below the reference criteria.

The upper drainage of Sarpy Creek appears to be organically polluted to some extent with high BOD_5 concentrations; median values were generally greater than those obtained in other streams. However, this pollution does not appear to be caused directly by municipal discharge due to the low fecal coliform

TABLE 66. Summary of miscellaneous constituent and trace element concentrations measured in the Sarpy Creek drainage.

	Upper Sarpy Creek drainage near Westmoreland								Sarpy Creek near Hysham							
	Miscellaneous constituents and total recoverable metals				Dissolved metals				Miscellaneous constituents and total recoverable metals				Dissolved metals[a]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Br	23	0.0	0.0	0.0												
COD	26	11	193	38												
Color	26	5	150	43												
DO[b]									14	16	108	80				
NH_3-N	29	0.1	3.2	<1												
O&G	94	0.0	14.4	2												
S	16	0.0	0.0	0.0												
Si	6	0.0	14.5	9.9					14	0.8	12	8.5				
Al	19	.05	3.9	.35	30	0.0	<.01	<.01	4	.11	1.5	.27	2	0.0	0.01	.005
As									11	0.0	.011	.002	2	.001	.002	.002
B									3	.16	.51	.33	14	.11	.68	.32
Ba													2	.06	.07	.07
Be									2	<.01	<.01	<.01	2	0.0	<.01	<.01
Cd	30	<.001	0.016	<.002					13	0.0	0.02	<.01	2	0.0	.001	.001
Co									2	.04	.08	.06	2	<.015	<.016	<.016
Cr	32	<.005	0.04	0.009 (.177?)					10	0.0	0.04	.003	2	0.0	<.01	<.01
Cu	42	<.002	0.06	0.01					13	<.01	0.09	<.01	2	.001	.003	.002
Fe	107	<.02	22	0.39	69	0.0	0.60	0.07	13	.14	11	.60	14	.01	.41	.07
Hg	36	<.0001	0.007	0.001					11	0.0	<.001	.0001	2	0.0	<.0001	<.0001
Li									2	.02	.07	.045	2	.04	.08	.06
Mn	41	.009	1.1	.15					11	.02	.69	.17 (6.0?)	2	.05	.13	.09
Mo													2	<.005	<.005	<.005
Ni	42	.003	.08	.01									2	.001	.005	.003
Pb									10	<.01	0.10	<.10	2	.001	.003	.002
Se									10	0.0	.001	0.0				
Sr													2	1.5	2.5	2.0
V									2	.04	.53	.29	2	<.008	<.008	<.008
Zn	43	<.005	0.09	0.012					8	<.01	0.12	0.04	2	.01	.01	.01

NOTE: Measurements are expressed in mg/l.

[a]Ag: <.002, N=2; Sn: 0.0, N=1.

[b]DO expressed as percentage of saturation.

(tables 64 and 65) and oil and grease (table 66) concentrations, although it might ultimately have been derived from this source via groundwater inputs. As alternatives, the high BOD_5 levels could have been derived from the same sources as the high nitrogen concentrations or from concentrated soil extracts reaching the stream. The latter alternative would probably color the water, aesthetically degrading the stream; the upper Sarpy samples were noticeably colored (table 66). Organic pollution from some source was also indicated by the upper creek's high COD levels and in the low percentage of DO saturations near Hysham. The BOD_5 concentrations appeared to be significantly diluted by the time the stream reached its mouth, and they were of insufficient magnitude to consistently reduce the stream's DO concentrations to levels in violation of the state criteria for a $B\text{-}D_3$ stream.

Most of the trace elements were detected in at least some of the samples from Sarpy Creek (table 66). High TR concentrations were obtained in some instances, especially Fe and Mn, but also Al, B, Sr, Si, and V. Some of the minor constituents--Ag, Be, Br, Mo, and S--were never detected in the samples. Several of the remaining minor constituents--As, Cr, Li, Ni, and Se--may cause water quality problems due to their low median and maximum TR concentrations. In some cases, median TR or dissolved levels were below various criteria, but occasional samples--Cd, Co, Cu, Pb, V, and Zn--had TR concentrations in excess of reference levels. These six constituents probably did not indicate water quality problems in Sarpy Creek, but they would be more likely to than the trace elemenets mentioned previously.

Median TR concentrations of Al, Fe, and Mn exceeded various water quality criteria, indicating that these trace elements are potentially limiting. However, as the median dissolved concentrations of the first two parameters were less than the reference levels, Al, Fe, and Mn probably did not detract from water use except in a few instances when dissolved levels were high (e.g., in 14 percent of the samples, iron concentrations were greater than 0.3 mg/l). B, Ba, Si, and Sr did not indicate water quality problems. Of the trace elements, therefore, mercury seems to have the greatest potential to affect the aquatic biota and other water uses, particularly in the upper reach of Sarpy Creek. Additional data would be necessary, however, to more fully assess the extent of this possible effect.

ARMELLS CREEK DRAINAGE

Armells Creek is another small tributary to the Yellowstone River, and is not expected to have a substantial effect on mainstem quality. Armells Creek probably has a greater tendency towards perenniality than Sarpy Creek. Armells Creek also drains an active strip mining area with a coal-fired electrical generating facility, and, as a result, a great deal of water quality information has recently been gathered on the stream by the USGS (USDI 1976) and by the state WQB (Montana DNRC 1974). The USGS maintains three sampling stations in the drainage as indicated in tables 67-69, and the more dispersed collections of the state WQB were combined in conjunction with these three USGS locations.

Many of the water quality features observed in Sarpy Creek also occur in Armells Creek. However, certain differences are evident. Both streams had high TDS concentrations, which significantly degrade the water quality. This

TABLE 67. Summary of the physical parameters measured in the east fork of Armells Creek and Sheep Creek tributary (one sample) near Colstrip.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	4	0.0	3.7	1.45	7	0.05	169	1.8	9	0.07	21	2.04	6	1.4	20E	4.0
Temp	3	6.0	19.0	7.0	7	0.0	5.0	0.5	9	0.0	24.0	11.8	8	9.0	26.1	15.5
pH	4	8.20	8.80	8.3	7	7.5	8.6	7.9	9	7.7	8.30	8.1	8	7.60	8.80	8.05
SC	4	2330	4524	3185	7	290	4820	3780	9	703	5043	3700	8	1299	8850	3400
TDS	4	2000	3835	2870	7	178	3720	2970	9	514	4885	3150	7	981	8955	3310
Turb	4	0	25	2	7	1	40	4	9	4	155	10	8	2	135	9
TSS	0	--	--	--	2	10.5	39.0	24.8	5	7.2	245	28	3	31.2	201	77
DO	2	8.6	11.1	9.9	7	8.7	11.0	10.0 (1.9?)	8	8.0	12.5	9.8	6	3.5	15.4	8.8
BOD	2	1.2	1.3	1.3	7	0.1	4.4	0.7 (9.5?)	9	1.7	5.3	2.8 (11.?)	4	0.6	1.7	1.2
FC	0	--	--	--	2	0	0	0	5	0	36	0	1	--	--	0
Ca	4	48	285	145	7	22	280	240	9	11	290	228	8	98	291	210
Mg	4	81	362	175	7	13	340	240	9	2.9	487	290	8	91	835	315
TH	4	455	2200	1100	7	110	2100	1600	9	40	2520	1800	8	620	4165	1850
Na	4	220	1030	261	7	13	410	300	9	72	669	310	8	50	1220	310
K	2	16	19	18	5	7.4	23	21	4	8.9	21	17	7	12	18	17
SAR	4	2.5	21	3.1	7	0.5	4.0	3.7	9	1.5	9.5	3.6	8	0.9	8.2	3.5
HCO_3	4	376	651	512	7	71	621	549	9	175	612	506	8	159	570	419
TA	4	308	593	420	7	58	509	450	9	144	502	419	8	130	468	348
SO_4	4	1200	2078	1585	7	75	2300	1900	9	170	3048	2000	8	564	6184	2100
Cl	4	18	86	42	7	4.1	66	48	9	0.2	52	26	8	5.3	75	49
F	4	0.3	0.7	0.5	5	0.0	0.7	0.5	8	0.1	0.6	0.3	7	0.3	0.5	0.3
N	4	0.03	0.10	0.04	7	0.06	0.52	0.13	9	0.0	1.81	0.04	8	0.0	0.89	0.09
P	4	0.02	0.28	0.03	7	0.0	0.22	0.04	9	<.01	0.30	0.03	8	0.01	0.33	0.06

NOTE: Measurements expressed in mg/l.

TABLE 6[illegible] [illegible] the physical parameters measured in the west fork of Armells Creek near Colstrip.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	1	--	--	0.01	7	0.01	3.11	0.05	7	0.5	28	1.60	5	0.10	17	2.0
Temp	1	--	--	5.0	7	0.0	9.0	2.0	7	0.0	15.0	6.0	5	7.5	22.5	18.5
pH	1	--	--	8.6	7	7.4	8.9	7.8	7	7.5	8.4	7.95	5	7.7	8.1	8.1
SC	1	--	--	6740	7	3272	7100	5000	7	765	5820	4190	5	3700	6000	5200
TDS	1	--	--	5710	7	2510	5660	3810	6	383	5026	4695	5	3270	5030	4550
Turb	1	--	--	20	7	2	20	3	7	4	210	17	5	3	55	10
TSS	0	--	--	--	1	--	--	10.5	3	16.8	1504	28	0	--	--	--
DO	1	--	--	11.6	7	6.4	11	10.2	7	8.8	13.2	11.2	5	6.7	8.8	8.3
BOD	1	--	--	1.7	6	0.5	4.4	2.0	7	0.8	8.4	1.5	5	0.9	2.1	1.4
FC	0	--	--	--	1	--	--	0	3	0	190	6	0	--	--	--
Ca	1	--	--	140	7	130	280	167	6	33	250	206	5	160	200	200
Mg	1	--	--	300	7	120	290	190	6	27	301	255	5	160	280	230
TH	1	--	--	1600	7	820	1900	1300	6	190	1720	1650	5	1100	1600	1400
Na	1	--	--	1200	7	468	1200	690	6	57	940	889	5	630	1100	930
K	1	--	--	16	6	10	15	14	4	6.9	14	12	5	12	15	13
SAR	1	--	--	13	7	6.6	12	8.2	6	1.8	9.9	9.5	5	8.2	12	11
HCO_3	1	--	--	411	7	353	875	486	6	134	748	658	5	481	666	593
TA	1	--	--	347	7	290	718	417	6	110	614	540	5	395	546	486
SO_4	1	--	--	3800	7	1500	3400	2300	6	180	3000	2900	5	2000	3200	2800
Cl	1	--	--	44	7	18	39	25	6	0.2	31	19	5	22	81	27
F	1	--	--	0.2	6	0.2	0.4	0.3	6	0.1	0.6	0.4	5	0.3	0.4	0.3
N	1	--	--	0.0	7	0.0	0.36	0.0	7	0.0	0.09	0.0	5	0.0	0.12	0.02
P	1	--	--	0.04	7	0.01	0.06	0.02	7	0.0	0.27	0.02	5	0.01	0.11	0.04

NOTE: Measurements expressed in mg/l.

TABLE 69. Summary of the physical parameters measured in Armells Creek near Forsyth.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	4	0.05	2.1	0.54	12	0.24	462	1.94	9	2.30	76	4.2	7	1.6	19	3.2
Temp	4	7.0	25.0	16.5	12	0.0	5.5	0.0	9	0.0	14.0	7.0	8	13.0	27.8	21.3
pH	3	8.0	8.7	8.4	12	7.4	8.32	7.95	9	7.90	8.5	8.30	8	8.00	8.70	8.4
SC	4	3300	4240	4030	12	395	6500	3340	9	680	4750	3210	8	650	4230	3910
TDS	4	2240	3840	3025	11	245	4100	2560	8	379	4210	2707	7	480	4030	2960
Turb	4	1	50	14	12	6	400	20	9	15	400	33	7	6	210	18
TSS	0	--	--	--	5	23	180	28	4	38	93	64	3	23	380	51.2
DO	4	7.8	10.4	9.4	12	9.2	13.3	11.7	9	10.6	13.0	11.0	6	7.0	11.2	8.5
BOD	4	2.4	3.1	2.5	12	0.3	11.0	3.0	9	0.0	7.8	3.6	4	1.3	3.0	2.0
FC	0	--	--	--	3	0	1120	2	4	50	260	122	1	--	--	110
Ca	4	40	85	66	11	24	210	104	8	33	190	112	8	39	170	110
Mg	4	67	130	82	11	5.8	190	68	8	28	230	98	8	13	210	155
TH	4	420	750	480	11	110	1300	540	8	200	1400	683	8	152	1300	940
Na	4	560	960	840	11	35	1000	450	8	54	840	529	8	82	820	633
K	4	7.5	12	9.5	9	6.5	12	11	4	7.0	12	10.2	5	10	12	11
SAR	4	11	18	16	11	1.5	16	9.0	8	1.7	10.8	9.0	8	2.9	11.8	9.8
HCO_3	4	388	664	583	11	89	913	501	8	131	613	470	8	134	588	454
TA	4	370	545	508	11	73	749	411	8	107	503	390	8	110	482	393
SO_4	4	1200	2400	1700	11	110	2400	1500	8	180	2400	1472	8	205	2500	1800
Cl	4	16	27	22	11	4.7	39	20	8	4.8	260	20	8	5.5	29	23
F	4	0.4	0.6	0.5	9	0.1	0.6	0.4	6	0.2	0.4	0.3	6	0.3	0.4	0.4
N	4	0.01	0.07	0.03	11	0.04	0.32	0.13	8	0.01	0.17	0.07	8	0.0	0.12	0.01
P	4	0.02	0.14	0.07	11	0.01	0.37	0.07	8	0.01	0.51	0.03	8	<.01	0.09	0.04

NOTE: Measurements expressed in mg/l.

was especially noticeable in the moderately saline east and west forks of Armells Creek. For the most part, Armells Creek was much more saline than Sarpy Creek. Armells Creek was slightly saline at its mouth and demonstrated a downstream improvement in water quality and a decrease in TDS concentrations. The inverse relationship between flow and TDS was not well defined in Armells Creek, and, as a result, lowest TDS concentrations were not necessarily obtained during high-flow periods. This marking of flow-TDS relationships seems typical of small prairie streams.

Like Sarpy Creek, Armells Creek had a sodium sulfate composition which tended to become more pronounced downstream; this can be shown by the mean (Ca + Mg):Na and $HCO_3:SO_4$ ratios from each station as follows in table 70.

TABLE 70. Mean (Ca + Mg):Na and $HCO_3:SO_4$ ratios from the mouth and east and west forks of Armells Creek.

	(Ca + Mg):Na	$HCO_3:SO_4$
Mouth	0.35	0.31
East Fork	1.57	0.27
West Fork	0.47	0.19

Calcium-magnesium and bicarbonate were secondary ions in Armells Creek, and fluoride, chloride, and potassium were insignificant components. Due to the low (Ca + Mg):Na ratios, SAR values in Armells Creek were much higher than those in Sarpy Creek, creating a low-medium (east fork) to medium-very high (west fork and mainstem) sodium hazard for irrigation. Chloride levels were somewhat higher than those in Sarpy Creek, and sulfate concentrations were especially high in the more eastern stream. Magnesium concentrations generally exceeded calcium levels in the upper drainage of Armells Creek, and Ca:Mg ratios then declined downstream to the creek's mouth.

The high TDS and constituent concentrations in Armells Creek would be expected to affect many of the water uses described for Sarpy Creek. The west fork water would be poor or unfit as a source for stock animals, and waters in the east fork and mainstem would of only fair quality for this use (California WRCB 1951). None of these waters should be used for poultry. The high sulfate and bicarbonate concentrations in the creek would further degrade the water as a source for stock animals since these constituents exceeded limiting levels (tables 10-14). Also as a result of these features, Armells Creek, with its very hard water, would be particularly unsuitable as a source for municipal supply. In terms of irrigation, Armells Creek would have a poor quality, Class III water due to high SAR, sulfate, TDS, and specific conductance (very high salinity hazard) levels (tables 15 and 16). Boron, however, should not affect this use (<1 mg/l). Thus, the water in this creek would not be applicable to a variety of salinity-sensitive and semi-tolerant crop and forage species as summarized in table 17. In addition, the high TDS levels would be expected to have an adverse effect on the aquatic biota (Ellis 1944).

TSS concentrations in Armells Creek were not high in comparison to many other streams. They were generally similar to those in Sarpy Creek, and median values were less than those observed in the Yellowstone River. Occasionally high values were obtained in correspondence to high flows, but TSS would not be expected to have as great an effect on the aquatic biota as would salinity. Armells Creek has been designated a warm-water, B-D_3 stream by the State of Montana; however, like Sarpy Creek, its water quality does not appear to conform to the water-use description of this classification, due primarily to high salinities. Dissolved oxygen, pH, fecal coliform, and temperature levels were generally in accord with this classification.

BOD_5 levels in Armells Creek did not indicate organic pollution; this was generally substantiated by the high DO saturations (tables 71-73). In addition, Armells Creek did not appear to be eutrophic as it had low inorganic nitrogen concentrations (tables 67-69) during all seasons. Phosphorus concentrations were also low, and median values exceeded the P criteria only at certain seasons in the east fork and mainstem of Armells Creek. Thus the creek appeared to be N-limited. However, high inorganic nitrogen and ammonia levels (tables 71-73) were occasionally obtained, but only in samples from the east fork; this segment of Armells Creek was directly associated with strip mining activities. Median ammonia concentrations were not at levels high enough to alter the eutrophic status of the stream or to be toxic to aquatic organisms.

A variety of trace elements were analyzed in the Armells Creek samples as a result of the stream's juxtaposition to strip mining and electrical generating facilities. With the exception of silica (concentrations were below levels typical of surface waters, Sr, and ammonia, trace elements in Armells Creek can be separated into six groups on the basis of their maximum and median, TR and dissolved concentrations in relation to the water quality criteria. The six classes, ranked according to their potentials to detract from water quality, are summarized in table 74.

As seen in tables 71-73, most of the trace elements, except those in Group I on table 74, were detected in at least a few of the samples. In some instances, constituents were detected in a large percentage of the collections and were found in high concentrations. As observed in other streams, Al, B, Fe, Mn, Sr, and V were most noticeable. However, the high concentrations of many constituents were generally obtained in the TR form with dissolved levels comparatively low. Therefore, most of the trace elements, including ammonia and strontium, would not be expected to detract from the water quality of Armells Creek (that is, the trace elements included in Groups I through IV in table 74).

Of the 29 trace elements, Ba, Fe, Hg, and Mn may cause occasional water quality problems at particular locations, as dissolved levels sometimes exceeded certain reference criteria. In the upstream reaches, mercury may sometimes influence the aquatic biota (table 19), and barium may detract from the value of downstream waters as a source for irrigation. However, iron and manganese are probably more obvious problems to the creek's use; iron could affect the aquatic biota and lower the value of the stream as a surface water public supply, and manganese could detract from its potential for irrigation (tables 15 and 16) and human consumption. The poor water quality in Armells Creek is caused primarily by its extremely saline nature, which probably exerts a more direct effect on water use than do any of the trace elements.

TABLE 71. Summary of miscellaneous constituent and trace element concentrations measured in the Armells Creek drainage.

	East Fork Armells Creek								West Fork Armells Creek							
	Miscellaneous constituents and dissolved metals				Total recoverable metals				Miscellaneous constituents and dissolved metals				Total recoverable metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[a]	15	67	205	90					16	49	103	87				
NH_3-N	16	0.0	1.1	0.14					16	0.02	0.11	0.04				
Si	16	1.4	17	7.5					16	1.0	19	8.4				
B	16	0.12	0.97	0.71					16	0.13	0.71	0.51				
Cd					18	<.001	0.02	<.01					9	<.001	0.03	0.01
Cu					17	<.01	0.04	0.01					9	0.01	0.03	0.01
Fe	15	0.02	0.16	0.06	18	0.08	2.7	0.45	16	0.01	0.42	0.05	9	0.23	0.92	0.54
Mn					17	<.01	3.0	0.18					9	0.05	0.80	0.13

NOTE: Measurements are expressed in mg/l.

[a]DO expressed as percentage of saturation.

TABLE 72. Summary of trace element concentrations measured in the Armells Creek drainage.

	East and west forks Dissolved metals[a]				East and west forks Total recoverable metals			
	N	Min	Max	Med	N	Min	Max	Med
Ag	2	<.002	<.004	<.004				
Al	3	0.0	.03	.01	10	.02	.30	.14
As	3	.001	.002	.001	16	0.0	.006	.001
B					5	.21	.75	.40
Ba	2	.02	.06	.04				
Be	3	0.0	.01	.01	17	0.0	0.01	<.01
Cd	3	0.0	.001	0.0				
Co					3	.07	.08	.07
Cr	3	0.0	.01	.002	18	0.0	.04	.01
Cu	3	0.0	.016	.001				
Hg	3	0.0	.0001	0.0	25	0.0	.001	.0003
Li	.2	.05	.10	.075	17	<.01	0.13	0.05
Mn	3	0.0	.25	.04				
Mo	2	.002	.002	.002	14	0.0	.003	.001
Ni	3	0.0	.004	.004	14	0.0	.15	<.05
Pb	3	.002	.004	.003	16	0.0	.100	<.100
Se	2	0.0	0.0	0.0	17	0.0	.004	0.0
Sr	2	1.7	5.0	3.4				
V	2	.0016	.0017	.0017	3	.42	.71	.50
Zn	3	.01	.02	.02	23	0.0	.14	.01

NOTE: Measurements are expressed in mg/l.

[a]Ga: <.03, N=2; Bi, Co, Sn, Ti: <.04, N=2; Ge, Zr: <.05, N=2.

TABLE 73. Summary of miscellaneous constituent and trace element concentrations measured in Armells Creek near Forsyth.

	Miscellaneous constituents and dissolved metals[a]				Total recoverable metals			
	N	Min	Max	Med	N	Min	Max	Med
DO[b]	22	69	137	95				
NH_3-N	22	0.0	0.16	0.04				
Si	22	1.2	14	6.9				
Al	2	.01	.01	.01	6	.21	2.2	.64
As	2	.001	.002	.002	14	0.0	<.01	.002
B	22	.14	.60	.47	5	<.10	0.58	0.20
Ba	2	.082	.100	.091				
Be	2	0.0	<.01	<.01	15	0.0	0.02	<.01
Cd					19	<.001	0.02	0.01
Co					4	.03	.08	.07
Cr	2	<.01	0.01	0.01	16	0.0	.064	0.01
Cu	2	.001	.003	.002	19	<.01	0.30	0.01
Fe	22	0.0	.51	.03	19	.16	9.7	.75
Hg					18	0.0	.004	.0002
Li	2	.03	.04	.04	15	<.01	0.06	0.03
Mn	2	.06	.21	.14	17	.03	.33	.19
Mo	2	<.006	<.006	<.006 (.002)	11	0.0	.005	.002
Ni	2	.003	.006	.005	11	<.05	0.10	0.05
Pb	2	0.0	.003	.002	13	<.01	0.10	<.10
Se					15	0.0	0.001	<.001
Sr	2	1.5	2.6	2.1				
V	2	<.008	<.008	<.008 (.0023)	3	.03	.72	.39
Zn	2	<.01	0.02	--	14	<.01	0.04	0.02

NOTE: Measurements are expressed in mg/l.

[a]Cd, Se: 0.0; Hg: <.0001; Ag: <.002; Co, Ga, Sn, Ti: <.02; Bi, Ge: <.03; Zr: <.04; N=2.

[b]DO expressed as percentage of saturation.

TABLE 74. Trace elements in Armells Creek grouped according to their maximum and median, TR and dissolved concentrations in relation to water quality criteria.

Group[a]	TR Max	TR Med	Dissolved Max	Dissolved Med	Comments
I	Undetected		Undetected		No problems anticipated.
II	<	<	<	<	No problems anticipated.
III	>	<	<	<	Water quality problems doubtful.
IV	>	>	<	<	Low probability of continuous problems.
V	>	>	>	<	Occasional water quality problems.
VI	>	>	>	>	High probability of continuous problems.

NOTE: TR and dissolved concentrations of the trace elements within each group were either greater than (>) or less than (<) corresponding water quality criteria.

[a]The trace elements belonging to each group are the following:

Group I Ag, Bi, Ga, Ge, Sn, Ti, and Zr at all stations

Group II As, B, Be, Li, Mo, and Se at all stations; Ba and Cr in the east and west forks; and Zn in the mainstem near Forsyth

Group III Cu, Ni, and Pb at all stations; Zn in the east and west forks; and Cr in the mainstem near Forsyth

Group IV Al, Ce, Co, and V at all stations; Fe in the east fork; and Hg in the mainstem near Forsyth

Group V Hg and Mn in the east and west forks; Fe in the west fork and in the mainstem near Forsyth; and Ba in the mainstem near Forsyth

Group VI Mn in the mainstem near Forsyth

MISCELLANEOUS TRIBUTARIES AND SUNDAY CREEK

Several other small streams join the Yellowstone River between the Bighor and Powder rivers. Overall, the flows of these streams are smaller and are expected to have only a minor influence on mainstem water quality. Because these miscellaneous creeks are not directly affected by coal mining activities, very little water quality information has been collected from them other than that obtained from eight streams by the state WQB (Karp and Botz 1975, Karp et al. 1975b, Montana DNRC 1974). Due to the scarcity of data, this information was coordinated by combining streams into three groups as follows (USDI 1968):

1) small tributaries north of the Yellowstone River between Bighorn and Miles City--Starve-to-Death, Great Porcupine, and Little Porcupine creeks;

2) small tributaries south of the mainstem between Bighorn and Miles City--Reservation, Smith, Sweeney, and Moon creeks; and

3) Sunday Creek near and northeast of Miles City.

A few of these streams have rather extensive drainage areas; Sunday Creek probably has the largest discharge. Data for Sunday Creek were adequate for a flow-based classification of information, although this was not possible for the other streams.

These miscellaneous tributaries and Sunday Creek have been designated $B\text{-}D_3$ streams. As indicated in tables 75-78, the streams' pH ranges, temperature characteristics, fecal coliform levels (except in Sunday Creek), and dissolved oxygen concentrations were generally in accord with this classification. High fecal counts were obtained from Sunday Creek, which frequently (in four of seven samples) showed levels in violation of state criteria. The origin of these fecals is unknown, but they were probably derived from animal sources, judging from the remoteness of Sunday Creek's drainage area.

Overall BOD_5 concentrations were also high in Sunday Creek and in the other northern tributaries. This was not true of creeks draining the more southern regions of the Yellowstone Basin. The high BOD_5 levels were probably natural, considering the sparse human populations in the Bighorn-Miles City area. Most of these streams are probably non-eutrophic with very low median phosphorus concentrations and low nitrogen levels; however, occasionally high values of these parameters were obtained in some samples. The only exception was Sunday Creek, which tended towards eutrophy during low-flow periods.

The waters in Sunday and the Group I and II creeks (table 74) had a sodium sulfate composition with bicarbonate as the secondary anion. Calcium concentrations significantly exceeded magnesium levels. This, coupled with the high chloride concentrations in the northern tributaries (including Sunday Creek), suggests different geologies in the northern and the southern drainages of these streams. Sunday Creek is particularly noticeable in having high chloride concentrations, which significantly exceeded the creek's Ca + Mg levels. This is a unique feature among the streams inventoried so far in this report, and suggests different rock formations in the northern portions of the Yellowstone Basin. However, fluoride and potassium concentrations were again low in these small tributaries and did not indicate water quality problems. Similarly, TR trace element concentrations in the Group I and II streams (tables 75 and 76) and in Sunday Creek (tables 77 and 78) were generally similar to those found in Armells Creek. High concentrations of certain constituents were occasionally obtained in excess of certain reference criteria (e.g., Co, Fe, Hg, Mn, V, and Zn), but in general, median TR levels indicated low dissolved concentrations and did not suggest difficulties in water use. Iron, which had significantly high TR levels in some samples, may be the major exception. Data were insufficient to describe the status of mercury in this regard.

TABLE 75. Summary of the physical parameters measured in small tributaries to the Yellowstone River between the Bighorn and Powder rivers.

	Tributaries to the north of the Yellowstone River[a] in mg/l				Tributaries to the south of the Yellowstone River[b] in mg/l			
	N	Min	Max	Med	N	Min	Max	Med
Flow	12	0.0	10E	0.5	9	0.17	1.47	0.79
Temp	11	0.0	17.7	13.0	9	0.0	19.5	9.2
pH	12	6.60	8.20	7.75	9	7.50	8.60	8.30
SC	19	1011	6290	2165	9	807	2200	1918
TDS	12	695	4100	1684	9	606	1778	1530
Turb	10	6	350	17	9	1	340	12
TSS	10	6.5	824	36.3	9	3.5	482	21.5
DO	6	9.8	12.0	10.5	9	8.4	12.9	10.7
BOD	6	3.1	8.2	4.2	9	1.1	10.1	2.6
FC	6	0	80	4	8	0	460	4
Ca	12	51	465	131	9	39	98	57
Mg	12	11	248	63	9	0.0	69	34
TH	12	174	1598	588	9	101	530	266
Na	12	45	800	328	9	116	431	278
K	4	11	25	15	0	--	--	--
SAR	12	0.9	8.8	5.8	9	3.8	11.7	7.7
HCO_3	12	18	451	249	9	218	608	458
TA	12	15	370	205	9	179	516	375
SO_4	12	410	2950	1067	9	205	745	648
Cl	12	3.6	349	33	9	0.0	15	8.3
F	7	0.3	2.7	0.5	5	0.3	0.9	0.5
N	12	0.0	1.88	0.08	8	0.0	0.43	0.06
P	12	0.0	0.10	0.01	9	<.01	0.09	0.01

[a]Two samples from Starve-to-Death Creek, five samples from Great Porcupine Creek, and five samples from Little Porcupine Creek.

[b]Three samples from Reservation Creek, two samples from Smith Creek, two samples from Sweeney Creek, and two samples from Moon Creek.

TABLE 76. Summary of the total recoverable metals measured in small tributaries to the Yellowstone River between the Bighorn and Powder rivers.

	N	Min	Max	Med
As	2	<.01	<.01	<.01
B	4	.15	1.4	.34
Be	2	<.01	<.01	<.01
Cd	14	<.001	<.01	0.001
Co	2	.05	.07	.06
Cr	2	.03	.04	.035
Cu	14	<.01	0.02	<.01
Fe	14	.16	6.5	.52
Hg	13	<.001	0.002	<.001
Li	2	<.01	<.01	<.01
Mn	11	<.01	0.50	0.06
Pb	3	<.01	<.01	<.01
Se	2	<.001	<.001	<.001
V	2	.46	.63	.55
Zn	14	<.01	0.04	0.01

TABLE 77. Summary of the physical parameters measured in Sunday Creek near Miles City.

	Flow less than 9 cfs.				Flow greater than 9 cfs.			
	N	Min	Max	Med	N	Min	Max	Med
Flow	6	0.0	8.7	2.04	5	10E	198	50E
Temp	6	0.5	30.1	9.1	5	5.0	23.5	13.5
pH	6	7.13	8.89	8.00	5	7.50	8.62	8.30
SC	6	623	2550	1148	5	345	3274	1610
TDS	6	427	1948	826	5	422	2021	1103
Turb	5	4	250	35	5	10	3000	210
TSS	6	10.0	358	52.3	5	7.0	5650	1004
DO	6	8.1	12.2	11.1	3	8.9	11.0	10.3
BOD	5	1.4	>11	5.4	3	4.2	6.9	4.3
FC	4	0	7000	213	3	0	1030	600
Ca	6	13	64	25	5	15	81	48
Mg	6	4.6	28	8.2	5	1.2	31	17
TH	6	52	269	94	5	43	331	191
Na	6	105	485	220	5	80	563	265
K	3	5.8	6.8	6.5	4	8.1	65	9.1
SAR	6	5.6	13.4	9.9	5	3.9	13.5	8.2
HCO_3	6	130	616	224	5	145	290	219
TA	6	106	505	197	5	119	242	180
SO_4	6	103	745	243	5	112	570	332
Cl	6	0.6	374	60	5	10	556	118
F	4	0.2	0.5	0.4	4	0.2	1.4	0.4
N	6	0.0	4.5	0.40	5	0.02	0.69	0.11
P	6	0.01	0.59	0.15	5	0.01	0.12	0.01

NOTE: Measurements are expressed in mg/l.

TABLE 78. Summary of the total recoverable metals measured in Sunday Creek near Miles City.

	N	Min	Max	Med
As	2	<.01	<.01	<.01
B	6	<.10	0.17	0.11
Cd	9	<.001	0.001	<.001
Cr	1	--	--	<.01
Cu	9	<.01	0.08	0.01
Fe	9	.25	18	1.1
Hg	3	<.0002	<.001	<.001
Mn	9	<.01	1.06	0.04
Pb	2	<.01	<.05	<.05
Sr	1	--	--	.58
V	1	--	--	<.10
Zn	9	<.01	0.20	<.01

NOTE: Measurements are expressed in mg/l.

Levels of TSS and turbidity in the Group I and II streams were generally similar to those in Armells and Sarpy creeks. Occasionally high sediment concentrations were obtained, probably in association with high flows, but low median values. The median TSS concentrations in these streams indicate an excellent-to-good fishery (European Inland Fisheries Advisory Commission 1965), ignoring the probable effects of high TDS concentrations and low flows. Thus, in these streams, salinity seems to be the major factor degrading water quality.

In Sunday Creek, TSS-turbidity levels were significantly higher, particularly at high flows, and noticeably high values were obtained at times--as high as 5.7 mg/l. Considering the low TDS concentrations of the stream, TSS-turbidity may be a major detraction from stream quality, potentially affecting the stream's fishery, if there is one, and lowering the value of the water as a public supply. Salinity also degrades Sunday Creek's water quality.

Although high TDS-specific conductance levels were occasionally obtained in samples from these small tributaries, the overall salinities in these Group I and II streams were significantly less than those in the Armells Creek drainage and generally similar to those in Sarpy Creek near its mouth. The streams with drainages to the south of the Yellowstone River were less saline than those to the north,except Sunday Creek which had the lowest salinity of any small stream in the Bighorn-Miles City portion of the Yellowstone Basin. The masking of the TDS-flow relationship was also evident in Sunday Creek, where TDS and flow, like TSS and flow, appeared to be directly related. Regardless of the lower TDS concentrations, salinities were still at adequate levels in these various streams to potentially influence the aquatic biota and restrict many of the water uses. Effects on aquatic life would be most noticeable in the Group I and II creeks, as median TDS and specific conductance levels were greater than 1350 mg/l and 2000 μmhos/cm, respectively. Such effects would be lower in Sunday Creek, but TDS and SC levels may still have some detrimental effects with levels at 670 mg/l and 1000 μmhos/cm.

Using TDS as a measure of quality, the waters in these streams would probably be good for application to all stock animals (Seghetti 1951), particularly in Sunday Creek where median sulfate concentrations were low. Sulfate levels in the other tributaries, primarily in the Group I streams (tables 75 and 76), however, could degrade the value of the stream for this use because median sulfate concentrations either exceeded the limiting levels for stock (in the northern tributaries) or exceeded the animals' threshold levels (in the southern tributaries) (tables 10-14).

These eight streams would be poor sources of surface water for public supply due to their hardnesses (Bean 1962) and high TDS and sulfate levels. In Sunday Creek (tables 77 and 78), this would account for the occasionally high turbidity, fecal coliform, and chloride concentrations. Boron would not affect the use of the water for municipal supply or irrigation, but the Group I and II tributaries would probably still have a poor quality, borderline Class I-II water for irrigation as a result of their high sodium and SAR values (producing a medium sodium hazard), high sulfate concentrations, and high TDS-SC levels (producing a high salinity hazard) (tables 15 and 16). With the generally lower TDS and sulfate concentrations, Sunday Creek would probably have a better Class II water for irrigation. It would not have a Class I water for this use because of its high sodium concentrations and SAR values and its tendency to have high chloride levels. In general, these streams have a poor-to-fair water quality.

ROSEBUD CREEK DRAINAGE

Rosebud Creek Mainstem

Rosebud Creek is a large tributary in eastern Montana that joins the Yellowstone River between Forsyth and Miles City (USDI 1968). Its flow is significantly smaller than that of the Bighorn River, but it has a larger discharge than many streams east of Myers. Rosebud Creek does not have a substantial effect on mainstem quality judging from the fact that there is no real change in Yellowstone water chemistry between Forsyth and Miles City (tables 56 and 57).

Due to the higher flows, Rosebud Creek is a more suitable source of water for uses such as irrigation than the smaller Bighorn-Miles City streams. As a portion of the Rosebud drainage lies very close to the Colstrip strip mining development, particularly the Peabody mine, an extensive water quality sampling program was recently initiated by the USGS on the creek (USDI 1976). The USGS maintains four sampling stations on the stream (table 3); to expand the data base and to facilitate this review, water quality information from these stations was combined to represent two reaches of the creek--a middle reach in close association with Colstrip, and a lower reach near the stream's mouth near Rosebud. Data available from the state WQB for Rosebud Creek (Karp and Botz 1975, Montana DNRC 1974) were combined with the USGS information, and these data were sufficient for a seasonal classification. In addition, some data are also available from the state WQB for an upper reach of the creek near its headwaters in the Rosebud Mountains, upstream from Busby. The data for this upper segment were flow-classified, as shown in tables 79 and 80.

The water quality in upper Rosebud Creek was good compared to other tributaries in the Bighorn-Powder rivers portion of the Yellowstone Basin. Dissolved concentrations were much lower, and TDS levels were similar to those obtained from the Bighorn and Tongue rivers (table 48). However, TDS concentrations in this segment were about 20 percent to 110 percent higher than those in the Yellowstone River near Forsyth, depending upon season, and they were found to be a magnitudes sufficient to degrade this reach as a surface water public supply (i.e, median TDS values were greater than the standards for this parameter and water use as summarized in table 9). According to the EPA (1976), waters with TDS concentrations between 500 mg/l and 1000 mg/l can have detrimental effects on sensitive crops. The stream's salinity also could have a mild effect on the aquatic biota in this segment--median values were between 400 mg/l and 670 mg/l.

In contrast, the upstream waters were excellent for the watering of all stock animals, and this reach for the most part probably has a good Class I water for irrigation, as it has low boron, SAR, chloride, sulfate, and SC-TDS levels. The stream had a low sodium hazard and a medium-high salinity hazard for irrigation (USDA 1954).

TABLE 79. Summary of the physical parameters measured in the upper reach of Rosebud Creek near Kirby-Busby.

	Less than 23 cfs.				Greater than 23 cfs.			
	N	Min	Max	Med	N	Min	Max	Med
Flow	5	5.7	22.7	11.2	2	63.8	75.6	69.7
Temp	5	0.0	18.0	0.0	2	0.0	11.8	5.9
pH	5	8.00	8.40	8.30	2	7.60	8.30	7.95
SC	5	760	997	785	2	485	805	645
TDS	5	613	851	672	2	363	705	534
Turb	4	2	10	8	2	2	78	40
TSS	4	9	28	15	2	25.9	254	140
DO	5	7.9	12.9	11.3	2	9.8	11.6	10.7
BOD	5	1.7	4.3	3.2	2	3.0	--	-- (11.4?)
FC	5	2	7700	41	2	30	480	255
Ca	5	58	88	72	2	47	66	57
Mg	5	41	73	57	2	19	60	40
TH	5	381	473	403	2	197	412	305
Na	5	11	46	23	2	18	28	23
K	0	--	--	--	0	--	--	--
SAR	5	0.2	0.9	0.5	2	0.6	0.6	0.6
HCO_3	5	367	472	431	2	213	429	321
TA	5	315	387	357	2	175	352	264
SO_4	5	85	189	118	2	61	118	90
Cl	5	0.3	1.6	1.5	2	2.5	3.1	2.8
F	2	0.5	0.5	0.5	1	--	--	0.2
N	5	0.01	0.21	0.05	2	0.03	0.25	0.14
P	5	0.01	0.07	0.02	2	0.03	0.17	0.10

NOTE: Measurements are expressed in mg/l.

TABLE 80. Summary of total recoverable metals measured in the upper reach of Rosebud Creek near Kirby-Busby.

	N	Min	Max	Med
As	5	<.01	0.01	<.01
B	1	--	--	.07
Be	1	--	--	<.01
Cd	7	<.001	<.01	<.01
Co	1	--	--	.01
Cr	3	<.01	<.01	<.01
Cu	7	<.01	0.01	<.01
Hg	4	<.001	<.001	<.001
Fe	7	.08	3.2	.44
Mn	2	.08	.21	.15
Pb	5	<.01	<.01	<.01
Se	1	--	--	<.001
V	1	--	--	.09
Zn	6	<.01	0.01	0.01

NOTE: Measurements are expressed in mg/l; Li: <.01, N=1.

None of the major ionic constituents had concentrations high enough to degrade any water uses. Trace elements, also, showed low concentrations (tables 79 and 80), except the high TR iron and manganese concentrations. The high TR iron and manganese concentrations could affect the aquatic biota (table 19), and, in combination with the hardness of the water, could detract from the domestic use of the upper stream.

The chemical composition of upper Rosebud Creek was somewhat different from other streams in the Bighorn-Miles City segment of the Yellowstone drainage (USDI 1968). The waters were calcium bicarbonate, indicating limestone formations in the Rosebud Mountains, and magnesium and sulfate were secondary ions. Calcium concentrations were significantly higher than magnesium concentrations. Chloride and fluoride were insignificant constituents, and sodium concentrations were also low. Such low sodium concentrations produced particularly low SAR values considering the extremely hard nature of the water.

However, several downstream changes in the chemical composition of Rosebud Creek made the lower segment more consistent with other Bighorn-Miles City tributaries. Apparently, intermediate inputs to Rosebud Creek, geographically on line with the upper Armells, Sarpy, and Tullock creek drainages, have similar water quality. Fluoride, chloride, and potassium continued to be insignificant constituents, but the waters in Rosebud Creek tended to become more sodium sulfate in character downstream, with higher SAR values and with such great increases in magnesium that magnesium levels exceeded calcium concentrations in the lower segments (tables 82 and 83). This trend towards a sodium sulfate water became most noticeable in the extreme lower reach of Rosebud Creek near its mouth, as indicated in table 81.

TABLE 81. Low-flow and high-flow levels of (Ca + Mg):NA, Ca:Mg, and $HCO_3:SO_4$ in Rosebud Creek.

	(Ca + Mg):Na		Ca:Mg		$HCO_3:SO_4$	
	Low Flows	High Flows	Low Flows	High Flows	Low Flows	High Flows
Upper Rosebud	5.61	4.22	1.26	1.42	3.65	3.57
Middle Rosebud	2.41	2.89	0.87	0.96	1.61	1.82
Lower Rosebud	1.80	1.74	0.81	0.87	1.30	1.48

Such downstream changes were less noticeable during the high-flow period when runoff from the Rosebud Mountains would be greatest.

Rosebud Creek has been classified a B-D_3 stream by the State of Montana (Montana DHES, undated). This designation is appropriate for the high maximum warm-weather temperatures of this stream in its lower reaches, and its pH and dissolved oxygen levels in all segments. The lower pH values were most consistently obtained in the winter rather than during the May-July runoff period. In the upper reach, however, lowest values were obtained in conjunction with the higher flows. As observed on almost all of the streams in the Yellowstone Basin, DO concentrations were highest during the cold-weather periods and lowest during the summer in association with the high water temperatures. Occasionally,

TABLE 82. Summary of the physical parameters measured in the middle reach of Rosebud Creek near Colstrip.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	9	15	52	36	19	18	100E	32	11	24.5	236	64	12	55	258	110
Temp	9	7.5	20.5	16.0	20	0.0	4.5	0.0	13	0.0	13.5	0.5	13	9.5	24.0	19.5
pH	9	8.3	8.8	8.4	20	7.5	8.4	8.05	13	7.5	8.9	8.30	13	8.1	8.70	8.3
SC	9	930	1500	1060	20	699	1860	1315	13	310	1400	1230	13	900	1900	1000
TDS	9	707	841	782	19	523	1040	899	12	198	1150	846	13	627	886	703
Turb	9	7	80	20	19	5	20	10	13	8	190	60	12	46	200	115
TSS	0	--	--	--	5	8.0	36	20.8	5	13.5	597	254	1	--	--	112
DO	9	6.2	11.2	8.1	20	7.0	12.8	11.5	11	9.2	13.0	10.1	13	6.6	9.7	7.6 (2.8?)
BOD	3	1.0	2.6	1.2	10	0.2	9.3	0.7	9	0.6	4.1	3.1	6	1.5	2.9	2.4
FC	0	--	--	--	3	2	100	20	4	4	40	21	1	--	--	20
Ca	9	62	80	66	19	58	104	89	12	28	93	80	13	56	82	75
Mg	9	79	98	90	19	34	120	95	12	19	110	86	13	68	89	78
TH	9	490	590	540	19	286	730	610	12	150	690	560	13	470	570	500
Na	9	56	86	66	19	31	98	75	12	13	120	69	13	44	72	53
K	9	8.7	12	10	17	9.1	11	10	8	8.7	12	9.1	12	7.3	9.0	8.0 (1.1?)
SAR	9	1.1	1.6	1.2	19	0.8	1.6	1.4	12	0.5	2.0	1.3	13	0.9	1.4	1.0
HCO_3	9	411	504	438	19	254	617	551	12	132	520	483	13	376	472	455
TA	9	350	425	365	19	209	506	452	12	108	427	396	13	322	387	373
SO_4	9	250	350	270	19	140	430	327	12	54	560	314	13	190	330	250
Cl	9	4	6	5	19	3.0	7.4	6	12	1	7	4.0	13	3.0	13	4.0
F	9	0.5	0.7	0.6	18	0.3	0.6	0.6	8	0.2	0.7	0.6	12	0.4	0.6	0.5
N	9	0.0	0.02	0.01	19	0.0	0.37	0.2	13	0.0	0.23	0.1	13	0.0	0.42	0.15
P	9	0.03	0.15	0.07	19	0.0	0.11	0.04	13	0.02	0.23	0.06	13	0.02	0.41	0.18

NOTE: Measurements expressed in mg/l.

TABLE 83. Summary of the physical parameters measured in the lower reach of Rosebud Creek near Rosebud.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	13	4	55	31	19	14	180	36.9	12	30.6	244	70	15	29	905	109
Temp	12	6.0	22.6	12.0	22	0.0	3.5	0.3	16	0.0	14.2	3.0	20	10.0	27.8	18.5
pH	13	8.3	8.50	8.40	19	7.40	8.4	8.0	14	7.6	8.50	8.3	18	7.88	8.70	8.30
SC	13	1000	1598	1230	19	584	2060	1500	14	330	1550	1177	18	580	1538	1059
TDS	13	710	1345	891	18	419	1210	946	13	215	1100	943	17	378	1268	841
Turb	12	5	800	50	18	15	300	28	15	12	240	100	17	38	2500	180
TSS	2	19	96.2	57.6	7	22	200	52	8	33	2620	194	8	97.3	5100	311
DO	10	5.9	11.4	8.5	19	9.0	13.0	12.1	14	9.8	12.6	11.4	16	3.9	9.6	8.3
BOD	3	1.2	3.8	2.2	7	0.2	2.7	1.5 (11.6?)	10	0.7	4.9	3.3	8	0.8	6.1	1.8
FC	0	--	--	--	2	16	240	128	6	0	170	62	3	70	135	100
Ca	13	51	135	71	18	49	110	82	13	26	87	66	17	25	85	69
Mg	13	72	100	91	18	13.3	120	96	13	17	100	81	17	12	102	79
TH	13	470	634	560	18	183	770	595	13	140	630	510	17	110	600	500
Na	13	69	155	90	18	47	140	91	13	21	140	90	17	51	150	85
K	11	8.8	14	11	17	8.9	11	10	8	6.9	12	8.7	15	5.0	13.5	8.3
SAR	13	1.4	2.8	1.7	18	1.4	2.2	1.7	13	0.8	2.5	1.7	17	1.0	3.8	1.5
HCO_3	13	336	504	469	18	163	636	486	13	133	540	417	17	187	484	445
TA	13	326	429	385	18	134	522	415	13	109	443	358	17	153	397	376
SO_4	13	270	495	340	18	137	490	380	13	62	550	338	17	140	505	300
Cl	13	4.1	8.0	6	18	4	8	6	13	2.6	6.3	4.8	17	3.0	7.3	4.7
F	13	0.5	0.7	0.6	17	0.3	0.7	0.6	8	0.2	1.1	0.5	15	0.3	0.6	0.5
N	13	0.01	0.34	0.02	18	0.01	0.31	0.07	13	0.0	0.22	0.13	17	0.0	0.5	0.20
P	13	0.01	0.75	0.08	18	0.02	0.40	0.06	13	0.01	0.31	0.08	17	0.01	0.67	0.14 (2.3?)

NOTE: Measurements expressed in mg/l.

unexpectedly low DO concentrations were obtained, but these instances appeared to be correlated with extremely high TSS concentrations and high settleable solids contents (e.g., the May-July data in table 83) rather than with organic discharges. In general, median BOD_5 levels did not indicate organic pollution, and only 16 percent of the samples had BOD_5 levels greater than 3.9 mg/l. These occasionally high BOD_5 values, approaching 10 mg/l, were probably natural (as in Beauvais Creek) rather than the result of man's activities. DO percentage-of-saturation data indicated no extensive organic inputs to Rosebud Creek; only 17.5 percent of the samples had DO concentrations less than 85 percent saturation, and less than 10 percent had DO levels less than 80 percent saturation. In addition, median DO concentrations in Rosebud Creek were greater than 90 percent of saturation (table 84). Thus, temperature, pH, BOD_5, and DO levels in Rosebud Creek do not seem to detract from the quality of its water. Although fecal coliform concentrations were high in some samples from Rosebud Creek, median values were generally in line with the state's average criteria (except the upper station at high flows), and only 8 percent of the samples had fecals in excess of the state standard for grab samples (all from the upper reach). As a result of these features, and because Rosebud Creek is non-eutrophic and N-limited, the high total solids concentrations, particularly in the lower segments, appear to be the major water quality problems in the stream.

Dissolved solids concentrations in Rosebud Creek tended to increase downstream to its mouth, probably due to its extensive prairie drainage system below Busby. An increase in median TDS of 31.6 percent occurred during high flows between the upper segment above Busby and the middle reach near Colstrip, with a 16.4 percent to 33.7 percent increase during the low-flow periods. An increase of about 57.3 percent at high flows and between 32.6 percent and 40.8 percent at low flows developed through the entire length of the stream to its lower reach near Rosebud. These TDS increases were caused primarily by increasing Mg, Na, and SO_4 concentrations; increases in Ca and HCO_3 were small, and K, Cl, and F continued to be insignificant constituents in the lower stream. Suspended solids also tended to increase downstream, mostly near the creek's mouth at low flows (table 83).

All of these features indicate a downstream degradation in water quality and additional restrictions on water use. For example, although TSS concentrations were high at high flows in the upper segment above Busby (tables 79 and 80), the overall median TSS level in this segment (22 mg/l) indicated an excellent fishery (European Inland Fisheries Advisory Commission 1965). In the lower reach, however, an annual median TSS concentration of 142 mg/l indicates only a fair fishery (European Inland Fisheries Advisory Commission 1965). In turn, the greater downstream salinities with TDS generally in excess of 670 mg/l are another source of degradation to the Rosebud fishery. That is, TDS and SC levels in the middle and lower reaches of Rosebud Creek were at levels sufficient to suggest adverse effects on the aquatic biota, although these effects would be small with TDS and SC less than 1350 mg/l and 2000 μmhos/cm.

The water in lower Rosebud Creek was of lesser quality for municipal supply than that upstream as a result of the high TDS and sulfate concentrations and the high turbidities. For example, the annual median turbidity of the lower reach of Rosebud Creek (84 JTU) was much greater than that upstream (about 8 JTU) and greater than the permissible criteria for surface water public supplies established by the NTAC (1968). Also, the waters in the lower reaches

TABLE 84. Summary of miscellaneous constituent and trace element concentrations measured in the middle and lower reaches of Rosebud Creek.

	Middle reach near Colstrip								Lower reach near Rosebud							
	Miscellaneous constituents and dissolved metals[a]				Total recoverable metals				Miscellaneous constituents and dissolved metals[b]				Total recoverable metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[c]	50	53	118	91					47	67	113	95				
NH_3-N	21	0.0	0.11	0.02					21	0.0	0.09	0.01				
Si	45	7.1	22	16					46	7.5	21	14				
Al	4	0.0	.01	.01	13	.20	8.8	.57	4	0.0	.01	.005	12	.70	6.4	1.8
As	6	.001	.028	.003	25	0.0	.018	.002	5	0.0	.003	.002	25	0.0	.010	.002
B	46	.10	.24	.16	2	.13	.22	.18	46	.09	.23	.18	8	<.10	0.21	0.17
Ba	3	.080	.110	.100					3	.070	.042	.092				
Be	4	0.0	0.01	<.01	15	0.0	.01	0.0	4	0.0	0.01	<.01	13	0.0	0.01	<.01
Cd					28	0.0	0.02	<.01					34	0.0	0.02	<.01
Co					2	.01	.02	.015					3	.01	.03	.01
Cr	4	0.0	<.01	<.01	23	0.0	.02	0.0	4	0.0	0.01	<.01	26	0.0	.04	.01
Cu	4	0.0	.003	.002	29	0.0	.13	.01	4	0.0	.002	.001	34	<.01	0.06	0.01
Fe	46	0.0	.21	.03	28	.31	16	.80	46	0.0	.16	.02	34	.34	32	2.5
Hg				-	24	0.0	.001	.0001					29	0.0	.0012	.0002 (<.01)
Li	4	.050	.055	.052	10	<.01	0.06	0.05	4	.040	.056	.052	13	<.01	0.06	0.05
Mn	4	.010	.020	.014	25	.02	.60	.06	4	0.0	.03	.03	31	.04	.57	.11
Mo	4	<.003	0.003	0.003	9	.002	.21	.002	4	<.003	0.003	<.003	5	.002	.003	.002
Ni	4	.001	.007	.001	5	<.05	0.05	<.05	4	0.0	.003	.002	10	0.0	0.10	<.05
Pb	4	0.0	.002	.001	25	<.01	0.10	<.10	4	0.0	.003	.001	28	<.01	0.10	<.10
Se	2	0.0	.001	.001	23	0.0	.002	.001	1	--	--	.001	26	0.0	0.001	<.001
Sr	3	1.1	1.9	1.9					4	1.1	1.7	1.3	3	.54	2.6	1.3
V	4	<.003	<.004	0.003	2	.03	.13	.08	4	<.004	<.004	<.004	5	<.05	0.13	<.10
Zn	4	0.0	0.03	<.01	20	<.01	0.08	0.02	4	0.0	.02	.01	24	<.01	0.33	0.02

NOTE: Measurements expressed in mg/l.

[a] Ag: <.001, N=3; Bi: <0.10, N=1; Cd, Co: < .01, N=3; Hg: <.0001, N=4; Ga, Ge, Sn, Ti, Zr: <.01, N=1.

[b] Ag: <.002, N=4; Cd: 0.0, N=4; Co: <.02, N=3; Hg: <.0001, N=4; Bi, Ga, Ge, Sn, Ti, Zr: <.02, N=1.

[c] DO expressed as percentage of saturation.

appeared to be of lesser quality for irrigation than above Busby, due primarily to the higher TDS-SC levels and salinities--the downstream increases in boron, fluoride, SAR, chloride, and sulfate would not alter the creek's classification. Rosebud Creek becomes a Class II water for irrigation near Colstrip, with a low sodium hazard but with a high salinity hazard, which would restrict its application to certain plant species. However, the downstream water quality would still be good for watering all stock animals (Seghetti 1951).

Discharge in lower Rosebud Creek was highest during the May-July period, probably caused by snowmelt runoff from its mountainous headwaters, and lowest in the August-to-October winter season. TDS concentrations were lowest during the runoff period (although the higher TSS levels in May-July detract from the better water quality), and highest in the winter. The creek had a secondary flow peak in the spring, probably caused by early runoff from the prairie lowlands. TSS levels were intermediate during this secondary flow peak, and TDS concentrations were high during this March-April period regardless of the greater flows. This probably stems from the poor water quality associated with lowland runoff in various small prairie streams. As a result, the usual inverse relationship between flow and TDS was not as apparent in Rosebud Creek, and the seasonal changes in median TDS concentrations between low and high flows were not as great as those in the Yellowstone River. These effects can be seen in table 85, which gives Yellowstone River data comparing stations above Livingston with largely mountainous drainages to those below Billings that are cumulatively affected by prairie inputs.

TABLE 85. Seasonal changes in median TDS concentrations between low and high flows in the Yellowstone River.

	High Flow: Low Flow	High Flow TDS: Low Flow TDS	Spring Flow[a]: Low Flow	Spring Flow TDS[a]: Low Flow TDS
Yellowstone-Corwin Springs	7.84	0.46	1.05	0.98
Yellowstone-Livingston	5.96	0.50	1.07	0.98
Yellowstone Billings	5.42	0.48	1.11	0.94
Yellowstone-Miles City	3.50	0.54	1.22	1.05
Yellowstone-Sidney	3.21	0.57	1.36	1.05
Rosebud-Rosebud	3.51	0.94	2.25	1.06

[a]March-April.

As indicated in table 85, both the seasonal flow and TDS variations declined downstream in the Yellowstone River, showing a direct relationship between spring flow and TDS in the lower reach.

Phosphorus concentrations were high throughout Rosebud Creek (tables 79, 80, 82, and 83); this was particularly noticeable in association with the high TSS levels during the high flows. Phosphorus concentrations were usually greater than the reference level for eutrophication during all seasons; 62 percent of the samples had concentrations greater than or equal to 0.05 mg P/l. However, the creek is probably non-eutrophic judging by the low median nitrogen concentrations; 93 percent of the samples were generally below the reference criteria. Therefore, only 4.5 percent of the samples from Rosebud Creek would be expected to have both phosphorus and nitrogen in excess of their criteria for eutrophication. Ammonia-nitrogen concentrations were also low (table 84), and probably would not be toxic to the stream's biota or alter the eutrophic status of the creek. The high inorganic nitrogen and ammonia concentrations occasionally observed in other streams and attributed to strip mining activities were not evident in Rosebud Creek. The stream did, however, demonstrate a summer low in nitrogen, and it had a major winter peak in concentrations and a secondary runoff peak in the middle reach (table 82). The winter maximum in nitrogen was not evident in the lower segment.

Many other trace elements were analyzed in samples from the lower two reaches of Rosebud Creek (table 84). To facilitate their review, these constituents were split into the following groups:

- Group I — Ag, Bi, Ga, Ge, Sn, Ti, and Zr in both reaches
- Group II — B, Ba, Be, Co, Cr, Li, and Se in both reaches; Ni and Zn in the middle reach; and Mo in the lower reach
- Group III — Cd, Cu, Pb, and V in both reaches; possibly As (one high dissolved reading was obtained) and Mo in the middle reach; and As, Ni, and Zn in the lower reach
- Group IV — Al, Fe, Hg, and Mn in both reaches

In general, trace element concentrations in Rosebud Creek seemed lower than those in Armells Creek (table 84). Practically none of these minor constituents were at concentrations high enough to indicate major water quality problems. This would include silica, strontium, and metals such as Al, Fe, and Mn that were observed in high concentrations in their TR forms. Such high TR concentrations were probably correlated with the high TSS levels of Rosebud Creek, as the TR concentrations of several metals (particularly Al, Fe, and Mn) increased downstream in association with the downstream increase in suspended sediment. Dissolved concentrations, however, did not increase to the creek's mouth. Of the trace elements, only iron may cause water quality problems.

Tributary Streams

The state WQB collected samples from four tributaries in the region (tables 86 and 87). All of these streams are located in the southern portions of the Rosebud Creek drainage above Colstrip; the most southern streams had chemical compositions similar to the composition of upper Rosebud Creek above Busby (e.g., the minimum data in tables 86 and 87--Indian Creek). These streams had low TDS-SC levels and a calcium bicarbonate water in which calcium was higher than magnesium, calcium and sulfate were the secondary ions, and sodium concentrations were high, producing higher SAR values. With the exception of TSS, which was in low concentrations, the median quality of the seven samples collected from these streams was most similar to those in the middle and lower

TABLE 86. Summary of the physical parameters measured in the Rosebud Creek tributaries near Kirby, Busby, and Lame Deer.

	N	Min	Max	Med
Flow	7	2.0	5E	2.9
Temp	7	0.0	16.3	4.5
pH	7	8.20	8.60	8.30
SC	7	577	1685	1181
TDS	7	485	1477	1034
Turb	7	2	23	7
TSS	7	6	69	21.0
DO	7	9.5	13.5	11.8
BOD	7	1.5	7.5	3.2
FC	7	0	550	12
Ca	7	54	74	65
Mg	7	37	129	86
TH	7	302	696	530
Na	7	11	150	83
K	0	--	--	--
SAR	7	0.3	2.5	1.6
HCO_3	7	328	652	534
TA	7	269	551	438
SO_4	7	47	462	212
Cl	7	0.2	8.8	3.8
F	1	--	--	1.0
N	7	0.0	0.66	0.03
P	7	<.01	0.29	0.04

NOTE: Measurements are expressed in mg/l.

One sample was taken from Indian Creek near Kirby, two samples were taken from Davis Creek near Busby, three samples were taken from Lame Deer Creek near Lame Deer, and one sample was taken from Muddy Creek near Lame Deer.

TABLE 87. Summary of the total recoverable metals measured in the Rosebud Creek tributaries near Kirby, Busby, and Lame Deer.[a]

	Total Recoverable Metals			
	N	Min	Max	Med
As	4	<.01	<.01	<.01
Cd	7	<.001	<.01	<.01
Cr	2	<.01	<.01	<.01
Cu	7	7	0.01	<.01
Fe	7	<.01	1.10	0.25
Hg	5	<.001	<.001	<.001
Mn	6	0.02	0.20	0.05
Pb	3	<.01	<.01	<.01
Zn	7	<.01	0.02	<.01

NOTE: Measurements expressed in mg/l.

[a]One sample was taken in Indian Creek near Kirby, two samples were taken from Davis Creek near Busby, three samples were taken from Lame Deer Creek near Lame Deer, and one sample was taken from Muddy Creek near Lame Deer.

reaches of Rosebud Creek. The tributary waters were non-eutrophic and nitrogen-limited with pH, dissolved oxygen, temperature, fecal coliform, BOD_5, and trace element levels in accord with state criteria for $B\text{-}D_3$ streams. Salinity and high concentrations of related constituents appeared to be the primary factors detracting from the water quality in these tributaries.

Median TDS-SC levels in these small streams were generally greater than those in Rosebud Creek; e.g., the tributaries had 1.09 to 1.23 times higher median TDS concentrations than the lower reach of Rosebud Creek (table 83), depending upon season. These differences were greater in an upstream direction (tables 79 and 80)--differences of 1.54 to 1.94 times higher were observed above Busy--correlating with the downstream increase in the mainstem below Busby. As a result, the same potential effects of salinity and other ions in Rosebud Creek would apply more strongly to these tributary streams. For example, although the water in the tributaries would still be good for stock on the basis of TDS (Seghetti 1951), the median bicarbonate concentration was high enough to further degrade its value for this use; median bicarbonate was greater than 500 mg/l--higher than the limiting level of this parameter for domestic animals (California WQCB 1963). The tributary waters would also be unfit for municipal supply due to the high TDS concentrations and hardness levels; however, lower sulfate concentrations were generally obtained from the smaller streams than in Rosebud Creek.

The tributaries provide a less suitable source of water (Class II) for irrigation; they have low sodium hazard (low SAR values) but high salinity hazard for this use. The greater salinities in some of the Rosebud tributaries may also have a slightly greater effect on the aquatic biota than does the mainstem, but the effect would be mild because TDS concentrations were generally less than 1350 mg/l. In turn, the effects of TSS on aquatic life would be minute in the Rosebud tributaries in comparison to the TSS influences predicted for the lower reaches of Rosebud Creek.

TONGUE RIVER DRAINAGE

Tongue River Mainstem

The Tongue River is one of seven major tributaries joining the Yellowstone River in Montana, and one of three major tributaries entering the mainstem east of Billings. The Tongue River's flow is only about 11 percent of the Bighorn's, but its discharge is about seven times greater than Rosebud Creek's. The Tongue at its mouth at Miles City has an annual average flow of about four percent of that of the Yellowstone at Miles City above their confluence (USDI 1974). Thus, the Tongue River may exert some influence on the water quality in the Yellowstone mainstem, assuming that it has a significantly lower quality than the bigger stream. This may also apply to the Powder River, located about 39 miles farther east near Terry. The annual average flow of the Tongue and Powder rivers is about 9.5 percent of that of the Yellowstone River at Miles City. The potential cumulative effects of the Tongue and Powder rivers on mainstem quality can be judged by comparing Yellowstone data obtained at Miles City (above the Tongue confluence, table 57) to the Yellowstone data obtained from sampling stations below Terry.

Two long-term water quality monitoring stations have been maintained by the USGS on the Tongue River (USDI 1966-1974a)--at the state line near Decker (an extreme upstream station where the river enters Montana above the Tongue River Reservoir), and at Miles City (an extreme downstream station near the stream's mouth). About 30 to 50 samples from these two locations have been analyzed each seasonal period for many of the water quality parameters, and the data from these two stations are directly comparable due to their similar periods of collection. In addition, the USGS has recently begun sampling three intermediate water quality stations on the Tongue River as summarized in table 3; about four to fourteen samples have been collected from these locations each seasonal period. Data from these intermediate locations are directly comparable to each other due to their similar sampling periods, but they are not as amenable for comparison with the long-term stations which have been sampled over a longer time span.

For this review, data from two adjacent and intermediate USGS stations were combined (Tongue River below Hanging Woman Creek near Birney and Tongue River at Tongue River dam near Decker) to represent a segment of the river immediately below the Tongue River Reservoir. In addition, considerable amounts of data are also available from the state WQB on the Tongue River and its tributaries. The USGS and the state WQB data were further combined to ultimately represent four reaches of the Tongue River as follows (USDI 1976):

1) near Decker above the reservoir (from near the state line to the inflow of the reservoir);
2) near Birney (from the Tongue River dam outflow to near Birney);
3) from near Ashland to the Brandenburg bridge; and
4) from Brandenburg bridge to near the river's mouth.

Of special interest in the water quality inventory of this drainage is the Tongue River Reservoir and its potential effect on mainstem quality; it is discussed later in this section.

The statistical summary of water quality data from the upper reach of the Tongue River is presented in table 88. The flow pattern in this reach is similar to the patterns in other streams located near their mountainous headwaters regions (e.g., the Yellowstone River near Livingston and the Little Bighorn River near Wyola). These streams have a winter low, a runoff peak in May-July, and intermediate and closely similar flows in the summer (August to October) and spring (March-April) periods. The March-April, secondary spring flow peak and associated TSS concentrations observed in the Little Bighorn River near Hardin and in lower Rosebud Creek was not observed in the upper reach of the Tongue River. This may be because of the upper river's proximity to the Bighorn Mountains and because it has no extensive prairie drainage system. Except during the runoff period, the inverse relationship between flow and TDS-SC was not obvious in the upper Tongue, even though the high-flow:low-flow ratio of 5.04 and the high-flow TDS:low-flow TDS ratio of 0.45 were similar to those obtained in the more mountainous segments of the Yellowstone River. The direct relationship between flow and TSS-turbidity, however, was noticeable.

In general, TDS concentrations in the upper Tongue were high when compared to those obtained in the upper Yellowstone (tables 25-28), and the Boulder and Stillwater rivers (Karp et al. 1976a). Of the larger streams in eastern Montana, TDS concentrations in the upper Tongue River were generally higher than those in the upper Little Bighorn River (table 42), slightly lower than those in the Bighorn River near St. Xavier (table 46), and generally similar to those in upper Rosebud Creek (tables 79 and 80). All of these stream reaches, and the upper Tongue, are close to each other and to mountainous regions; thus, TDS levels in the upper Tongue were not particularly high on a regional basis. Total dissolved solids concentrations were significantly lower in samples from the Tongue River than in samples from the small prairie streams such as Armells and Sarpy creeks (tables 64-69).

The upper reaches of the Tongue River have been classified as B-D_2 by the State of Montana; B-D_2 segments should have a marginal or transition zone, coldwater salmonid fishery (Montana DHES, undated). The high maximum summer temperatures of the upper Tongue indicate that this segment is definitely not B-D_1 in character. Dissolved oxygen concentrations, including the minimum levels obtained during warm-weather periods and median pH values, were within the state's criteria for a B-D_2 stream. Similar median pH values were obtained during all seasons, but median TDS levels demonstrated the characteristic cold-weather/warm-weather variations observed in Rosebud Creek and in other streams of the Yellowstone Basin. Neither the DO nor the BOD_5 concentrations suggested severe organic pollution. This observation was reinforced by the low TOC concentrations with a median TOC in the upper reach (9.1 mg/l) close to the national average for unpolluted surface waters (Lee and Hoodley 1967). Thus, pH, DO, and BOD_5 concentrations do not indicate water quality problems in the upper Tongue River. The outstanding issue is whether temperature is a water quality problem, and, if so, whether the upper Tongue has been appropriately classified a B-D_2 segment, or whether a B-D_3 designation would be more reasonable.

Fecal coliform concentrations were occasionally high in the upper Tongue, particularly during the runoff period, and sometimes violated state standards.

TABLE 88. Summary of the physical parameters measured on various sites on the Tongue River near Decker (above the Tongue River Reservoir).

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	41	74.2	694	324	47	93.4	1000	230	29	153	2550	328	47	35.2	3390	1160
Temp	25	5.0	24.5	12.5	27	0.0	4.0	0.0 (17.0?)	15	0.0	12.5	4.5	23	5.5	26.0	16.0
pH	43	7.7	8.5	8.2	45	7.0	8.5	8.1	28	7.0	8.5	8.2	47	7.0	8.6	8.1
SC	43	531	1070	798	46	475	897	773	28	531	1061	838	47	230	1190	379
TDS	42	326	762	528	45	313	685	515	28	358	853	566	46	130	810	233
Turb	7	3.5	20	10	12	1	30	7	6	5	70	17.5	5	28	100	40
TSS	4	6.6	16	11	1	--	--	10.0	3	6	31	14.0	5	11	121	85.5
DO	9	6.0	11.0	8.5	12	9.6	12.8	10.9	7	7.9	13.4	11.4	8	7.1	11.2	9.6
BOD	4	0.5	4.0	1.3	0	--	--	--	3	2.1	3.5	3.4	5	0.4	4.3	3.2
FC	8	0	96	43	11	24	540	68	6	2	130	16	5	23	2400	1800
Ca	42	38	91	69	46	30	84	71	28	43	110	67	46	24	70	38
Mg	42	27	85	50	46	26	77	47	28	25	72	50	46	4.6	80	18
TH	42	248	490	376	46	220	420	370	28	212	510	379	46	100	477	163
Na	42	15	68	38	45	19	48	34	28	21	59	41	46	5.5	110	13
K	42	2.3	6.9	4.0	45	2.2	7.6	3.5	26	1.6	11	3.9	44	1.3	5.8	2.2
SAR	42	0.4	1.4	0.8	45	0.6	1.0	0.8	28	0.6	1.2	1.0	46	0.2	2.2	0.5
HCO_3	42	171	331	282	46	159	330	284	28	143	314	266	46	100	271	143
TA	6	205	263	244	8	205	271	256	4	225	259	244	5	82	123	92
SO_4	42	100	370	210	46	120	270	200	28	125	330	240	46	8.5	478	67
Cl	42	1.5	13	4.0	46	1.0	17	5.0	28	1.0	8.1	5.0	46	0.0	8.9	2.0
F	42	0.2	0.6	0.4	45	0.2	0.5	0.4	28	0.3	0.6	0.4	44	0.1	0.5	0.2
N	44	0.0	0.16	0.05 (.9?)	50	0.0	1.1	0.31	30	0.0	0.84	0.11	48	0.0	0.54	0.09
P	10	0.0	0.12	0.03	15	0.01	0.32	0.08	8	0.01	0.38	0.08	10	0.0	0.39	0.06

NOTE: Measurements expressed in mg/l.

Of the samples analyzed for fecals, 17 percent had concentrations in excess of state criteria for grab samples, 23 percent exceeded 200 colonies per 100 ml, and the median concentration of fecals during the May-July period was even greater, and, therefore, in excess of the state's average standard. However, 93 percent of the annual coliform load was observed during the high-flow period, dictating that the fecals were derived primarily from non-human and natural sources. This observation, and the fact that only seven percent of the samples had fecal concentrations exceeding the permissible criteria for surface water public supply (2000 colonies per 100 ml), indicates that this variable was not a major problem in the upper reach.

Fluoride, chloride, and potassium were miscellaneous components of the calcium bicarbonate water in the upper Tongue, suggesting limestone formations within the upper drainage. Sulfate concentrations were also high and nearly equal to the bicarbonate levels; sulfate and magnesium were the secondary ions. In contrast, sodium concentrations were low, producing low SAR values; as a result, the waters were non-saline but very hard. The high calcium and sulfate concentrations indicate that gypsum formations are also present in the upper Tongue River drainage (Bighorn Mountains). Because suspended sediment concentrations in the upper Tongue were not particularly high, salinity and common ion concentrations were the major potential water quality problems. The median annual suspended sediment concentration was 30 mg/l, indicating a good fishery (European Inland Fisheries Advisory Commission 1965). Highest TSS-turbidity levels occurred at high flows, but the median value and the maximum concentration were still not particularly high in comparison to those in other rivers in the basin, including the Yellowstone mainstem.

Judging from the common constituents, the waters in the upper Tongue River can be considered generally suitable for agricultural supply and excellent for all stock animals (tables 10-14). The waters have a low sodium hazard for irrigation and low SAR values at all times, but they had a low-to-high salinity hazard for this use depending upon flow and season as shown in table 89.

TABLE 89. Salinity hazard for irrigation from the upper Tongue River depending upon flow and season.

	Percentage of samples having a particular salinity hazard:				
	low	medium	high	TDS > 500 mg/l	TDS < 500 mg/l
Aug-Oct	0.0	30.2	69.8	64.3	35.7
Nov-Feb	0.0	32.6	67.4	60.0	40.0
March-April	0.0	32.1	67.9	78.6	21.4
May-June	8.5	83.0	8.5	10.9	89.1

Overall, the upper Tongue has a Class I water for irrigation due to the low boron (less than 0.5 mg/l), SAR, chloride, sulfate, and SC-TDS levels (tables 15 and 16). However, according to the EPA (1976), waters with TDS concentrations in excess of 500 mg/l should be used cautiously on salinity-sensitive crop and forage plants (USEPA 1972). As indicated in table 89, the upper river would have TDS levels exceeding 500 mg/l for a large percentage of the early spring and late summer-early fall portions of the irrigation season and in the winter; the waters would have a high salinity hazard for irrigation during these periods. The best irrigation water from the upper Tongue would occur during the runoff season, which has a medium salinity hazard; runoff waters would be applicable to all crop and forage species for about 90 percent of the time during May, June, and July.

The upper Tongue should probably not be used as a surface water public supply if other more suitable sources of water are readily available. This is due primarily to the hard (May-July)-to-very hard (remainder of the year) water and to its high dissolved solids concentrations. As indicated in table 89, about 66 percent of the samples collected from the upper Tongue between August and April had TDS levels greater than 500 mg/l, in excess of the permissible criteria for public supply and the standard for drinking water (table 9). The water would be much more acceptable for public supply and drinking water during the May-July period, as only 11 percent of the runoff samples had TDS concentrations in excess of these criteria and standards. However, the stream's turbidities during the runoff season would degrade the segment as a municipal supply source because they would exceed 75 JTU and the permissible criteria for turbidity in 40 percent of the high-flow samples. In addition, sulfate would tend to detract from the value of the upper Tongue as a public supply--22 percent of the samples had sulfate concentrations in excess of recommended levels during the August-to-April period. Regardless of the general unsuitability of the upper Tongue for human use, salinity in this stream reach would have only mild effects, if any, upon the aquatic biota of the river. Only 7.5 percent of the samples had TDS levels in excess of 670 mg/l, and only 4.9 percent had a specific conductance in excess of 1000 μmhos/cm. The major portion of the samples from the upper river had TDS and SC levels between 400 and 670 mg/l (65 percent) and between 600 and 1000 μmhos/cm, respectively.

Low nitrogen and phosphorus concentrations were evident in the upper Tongue during the late summer-to-early fall period of peak biological activity (table 88); in turn, a peak in nitrogen levels was obtained during the dormant winter season. Except during the August-October period, median phosphorus concentrations were at levels high enough to suggest eutrophic conditions, although they did not exceed the EPA's (1974b) criteria for eutrophication. The stream was probably non-eutrophic due to the low median nitrogen concentrations during all seasons except the less critical and dormant winter season of low temperatures (near 0.0°C). About 17 percent of the samples from the upper Tongue had nitrogen levels in excess of the reference criteria (0.35 mg N/l), and 72 percent of these violations occurred during the winter season. However, only 1.7 percent of the samples had nitrogen levels in excess of the EPA's criteria. In contrast, 56 percent of the samples had phosphorus levels in excess of the criteria, and 5 percent had concentrations greater than the EPA's more stringent reference levels. As a result, only 9.4 percent of the total samples from the upper Tongue had both phosphorus and nitrogen at levels sufficient to cause eutrophy; 25 percent of the winter samples would have this status and only 3.5 percent would have this characteristic during the warmer weather periods of the rest of the year. Less than 0.1 percent of the samples had both phosphorus and nitrogen in excess of the EPA's reference criteria. These relationships further indicate an absence of eutrophy in the upper Tongue River.

Although high salinity levels restrict certain water uses, the non-eutrophic waters of the upper Tongue have fairly good quality. Trace element concentrations, which are discussed in greater detail later in this section, do not generally detract from this quality. Of considerable itnerest, therefore, is the potential effect of the Tongue River Reservoir on the upper Tongue's quality; below are five possible effects:

1) concentrations of dissolved constituents via a water residence in the reservoir, and, consequently, an evaporation;

2) a lessening of seasonal oscillations in TDS and chemical composition;

3) an alteration of seasonal chemical compositions through a water retention time and mixing;

4) action as a nutrient and sediment trap or sink; and

5) changing the fecal coliform, BOD_5, DO, pH, and temperature characteristics of the stream.

Some of these effects may be related to an alteration of the seasonal flow patterns of the stream through artificial regulation with a general reduction in stream discharge as a result of reservoir evaporation. These assessments can most readily be made by comparing water quality and flow data from the inflow to the reservoir (i.e., the reach above the reservoir near Decker, table 88) to that from the outflow (i.e., the reach of the Tongue below the reservoir near Birney, table 90). However, these stations may not be comparable due to the different periods of collection; thus, the data from the river near Miles City should also be considered in this regard as a check. In terms of subsequent water quality changes below the reservoir, comparisons of data from the Birney segment to that from the downstream Ashland-Brandenburg reach (table 91) are most appropriate. An assessment of the overall changes in water quality in the Tongue River from the state line to its mouth can readily be made by comparing data from the upper reach above the reservoir to that from the river near Miles City (table 92) because these sites had similar sampling periods.

The most obvious effects of the Tongue River Reservoir on downstream quality were related to changes in the river's TSS and fecal coliform concentrations; these particular alterations might be considered beneficial. Fecal coliform levels were noticeably lower in the river below the reservoir, probably as a result of water residence time in the impoundment with a subsequent die-off of coliform organisms. The low concentrations of fecals were obvious in the Birney and the Ashland-to-Brandenburg segments of the river. Although coliform levels tended to increase slightly below Brandenburg, the effect of the reservoir on this variable was apparent to the lower reach of the stream, as the Miles City segment also demonstrated low bacteriological concentrations. As a result, fecal coliforms pose only occasional problems for use as public supply in the lower segments of the Tongue--only 3.7 percent of the samples collected from the river below the dam had fecals in excess of state criteria.

In addition to the decline in coliform levels, TSS concentrations were definitely lower in the river immediately below the impoundment than in the Decker reach. The reservoir, therefore, apparently acts as a sediment trap. The annual median TSS concentration declined from 30 mg/l above the reservoir

TABLE 90. Summary of the physical parameters measured on various sites on the Tongue River near Birney (below the Tongue River Reservoir).

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	12	143E	650	225 (23?)	12	21.2	302	155	3	217	500	283	8	432	3500	930
Temp	14	10.0	22.0	14.8	14	0.0	9.9	1.0	5	0.0	7.0	3.8	8	8.0	23.0	15.4
pH	11	8.0	8.6	8.32	14	8.0	8.5	8.22	5	7.8	8.4	8.4	8	7.7	8.4	8.3
SC	13	372	949	725	14	765	1310	913	5	368	2550	890	8	280	801	670
TDS	10	228	743	543	13	480	1220	717	4	226	694	559	8	176	650	418
Turb	8	1	13	6.6	10	1	7	2.5	2	2	5	3.5	3	19	42	22
TSS	6	3	9	5.4	6	2.4	12.6	4.1	3	3	12.8	6.0	5	16.4	58	24
DO	11	7.2	10.3	8.8	13	11.4	13.9	12.2	5	9.4	13.8	11.4	8	7.4	10.0	9.3
BOD	6	0.8	3.3	1.4	5	1.8	3.7	2.2	3	2.3	3.7	2.8	5	1.7	3.9	2.2
FC	6	0	300	10	6	0	9	1	2	0	1	1	0	--	--	--
Ca	10	36	77	67	13	64	83	74	4	35	73	70	8	30	67	54
Mg	11	17	55	47	14	44	110	53	4	17	50	48	8	13	46	38
TH	10	160	404	365	13	340	660	410	4	160	380	373	8	130	352	240
Na	10	15	51	39	13	37	170	52	4	18	56	47	8	13	51	34
K	10	2.7	5.3	4.6	12	3.4	15	4.6	3	4.6	6.9	6.9	6	1.7	5.8	2.9
SAR	10	0.5	1.1	0.9	13	0.6	2.9	1.0	4	0.6	1.3	1.0	8	0.5	1.2	0.9
HCO_3	11	157	300	274	13	271	621	300	4	125	240	287	8	122	254	225
TA	11	129	246	225	13	222	509	246	4	103	240	235	8	100	209	184
SO_4	10	71	260	225	13	190	500	255	4	77	270	235	8	47	235	165
Cl	10	2	5	3.7	13	1.2	10	4	4	2.0	4	3.4	8	1.4	5	3.0
F	10	0.2	0.4	0.3	12	0.2	1.1	0.3	4	0.2	0.4	0.3	6	0.2	0.3	0.2
N	13	<.01	0.3	0.02	18	0.0	0.7	0.02	7	0.02	0.8	0.2	10	0.0	0.4	0.1
P	13	0.01	0.21	0.03	18	0.0	0.03	0.01	7	<.03	0.38	0.05	10	0.0	0.4	0.1

NOTE: Measurements expressed in mg/l.

TABLE 91. Summary of the physical parameters measured on various sites on the Tongue River near Ashland-Brandenburg.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	11	187	806	245	11	83	298	218	6	202	1340	278	11	423	4270	780
Temp	11	5.5	22.5	14.9	13	0.0	9.3	0.7	6	0.0	10.5	3.0	11	14.0	26.0	18.0
pH	11	7.4	8.6	8.4	13	7.7	8.4	8.2	6	7.3	8.4	8.15	11	7.6	8.6	8.2
SC	11	452	1060	916	13	850	1430	1065	6	420	1073	1007	10	315	870	628
TDS	8	356	802	632	14	528	1265	748	5	225	797	773	7	203	694	564
Turb	8	1	18	2.2	13	1	20	3	5	3	200	8	4	48	150	73
TSS	6	1.8	13	3.1	8	1.0	33	4.0	5	<1	19	11	7	19	216	74
DO	9	7.2	12.0	9.7	12	8.0	12.8	11.7	7	9.4	13.0	12.7	11	6.8	12.9	8.4
BOD	5	1.3	3.4	1.8	6	1.5	3.4	2.1	5	0.7	4.6	3.5	8	1.0	4.6	2.8
FC	4	0	10	0	7	0	65	0	3	0	0	0	3	0	29	20
Ca	8	52	71	66	13	63	88	75	5	27	76	67	7	25	71	63
Mg	8	28	62	51	13	44	81	55	5	17	71	53	7	25	71	47
TH	8	250	418	379	13	340	536	408	5	140	410	404	7	120	373	350
Na	8	19	69	57	13	49	165	69	5	21	83	68	7	17	56	48
K	8	3.2	6.1	5.1	12	4.3	9.1	5.5	2	6.1	8.3	7.2	3	2.1	6.9	2.3
SAR	8	0.5	1.5	1.3	13	1.1	3.1	1.4	5	0.8	1.9	1.5	7	0.5	1.3	0.9
HCO_3	8	193	312	288	13	278	426	327	5	124	301	275	7	130	260	256
TA	8	175	266	240	13	228	356	268	5	102	256	226	7	107	220	210
SO_4	8	130	300	250	13	210	500	280	5	80	320	290	7	42	260	240
Cl	8	2.0	5	4.1	13	3.0	7.2	5	5	2.0	5	3.5	7	0.8	4.0	3.0
F	8	0.3	0.4	0.3	13	0.3	0.5	0.3	3	0.2	0.4	0.3	4	0.1	0.3	0.3
N	10	0.0	0.1	0.01	13	0.0	0.12	0.02	6	0.0	0.1	0.04	11	0.01	0.23	0.07
P	10	0.0	0.08	0.02	13	0.0	0.06	0.01	6	<.01	0.3	0.03	11	<.01	0.26	0.09

NOTE: Measurements expressed in mg/l.

TABLE 92. Summary of physical parameters measured in the Tongue River near Miles City.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	47	33	1070	235	52	70	1370	237	31	154	3370	430	48	52	4510	811
Temp	23	6.1	24.4	17.0	27	0.0	9.4	0.0	16	0.0	20.3	4.3	25	11.0	28.0	18.0
pH	46	7.5	8.6	8.0	54	7.0	8.8	8.1	31	7.2	8.7	8.2	49	7.5	8.6	7.9
SC	46	530	1170	811	54	377	1530	1020	31	441	1170	930	49	362	1100	628
TDS	44	362	817	518	50	243	1242	686	30	282	857	631	47	215	748	411
Turb	7	2	130	19	10	1	20	7	4	12	500	206	8	23	1200	130
TSS	5	5.1	76.2	24	3	2.2	11.8	8.2	4	9	594	40	9	22	814	264
DO	9	8.2	11.6	9.7	9	10.6	13.2	12.9	6	9.0	13.3	10.9	12	6.5	9.8	8.4
BOD	5	0.7	3.0	1.8	2	1.4	2.6	2.0	4	2.1	3.5	3.0	9	0.6	6.2	2.2
FC	6	0	10,700	11	6	0	290	6	5	0	59	8	6	20	2800	37
Ca	27	44	76	57	33	58	95	77	18	31	78	67	26	27	72	49
Mg	27	25	56	38	33	39	72	57	18	17	62	49	26	14	51	29
TH	46	186	441	313	53	124	520	410	30	150	450	370	48	150	394	243
Na	46	32	110	60	53	26	130	74	30	29	100	70	48	17	110	47
K	27	3.0	9.9	4.9	33	4.0	8.7	5.5	16	4.5	8.2	6.0	23	1.9	7.8	3.7
SAR	46	0.9	2.5	1.5	53	1.0	3.0	1.6	30	1.0	2.4	1.6	48	0.6	2.5	1.2
HCO_3	46	204	365	262	53	136	448	334	30	139	343	286	48	137	316	226
TA	8	174	255	237	10	215	356	286	5	125	268	220	8	113	218	156
SO_4	46	120	360	210	53	78	475	282	30	88	360	262	48	68	360	158
Cl	27	1.7	6	3.4	34	3.4	12	5.1	18	2	8.9	4.4	26	0.6	5.7	2.9
F	27	0.2	0.8	0.3	33	0.2	0.6	0.3	17	0.2	0.6	0.3	24	0.2	0.6	0.3
N	26	0.0	0.22	0.05	32	0.0	0.3	0.06	19	0.0	0.35	0.06	26	0.0	0.21	0.06 (.97?)
P	14	.008	.18	.02	18	0.0	.15	.015	9	0.0	.82	.01	15	0.0	.31	.027 (1.0?)

NOTE: Measurements expressed in mg/l.

to about 10 mg/l in the Birney reach, with an annual median TSS concentration of 23 mg/l in the downstream Ashland-to-Brandenburg segment. TSS levels also tended to increase downstream below the reservoir, and this increase was most obvious at high flows and in the Miles City reach of the river, which had an annual median concentration of 82 mg/l. Thus, regardless of the reservoir's influence, the Tongue fishery's quality would lessen in a downstream direction, judging from TSS levels. The fishery should be good above the impoundment, excellent below the dam to Brandenburg due to the trapping effect of the reservoir, and fair near Miles City as a result of the marked downstream sediment accumulation below Brandenburg. This accrual of sediment and consequent turbidity was apparently at high enough levels in the Miles City segment to also degrade the value of the stream as a surface water public supply for a large portion of the year (> 75 JTU).

The Tongue River Reservoir also apparently acts as nutrient sink with generally lower concentrations of nitrogen and phosphorus obtained in the lower reach of the river from the dam to Miles City. This downstream reduction in nutrient concentrations was greatest during the winter, and resulted in an elimination of the November-February nitrogen peak in the lower river; the only exception to these reductions occurred during the runoff period in the segment of the river immediately below the dam near Birney. The entire lower segment of the river was definitely non-eutrophic during all seasons and much less eutrophic than upstream above the reservoir; this was most noticeable in the reach of the river near its mouth near Miles City. The lower river, like the reach near Decker, was probably nitrogen-limited, but low phosphorus concentrations would be much more critical in curtailing stream production in the Miles City reach than in any of the remaining segments of the stream. Based on the critical nutrient data (table 92), the low primary production potential of the Miles City reach of the river could reduce the harvest of the Tongue fishery. In the lower river, only 0.7 percent of the samples would have both nitrogen and phosphorus concentrations in excess of their reference criteria, contrasting to a 9.4-percent value for samples from the Decker segment.

The reservoir apparently had little or no effect on the pH, temperature, dissolved oxygen, and BOD_5 characteristics of the stream; none of these parameters violated state criteria for a B-D_2 or B-D_3 stream (table 8) or indicated pollution problems in the lower segments of the Tongue River. BOD_5 values might have declined below the reservoir, and all reaches demonstrated a March-April high in this variable with an obvious low during the August-October season; the BOD_5 concentrations did not indicate organic pollution in any instance. This was also reflected in the stream's generally high DO concentrations and in the absence of definite, consistent downstream DO changes in the river.

The inverse relationship between DO and warm-weather/cold-weather temperatures was again evident in the Tongue. The river had slightly warmer winter temperatures immediately below the dam than in the Decker reach, but with cooler grab sample temperatures in the spring and lower warm-weather maximums in the Birney segment. This trend was reversed in the river below the reservoir towards Miles City, where winter temperatures again approached 0.0°C and a general downstream increase in median and maximum values were evident below Birney through the remainder of the year. Grab sample temperatures appeared to be higher in Miles City than in the Decker reach, which corresponds to the classification change of the Tongue River from a B-D_2 to a warm-water, B-D_3 stream towards its mouth. The high maximum temperatures near Miles City also indicate a $B-D_3$ stretch of water. The general tendency for the Tongue to have warmer downstream temperatures can also be seen in the once-daily temperature data from the USGS (USDI 1966-1974b) for the June-September period (1970-1974) as seen in table 93.

TABLE 93. Percentage of temperature readings in the Tongue River during the June-September period, 1970-1974, greater or less than a particular temperature.

Temperature Range	Tongue River near Decker	Tongue River at Miles City
<19.4°C	66.6	53.2
>19.4°C	33.4	46.8
>20.0°C	32.6	42.0
>22.0°C	8.9	10.3

SOURCE: USDI 1966-1974b.

The Tongue River Reservoir apparently has a definite effect in reducing down-reservoir flow volumes in the Tongue River; this is evident both in the USGS (1974) average discharge data for various sites on the river and in the flow data of tables 88 and 90-92. The USGS has obtained a yearly mean flow at the state line near Decker (above the impoundment) of 496 cfs (14 years of record) with an 8.5 percent decrease in average discharge at the dam (to 454 cfs with 35 years of record) (USDI 1974). Evaporation from the reservoir probably accounts for at least a portion of this loss in water volume. An additional 5.4 percent decrease in average annual flow is evident in the Tongue at Miles City (to 427 cfs with 31 years of record) (USDI 1974). This added downstream loss in water volume may be due, in part, to subsequent diversions for irrigation because of minor tributary inputs below the dam. Yearly discharges as cubic-feet-per-second, calculated from the data in tables 88 and 90-92 by weighting the median flows on the basis of months-per-seasonal-period, were similar to the annual mean flows obtained by the USGS as follows (including the percentage of difference between the two determinations):

Tongue River above the reservoir near Decker--503 cfs (+ 1.4 percent);

Tongue River below the dam near Birney--388 cfs (- 14.5 percent);

Tongue River near Ashland-Brandenburg--375 cfs; and

Tongue River near Miles City--413 cfs (- 3.3 percent).

The greatest discrepancy between the two sets of annual flow estimates was obtained on the Birney reach (and the Ashland-to-Brandenburg segment), on which the tabulated data would not be as readily comparable to the USGS information as the other locations due to the shorter period of collection and smaller sample size. As a result, inter-reach flow comparisons are most valid when made between the Decker and Miles City and between the Birney and Ashland-Brandenburg data.

The Birney:Ashland-Brandenburg comparison (tables 90 and 91) indicates a downstream decline in flow below the reservoir while the Decker:Miles City comparison (tables 88 and 92)) shows the overall decline in yearly flow through the Montana reach of the Tongue (about 17.9 percent). The Decker:Miles City comparison suggests definite alterations in the seasonal flow patterns of the river from above the reservoir to the stream's mouth; these alterations can be seen in the percentage change in flow by season from the Decker to the Miles City reach as follows: August-October, -27.5 percent; November-February, +3.0 percent; March-April, +31.1 percent; and May-July, -30.1 percent.

Flows remained relatively constant from the upper to the lower reach of the river during the winter months, indicating that reservoir inflow equalled outflow. In contrast, the lower reach had significantly higher flows than the upper segment in March and April, suggesting an artificial regulation wherein the reservoir was drawn down in anticipation of the runoff season (outflow greater than inflow); however, an early spring runoff from the lowlands below the reservoir could also have contributed to the secondary March-April flow peak--particularly noticeable at Miles City (table 92). The lower reach below the impoundment had significantly lower flows than the upper segment during the runoff season; this might have been related to reservoir regulation through a storage of good quality runoff water in which the inflow was greater than the outflow. Downstream flows were also significantly lower during the August-October period, which might have been due at least partially to irrigation diversions below the reservoir during this period of the year.

Such reductions in river flow below the reservoir--8.5 percent near Birney and 13.9 percent to Miles City (USDI 1974)--would imply a concentration of the dissolved constituents in the upper Tongue of about 9.2 percent to the lower stream near Birney and about 16.2 percent near Miles City. Annual median TDS levels were found to be about 25.4 percent higher in the reach immediately below the reservoir than near Decker and 19.7 percent greater at Miles City as follows: Decker reach, 456 mg/l; Birney reach, 572 mg/l; Ashland-Brandenburg segment, 677 mg/l; and the Miles City reach, 566 mg/l. The annual TDS load of the river near Decker was similar to that at Miles City--619 tons per day and 631 tons per day, respectively, and the 1.9 percent downstream increase in loads might have been a reflection of tributary inputs to the lower river. Tributary inputs may also account for the greater increase in TDS at Miles City than was predicted on the basis of water volume loss. As a result, the Decker: Miles City comparison (tables 88 and 92) suggests an overall downstream increase in TDS in the Tongue River.

The Decker:Birney comparison indicates that a part of this downstream increase in TDS was due to the concentrating effects of the reservoir, and the Birney:Ashland-Brandenburg comparison points to a subsequent increase in TDS below the reservoir to Miles City. However, this latter feature was not totally consistent in the data from Birney to Miles City; i.e, data from the Ashland-to-Brandenburg reach appeared to be anomalous. This apparent anomaly was most likely due to the incomparability of data from the Birney:Ashland-to-Brandenburg reaches to that from the Miles City segment because of their different collection periods (table 3). Water quality runs conducted by the state WQB along various stations on the lower river at similar dates also indicated a downstream increase in TDS (about 23 percent) between Birney and Miles City; this can be shown by the station (USDI 1968) means of TDS and SC across the six collection sites listed in table 94.

TABLE 94. Downstream increases in TDS in the Tongue River between Birney and Miles City.

Tongue River Station	TDS (mg/l)	SC (μmhos/cm)	TDS/SC
Pyramid Butte above Birney	711	909	0.78
Birney Village	761	953	0.80
Ashland	762	951	0.80
Brandenburg	818	1060	0.77
Carland	851	1081	0.79
Miles City	876	1098	0.80

The Decker:Birney water quality data are not readily comparable because of different collection periods; this may account for the wide discrepancy between the predicted percentage increase (9.2 percent) in TDS on the basis of water volume lost and the observed increase (25.4 percent) from above to below the reservoir. Therefore, the Tongue River's downstream increase in TDS from Decker to Miles City cannot be quantitatively separated from the effect of the downstream effects below the reservoir on the basis of the data in tables 88 and 90-92. Data from the limnological investigations of the Tongue River Reservoir may more accurately describe the impoundment's influence in concentrating downstream dissolved solids because the reservoir's inflow and outflow are regularly sampled in these studies.

The influences of the impoundment on lessening seasonal fluctuations in TDS concentrations and chemical composition and its effect in altering seasonal and downstream chemical compositions are much more obvious from the data in tables 88 and 90-92. The lessening of seasonal TDS oscillations are shown by the ratios of low-flow seasonal TDS concentrations of the four Tongue segments to their runoff TDS levels in table 95.

TABLE 95. Ratios of low-flow seasonal TDS concentrations to runoff TDS levels in the four Tongue segments.

	Decker Reach	Birney Reach	Ashland-to-Brandenburg Reach	Miles City Reach
Aug-Oct	2.27	1.30	1.46	1.26
Nov-Feb	2.21	1.72	1.70	1.67
March-April	2.43	1.34	1.60	1.54
May-June	1.00	1.00	1.00	1.00

These ratios were significantly lower below the reservoir, indicating the development of reduced differences between runoff and low-flow TDS concentrations below the impoundment; this suggests a mixing of seasonal waters as they are stored in the reservoir. The high TDS season occurred during the March-to-April period in the upper segment of the Tongue, but high TDS levels developed during the winter season below the dam. TDS concentrations were lower during the late summer-early fall than during the runoff period in the Birney-to-Miles City reach of the Tongue; this would be advantageous for irrigation purposes.

Downstream increases in TDS from Decker to Miles City varied considerably between the four monthly periods. The total downstream percentage increases in TDS by season were: August to October, -1.9 percent; November to February, 33.2 percent; March to April, 11.5 percent; and May to July, 76.4 percent. Such seasonal differences were probably the results of reservoir mixing. For example, the good quality of runoff water coming into the reservoir would be altered somewhat by combining with the previously stored lower quality of low-flow water; this mixed water would then be released, partially accounting for the 76.4 percent increase in TDS downstream below the dam during the May-July period. However, a part of the seasonal increases in TDS may also have been due to tributary inputs to the river below the reservoir. The downstream increase in TDS was lowest during the August-October period, contributing to the development of a fairly good water quality in the lower river during a critical phase of the irrigation season.

The effect of the reservoir in lessening the Tongue's downstream seasonal fluctuations in chemical composition and initiating a general downstream chemistry change is shown in table 96. In the upper Tongue, the (Ca + Mg):Na and HCO_3:SO_4 ratios were high during the runoff season when influences from the mountainous headwater areas having calcium bicarbonate waters would be at their greatest. The ratios were lowest during the March-April period in correlation with the early runoff from lowland areas having a sodium sulfate water. The two ratios from the late summer through winter were intermediate to these seasonal extremes. This pattern has been observed in the Little Bighorn and Yellowstone rivers. In the lower river, however, such obvious seasonal differences in ratios and chemical compositions were largely ameliorated with the calcium-magnesium-sodium and bicarbonate-sulfate relationships which were similar through all seasons and not descriptive of any obvious seasonal patterns (except the low HCO_3:SO_4 ratio during the spring near Miles City). These developments were also probably related to the reservoir mixing of seasonal waters before release. A general tendency for the river to become more sodium sulfate in character towards its mouth is also indicated by these ratios, particularly those based on annual median concentrations. The more sodium-sulfate water in downstream reaches near the mainstem is also characteristic of many streams in the Yellowstone Basin.

The downstream increase in total dissolved solids indicates a general downstream degradation of water quality in the Tongue River. As a result, the waters in the lower segments of the river would restrict use more than would waters upstream from the reservoir. Calcium and magnesium concentrations did not increase to any great extent in the Tongue River towards its mouth, and the downstream increases in TDS and SC were primarily related to the 2.0-fold increase in annual median sodium concentrations from Decker to Miles City with 1.2- and 1.3-fold increases in sulfate and bicarbonate, respectively. However, the river was generally calcium bicarbonate in nature throughout its length in Montana, although the stream tended to have a calcium-sodium bicarbonate water near its mouth. Calcium exceeded magnesium in all segments during all seasons; magnesium, sodium, and sulfate were secondary ionic constituents, and fluoride, chloride, and potassium were insignificant constituents. The waters were very

TABLE 96. Seasonal (Ca + Mg):Na and $HCO_3:SO_4$ ratios in the Tongue River.

	Decker reach (Ca + Mg):Na	Decker reach $HCO_3:SO_4$	Birney reach (Ca + Mg):Na	Birney reach $HCO_3:SO_4$	Ashland-Brandenburg reach (Ca + Mg):Na	Ashland-Brandenburg reach $HCO_3:SO_4$	Miles City reach (Ca + Mg):Na	Miles City reach $HCO_3:SO_4$
Aug-Oct	3.13	1.34	2.92	1.22	2.05	1.15	1.58	1.24
Nov-Feb	3.47	1.42	2.46	1.18	1.88	1.17	1.81	1.18
Mar-Apr	2.85	1.10	2.51	1.22	1.76	0.95	1.65	1.09
May-June	4.31	2.13	2.70	1.36	2.29	1.07	1.65	1.43
Annual Median	3.32	1.39	2.65	1.23	1.97	1.10	1.70	1.22

hard during all seasons in the lower segments, and they were generally non-saline with the exception of a few slightly saline winter samples.

Waters in the lower Tongue River below the dam (tables 90-92) have a low sodium hazard (SAR values less than 3.1), but a high salinity hazard for irrigation during the low-flow periods of the year, and a medium salinity hazard during the runoff season (USDA 1954). Like the upper segment, the lower Tongue also has largely a Class I water for irrigation due to the low boron (less than 0.5 mg/l), SAR, chloride, sulfate, SC, and TDS levels (tables 15 and 16). However, this water is less suitable for the irrigation of salinity-sensitive crop and forage plants than the water in the Decker reach because a higher proportion of the lower Tongue samples had TDS concentrations in excess of 500 mg/l (USEPA 1976). The major exception would be the August-October period. The greater potential effects of salinity on using the lower Tongue waters for irrigation against using that upstream above the reservoir is shown in table 97.

TABLE 97. Salinity hazard for irrigation in the upper and lower Tongue River.

	Percentage of samples having a particular salinity hazard:					
	upper Tongue near Decker			lower Tongue below the dam		
	medium	high	TDS > 500 mg/l	medium	high	TDS > 500 mg/l
Aug-Oct	30.2	69.8	64.3	35.7	64.3	58.1
Nov-Feb	32.6	67.4	60.0	3.7	96.3	93.5
March-April	32.1	67.9	78.6	21.4	78.5	76.9
May-June	83.0	8.5	10.9	59.7	40.3	38.7

The best water quality for irrigation occurred during the runoff season in all segments of the Tongue River, although there was a definite downstream degradation during this period with a greater proportion of the samples from the lower reach below the dam having a high salinity hazard. The runoff waters from the lower segments would probably be applicable to salinity-sensitive species about 61 percent of the time, as opposed to 90 percent of the time from the upper reach above the Tongue River Reservoir. This May-July degradation in downstream quality might have been related to reservoir concentrating effects and seasonal mixing, to the mode of reservoir operation, or to downstream tributary inputs with a poor water quality. A lesser quality or irrigation water was available from the Tongue during the late summer and early fall than during the runoff period, when there was a high salinity hazard in most of these warm-weather samples; these waters would be applicable to salinity-sensitive plants for only about 36 percent to 42 percent of the time during this season. The quality remained unchanged or improved downstream from August to October, contrasting with the degradation observed during the runoff season.

Absence of downstream change might have been due to reservoir operations causing the water quality to be artificially maintained for irrigation. That is, if water quality during August-October had been allowed to change in a fashion similar to that observed during the winter season, then the waters would have been much less fit for irrigation than was observed. The Tongue River during the March-April period also demonstrated a slight downstream degradation in quality and an increase in salinity; these waters would be generally unfit for the irrigation of salinity-sensitive species during about 77 percent to 79 percent of this early spring season.

The lower segments below the dam would also be generally unsuitable as a surface water public supply due to the water's extremely hard nature, high total dissolved solids concentrations, and high sulfate levels; the lower Tongue would be less suitable for this use than the upper reach due to the downstream increases in TDS and sulfate. In the lower segments of the river, 78 percent of the samples collected between August and April had TDS levels in excess of the permissible criteria and standards for public supply and drinking water; this was true of 66 percent of the samples above the reservoir. The waters of the lower Tongue would be more acceptable for public supply during the runoff period when the TDS levels are diluted, but it would still have a much lower value than the upper reach--about 40 percent of the lower reach May-July samples had TDS levels greater than 500 mg/l, and only 11 percent of the upstream segment samples. The high suspended sediment concentrations of the runoff season would tend to detract from the better water quality for municipal supply at this time, particularly near Miles City where 63 percent of the May-July samples had turbidities in excess of 75 JTU (compared to 40 percent of the samples collected above the reservoir); 14 percent of the samples collected between August and April near Miles City had turbidities in excess of this reference criteria. Turbidity would be much less critical above Miles City to the dam, as only 6 percent of the yearly samples would have turbidities greater than 75 JTU as a result of the trapping effect of the reservoir. Twice as many samples collected below the dam over the Decker reach had sulfate concentrations in excess of the recommendations for public supply (45 percent as opposed to 22 percent).

The downstream salinity increase in the Tongue River could also produce somewhat greater effects on the stream's biota in the lower segments than upstream. About 31 percent and 23 percent of the samples from the river below the Tongue River dam had TDS concentrations and SC levels greater than 670 mg/l and 1000 μmhos/cm, respectively; in contrast, only 7.5 percent and 4.9 percent of the samples from the upstream reach had TDS and SC in excess of these reference levels. However, the overall effects of salinity on aquatic life would be expected to be mild throughout the river from Decker to Miles City because most of the samples collected from the lower segments had TDS concentrations between 400 mg/l and 670 mg/l (50.8 percent) and less than 400 mg/l (18.3 percent). SC levels were usually between 600 μmhos/cm and 1000 μmhos/cm (59.6 percent) and less than 600 μmhos/cm (17.3 percent). The entire length of the Tongue River in Montana should be an excellent source of water for all stock animals because TDS and ionic constituent concentrations in samples from the stream were well below the threshold and limiting levels prescribed for these parameters (tables 10-14).

Data for miscellaneous constituents and numerous trace elements, in both TR and dissolved forms, are also available on the Tongue River from the USGS and the state WQB. These data were not seasonally classified and were compiled according to river reach as summarized in table 98 for the Birney and Decker segments and in table 99 for the Ashland-Brandenburg and Miles City segments. As indicated in these tables, ammonia concentrations were low and were not at levels high enough to significantly increase the eutrophic potential during most seasons. Ammonia was not at adequate pH levels to suggest toxicity to

TABLE 98. Summary of miscellaneous constituent and trace element concentrations measured in the Tongue River above Ashland, Montana.

	Various sites near Decker above the reservoir								Various sites below the reservoir and above Ashland							
	Miscellaneous constituents and total recoverable metals[a]				Dissolved metals				Miscellaneous constituents and total recoverable metals[b]				Dissolved metals[c]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[d]									23	87	107	93				
Fecal strep									1	--	--	10				
NH_3-N	8	0.02	0.14	0.06					13	<.01	0.13	0.03				
Si	77	3.4	14	8.1					24	1.1	7.7	5.3 (21?)				
TOC	4	4.8	16	9.1					7	6	10	9				
Ag													3	0.0	<.001	0.0
Al	3	.13	2.8	.50	7	0.0	.03	.01	9	<.10	0.54	0.29	5	.01	.12	.02
As	7	0.0	<.01	.002	2	0.0	0.0	0.0	8	<.001	<.01	0.002	5	0.0	.002	0.0
B	3	<.1	.12	.11	137	0.0	.38	.09 (.8?)	11	<.10	0.18	0.10	3	.10	.12	.11
Ba													3	0.0	.07	0.0
Be	1	--	--	<.01	2	0.0	<.01	<.01					5	0.0	.01	0.0
Cd	9	0.0	<.01	<.001	2	0.0	0.001	<.001	16	<.001	0.01	<.001				
Co	1	--	--	<.01												
Cr	4	0.0	0.01	<.01	2	0.0	0.01	<.01	4	<.01	0.01	<.01	1	--	--	.002
Cu	9	<.01	0.01	<.01	7	.002	.011	.004	22	0.0	0.02	<.01	6	.002	.004	.004
Fe	12	.05	4.8	.17	46	0.0	0.9	.12	18	.04	1.4	.15	18	0.0	.09	.03 (.26?)
Hg	8	0.0	<.001	<.001	7	0.0	.0002	0.0	21	0.0	<.001	<.0002	4	0.0	0.0001	<.0001
Li					2	0.0	.02	.01					3	.02	.03	.02
Mn	9	.02	.21	.06	2	.01	.03	.02	18	<.01	0.12	0.04	23	0.0	.12	.01
Mo					2	0.0	0.001	<.001					3	0.0	.002	.002
Ni					2	.002	.002	.002					5	0.0	.006	.002
Pb	6	0.0	<.10	<.05	7	.001	.009	.004	19	<.01	<.10	<.05	6	0.0	.006	.001
Se	4	0.0	<.001	0.0	9	0.0	.002	.001	10	0.0	0.001	<.001	6	0.0	.001	.001
Sr	2	.39	.57	.48					6	.55	.78	.63	3	.52	.73	.52
V	3	<.10	<.10	<.10	2	.001	.001	.001	11	<.05	<.11	<.10	5	.001	.009	.002
Zn	10	<.01	0.03	0.01	7	0.0	.03	.01	23	<.01	0.06	<.01 (.28?)	6	.002	.02	.01 (1.9?)

NOTE: Measurements are expressed in mg/l.

[a] Li: <.01, N=1.

[b] Be, Co, and Li: <.01, N=1.

[c] Cd: 0.0, N=1; Co: <.007, N=1.

[d] DO expressed as percentage of saturation.

TABLE 99. Summary of miscellaneous constituent and trace element concentrations measured in the Tongue River below Ashland, Montana.

	Various sites near Ashland-Brandenburg								Near Miles City							
	Miscellaneous constituents and total recoverable metals				Dissolved metals[a]				Miscellaneous constituents and total recoverable metals[b]				Dissolved metals[c]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Color									10	4	20	6				
DO[d]	22	61	106	96					23	79	110	97				
Fecal strep	1	--	--	0					12	16	3400	89				
NH_3-N	12	<.01	0.18	0.06					11	<.01	0.14	0.04				
Si	18	1.8	10	6.5					92	2.6	12	7.0				
TOC	5	8	17	10					7	6.8	27	16				
Ag					2	0.0	<.001	<.001								
Al	6	<.10	0.90	0.30 (6.0?)	2	0.0	.030	.015	3	.35	3.9	.60				
As	15	<.001	<.01	0.002	2	0.0	0.001	<.001	9	<.001	0.026	0.002	6	0.0	.001	0.0
B	11	<.10	0.49	0.11	15	.02	.17	.10	13	<.10	0.24	0.10	39	.025	.210	.110
Ba					2	.076	.090	.083					1	--	--	.09
Be					2	.01	.01	.01								
Cd	26	0.0	0.01	<.001	2	0.0	0.001	<.001	21	0.0	0.02	<.001	6	0.0	.001	0.0
Co									7	<.01	0.10	<.05	6	0.0	<.01	0.0
Cr	7	0.0	0.05	0.01	2	0.0	<.01	<.01	9	0.0	0.08	<.01	6	0.0	.01	0.0
Cu	28	0.0	0.03	<.01	2	.001	.005	.003	23	<.01	0.17	<.01	6	.001	.007	.003
Fe	26	.04	3.2	.21 (.13?)	15	0.0	.19	.04	21	.03	74	.68	74	0.0	.255	.03
Hg	24	0.0	<.001	<.0002	2	<.0001	0.0001	--	19	0.0	0.0035	<.0002	6	0.0	.0002	0.0
Li					2	.03	.03	.03	12	<.01	0.01	--	1	--	--	.03
Mn	22	<.01	0.20	0.02	2	0.0	.02	.01	19	.01	.68	.05	18	0.0	.02	.01
Mo					2	0.0	<.002	<.002								
Ni					2	.002	.008	.005								
Pb	20	<.01	0.10	.05	2	.001	.002	.002	18	0.0	<.10	<.05	6	.001	.005	.003
Se	9	0.0	.001	0.1					10	0.0	.003	.001	6	0.0	.001	0.0
Sr	9	.65	1.0	.77	2	.69	.94	.82	8	.08	1.3	.75	1	--	--	.86
V	10	<.05	<.11	<.10	2	<.003	<.003	<.003	11	<.05	0.17	<.10	1	--	--	.001
Zn	20	<.01	0.05	<.01	4	0.0	.08	.04	23	<.01	0.34	0.01	6	.01	.02	.01

NOTE: Measurements are expressed in mg/l.

[a]Co: <.01, N=2; Se: 0.0, N=1.

[b]Be: <.01, N=2.

[c]Ag: <.001, Al: 0.02, Be: 0.01, Mo: 0.0, Ni: 0.001; all N=1.

[d]DO expressed as percentage of saturation.

the river's biota, even at maximum concentrations.

The lower river below the dam was close to DO saturation in all segments, and the percentage of DO saturation tended to increase downstream in opposition to a general increase in TOC levels. Median TOC concentrations were near the national average for unpolluted streams (Lee and Hoodley 1967) between Decker and Brandenburg, and TOC was only slightly above the national average concentration near Miles City. Fecal strep concentrations did not indicate municipal-organic pollution, and the annual median fecal coliform:fecal strep ratio near Miles City (0.17) indicated that the fecal counts obtained from the Tongue River were probably derived from animal rather than human sources (Millipore Corporation 1972). Silica concentrations in the Tongue were also generally below the national average for surface waters (Davis 1964), and silica levels tended to drop immediately below the dam from up-reservoir concentrations, possibly as a result of phytoplankton utilization in the impoundment and an ultimate deposition to the sediments via the diatom frustules. Silica concentrations then tended to increase from Birney to Miles City.

None of these constituents suggested water quality problems. The high TDS levels of the stream, and the high TSS concentrations in some reaches and seasons, are the main detractions from the river's water quality.

Most of the trace elements in the Tongue River were in low concentrations and did not suggest major water quality problems. Of the total recoverable and dissolved concentrations, this includes Ag, As, Ba, Be, Cd, Co, Cr, Li, Mo, Ni, Pb, Se, and V. TR concentrations of Al, Fe, and Mn were occasionally high in the river samples, but this was probably related to suspended sediment levels, since the maximum-median TR levels of these parameters declined below the dam near Birney in correspondence with the decrease in TSS. The TR levels of Al, Fe, and Mn then demonstrated a subsequent downstream increase below the reservoir in correlation with the downstream increase in TSS; this was particularly noticeable near Miles City in relation to the high TSS concentrations of this stream segment. However, the dissolved concentrations of these three constituents were low and usually below their reference criteria. Only 2 percent and 4 percent of the samples from the Tongue had dissolved concentrations of Fe and Mn, respectively, in excess of these criteria. High TR concentrations of B, Cu, Sr, and Zn were also occasionally obtained in the Tongue samples, but the dissolved levels of B, Cu, and Zn were consistently below their reference levels, and Sr was not at adequate levels to pose water quality problems. Of the metals, therefore, only mercury appeared to have TR and dissolved concentrations high enough to detract from the stream's quality by sporadically exceeding the grab sample criteria for public supply and aquatic life (tables 9 and 19). Median dissolved concentrations of mercury were consistently below these reference levels, but 26.3 percent of the samples from the Tongue had detectable levels of this constituent, and 10.5 percent of the samples had concentrations as large as 2 μg/l.

Miscellaneous Tributaries

Most drainage basins, like the Tongue River system, are characterized by having a few major tributaries and numerous minor tributaries to the mainstem. Generally, water quality data are not available for the minor streams due to their small flow volumes or their intermittent-ephemeral natures. However, some data have been collected for such streams in the Tongue River drainage as a result of the strippable coal deposits in the region and the related necessity of preparing environmental impact statements.

The USGS has recently initiated a sampling program that includes many of these small streams (table 3), and the state WQB has collected some samples from several of these tributaries (table 6). Nevertheless, such data are not abundant due to the short periods of collection, and, since many of these small streams are intermittent or ephemeral, this would preclude sampling for several months of the year when the creeks happened to be dry, further reducing sample size. The data, therefore, were insufficient for a seasonal classification, and water quality information was combined geographically in order to expand the data base, as shown in table 100. Trace element data were further combined on this basis as shown in table 101. The major tributaries--Hanging Woman, Otter, and Pumpkin creeks--are considered in other sections of this report.

The various small and minor streams of the Tongue River drainage do not appear to be affected by large pollution inputs. Values of pH were neither distinctively high nor noticeably low, and they were within the state criteria for B-D streams. Dissolved oxygen levels were high and also within state standards, and median DO concentrations were usually within 10-11 percent of saturation. These features, plus the low BOD_5 levels, suggest a general absence of organic inputs; however, median TOC concentrations were above the national average, particularly in the lower streams of the drainage below Birney. Fecal coliform concentrations were low and did not suggest municipal pollution. These features, plus the fact that the TSS-turbidity levels of these small streams were not particularly high in comparison to those obtained from the Tongue River and other streams in the Yellowstone Basin, indicate that the high TDS and ionic constituent concentrations are the major features detracting from the water quality of these small tributaries. However, the importance of TDS varied considerably among the 15 creeks.

In some instances, TDS and ionic constituent concentrations were remarkably low and did not preclude any water uses. This is seen in the minimum values for the data sets and by some of the median concentrations. In these cases, collections were probably made during a runoff period from a recent rain or snowmelt, explaining the high maximum flows. Diluted TDS concentrations would be expected from these samples. The ephemeral streams of the region would probably produce this type of water quality data. The more southern tributaries of this nature above Birney were generally calcium-magnesium bicarbonate, and sodium and sulfate were the secondary ionic constituents. However, the more northern tributaries were sodium sulfate, which corresponds to the downstream chemical change in the Tongue River to a more sodium sulfate composition. SAR values were low in these two classes of streams.

Some samples were collected which had high TDS and ionic constituent concentrations. This is demonstrated by the maximum values of each data set and by the median data for Deer and Cook creeks. Streams having this type of water quality are probably the intermittent and perennial minor streams of the region, sampled during low-flow periods, with small but generally sustained flows (explaining the low minimum flows). Although low water volumes would probably preclude many of the water uses from these streams, they would probably have a poor class of water for irrigation during most of the year (Class II or

TABLE 100. Summary of the physical parameters measured in small streams in the Tongue River drainage.

	Deer Creek near Decker				Creeks above Birney (Bull, Canyon, Fourmile, Stroud, Squirrel, Young)				Cook Creek near Birney				Creeks below Birney (Bear, Beaver, Cow, Foster, Liscom, Logging, Threemile)			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	8	0.1	9	0.42	11	<1	14	2	13	0.4	43	1	21	0.05	300	7
Temp	8	0.0	20.2	10.8	11	0.0	19.0	0.5	13	0.0	19.0	2.0	21	0.0	19.5	2.0
pH	8	7.4	8.4	8.2	12	7.5	8.46	8.2	13	7.7	8.6	8.1	21	7.0	8.6	7.9
SC	8	450	6250	5350	11	170	2617	1240	13	270	2250	1840	21	120	4200	583
TDS	8	268	5299	4070	10	102	2179	835	12	152	1470	1325	21	84	3100	441
Turb	7	2	400	12	8	1	48	35	12	1	2400	3	21	2	200	30
TSS	1	--	--	29	5	4.7	124	85	1	--	--	2	3	2.0	32	8.0
DO	8	8.6	13.1	10.9	11	8.0	12.4	11.2 (18.1)	13	6.8	13.8	12.0	21	6.3	12.4	10.6
BOD	1	--	--	4.4	4	1.7	4.5	2.2	0	--	--	--	2	1.3	1.8	1.6
FC	0	--	--	--	3	0	76	13	0	--	--	--	2	0	>200	--
Ca	8	32	320	275	10	13	100	65	12	19	97	82	21	15	170	31
Mg	8	14	340	240	10	6.7	126	87	12	11	130	115	21	3.9	220	27
TH	8	140	2200	1650	10	60	732	548	12	93	780	670	21	59	1300	190
Na	8	30	875	685	10	6.5	372	45	12	16	200	190	21	3.7	780	43
K	7	7.9	17	10	7	7.1	15	9.9	12	4.7	15	13	19	5.0	20	9.0
SAR	8	1.1	8.6	6.9	10	0.3	6.0	1.1	12	0.7	3.5	3.1	21	0.2	13.0	1.5
HCO_3	8	86	638	563	10	71	603	402	12	92	670	639	21	60	747	137
TA	8	71	523	469	10	58	525	332	12	75	550	525	21	49	613	112
SO_4	8	130	3250	2550	10	26	966	275	12	46	670	550	21	15	1800	160
Cl	8	4	27	14	10	2	8.6	4.8	12	2	9	6	21	1.0	16	4
F	7	0.1	0.5	0.3	7	0.1	0.7	0.3	12	0.1	1.2	1.1	20	0.0	1.1	1.3
N	8	0.0	0.6	0.05	26	0.0	0.8	0.1	12	0.01	1.7	0.55	21	0.0	0.2	0.03
P	8	<.01	0.34	0.04	26	0.0	0.46	0.06	12	0.0	0.21	0.03 (1.5?)	21	<.01	0.54	0.16

NOTE: Measurements expressed in mg/l.

TABLE 101. Summary of miscellaneous constituent and trace element concentrations measured in small streams in the Tongue River drainage.

	Deer Creek and other creeks above Birney								Cook Creek and other creeks below Birney							
	Miscellaneous constituents and total recoverable metals				Dissolved metals[a]				Miscellaneous constituents and total recoverable metals				Dissolved metals[b]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[c]	14	78	129	90					32	63	117	89				
Si	14	4.1	19	7.2					31	2.7	28	8.8				
TOC	1	--	--	14					2	34	43	39				
Al	4	.06	.41	.12	2	.03	.06	.045	5	.10	11	.17	3	0.0	.02	.02
As	11	0.0	-.01	.002	2	.004	.004	.004	18	0.0	.005	.002	2	.001	.004	.003
B	1	--	--	16	14	.07	.19	.13					32	.07	.76	.16
Ba					1	--	--	.07					2	.043	.060	.052
Be					3	0.0	<.003	0.0					3	0.0	<.01	<.004
Cd	8	<.001	0.02	0.001	2	0.0	.001	--	18	<.001	0.03	0.01	3	0.0	<.03	0.0
Co					1	--	--	<.006					2	<.009	<.013	<.013
Cr	7	0.0	.06	.01	2	0.0	<.006	<.006	16	0.0	.02	.01	3	0.0	<.013	<.010
Cu	11	0.0	.07	.01	2	.005	.009	.007	17	<.01	0.05	0.01	3	.002	.008	.003
Fe	12	.08	5.0	.96	14	.01	.29	.10	18	.05	10	1.1	32	0.0	.23	.08
Hg	12	0.0	<.001	.0002	1	--	--	.0001	17	0.0	<.001	0.0 (.0002)	2	0.0	<.0001	<.0001
Li					1	--	--	.06					2	.10	.11	.105
Mn	12	.02	.85	.16	2	.02	.12	.07	17	<.01	0.17	0.08	3	.02	.05	.04
Mo					1	--	--	<.003					2	<.003	<.004	<.004
Ni					2	<.006	<.006	<.006 (.002)					3	<.006	<.008	<.008 (.002)
Pb	7	<.05	0.20	0.10	2	<.006	<.006	<.006 (.004)	16	<.10	<.10	<.10	3	<.009	<.013	<.013 (.006)
Se	7	0.0	0.0	0.0					16	0.0	.003	.001				
Sr	1	--	--	.55	1	--	--	.87					2	1.4	1.8	1.6
V	1	--	--	<.1	1	--	--	<.003					2	<.004	<.008	<.008
Zn	9	<.01	0.05	0.01	2	.01	.06	.035	7	0.0	.07	.01	3	0.0	.02	.01

NOTE: Measurements are expressed in mg/l.

[a] Ag: <.001, N=1.

[b] Ag: <.002, N=2.

[c] DO expressed as percentage of saturation.

Class III) and be poor sources of water for municipal supply (with high TDS, sulfate, and hardness levels) and stock (with high TDS, magnesium, and sulfate levels in excess of the threshold and limiting criteria for many stock animals, particularly in Deer Creek).

These streams, with their low flows, would also provide a poor environment for freshwater biota since TDS and SC levels usually exceeded 1350 mg/l and 2000 μmhos/cm. These streams had either a sodium sulfate (as in Deer Creek) or a sodium bicarbonate water (as in Cook Creek), with magnesium, calcium, and sulfate or bicarbonate the secondary ionic constituents; SAR values were high. Fluoride, chloride, and potassium were insignificant constituents of all of these miscellaneous waters, and nitrogen and phosphorus were not in concentrations high enough to suggest eutrophy, except in a few isolated samples. Trace element levels did not indicate water quality problems (table 101). Of these constituents, only manganese had dissolved concentrations in excess of the reference criteria (in 40 percent of the samples).

Hanging Woman Creek

Hanging Woman and Otter creeks, two of the major tributaries of the Tongue River, join the river in the southern portion of its drainage in Montana (USDI 1968). Hanging Woman Creek is the more southern of the two streams, flowing in a northerly direction from Wyoming and joining the mainstem near Birney. Although the volumes of flow in these two creeks are not particularly high, they appear to be perennial, as no days of zero flow were recorded by the USGS in 1974 (USDI 1974). Flows in Hanging Woman Creek were somewhat less than those in Otter Creek during this year. These streams had an average annual flow between 5 cfs and 8 cfs in 1974, and daily flows ranged from about 0.2 cfs in the late summer to values approaching 150 cfs during the chinook periods of the winter season (in January and February) (USDI 1974). Such early runoff events are characteristic of lowland prairie streams.

The added average discharge of the two creeks represents about 3 percent of the mean annual flow of the Tongue River; thus, these major tributaries could exert an influence on Tongue River quality, particularly if they happen to have the high TDS concentrations that are also typical of a prairie stream. Some water quality data have been collected from these two streams by the state WQB, and the USGS has recently initiated a monthly water quality sampling program on the creeks in conjunction with their flow gaging stations. As a result of these efforts, data for the major parameters were adequate for a seasonal classification as summarized in table 102 for Hanging Woman Creek.

The water quality in Hanging Woman Creek is characteristic of what might be expected from a lowland, eastern stream in the Yellowstone Basin; this is evident in its high TDS concentrations and SC levels and in its sodium sulfate composition. These features correlate with the downstream increases in TDS-SC in the Tongue River below the reservoir and to the river's chemical change towards a more sodium sulfate water in a downstream direction to Miles City. TDS concentrations in Hanging Woman Creek were between 2.43 times greater in the winter and 6.14 times greater during the runoff period than those in the Tongue River below the dam near Birney; data from these two locations are directly comparable due to their similar periods of collection (table 3). Specific

TABLE 102. Summary of the physical parameters measured in Hanging Woman Creek near Birney.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	0.4E	3.2E	2	11	1	65	3	7	2.E	125	2.9	5	0.4	10	7
Temp	7	8.0	20.5	16.0	11	0.0	6.5	0.0	7	0.5	9.0	3.8	5	10.0	22.0	15.0
pH	6	8.1	8.50	8.22	11	7.7	8.3	8.1	7	7.4	8.50	7.95	5	8.0	8.40	8.20
SC	7	2300	3210	2700	11	630	2680	2500	7	240	3963	2600	5	2814	4736	3310
TDS	6	1620	2526	2055	11	404	2283	1740	6	176	3668	2059	5	2110	4196	2565
Turb	2	6	12	9	4	6	42	11	4	4	187	23	1	--	--	24
TSS	2	2.5	13.8	8.2	4	9.0	30	17.7	4	11.0	67.5	19.5	2	33.0	70	51.5
DO	5	5.8	9.6	8.6	10	8.4	12.0	11.4	7	11.2	13.2	11.8	5	5.8	11.8	10.0
BOD	1	--	--	0.5	4	1.6	7.8	4.0	4	3.2	6.0	4.1	2	2.9	3.5	3.2
FC	3	5	1010	10	4	0	70	5	3	0	260	72	2	2	92	52
Ca	6	87	114	110	11	31	120	100	6	27	235	97	5	110	196	125
Mg	6	110	155	130	11	21	130	120	6	11	160	124	5	130	230	160
TH	6	700	858	810	11	160	794	770	6	110	1270	796	5	835	1438	1000
Na	6	300	440	360	11	63	370	300	6	17	620	341	5	370	725	430
K	6	15	18	16	9	11	19	14	3	7.0	15	8.0	3	14	16	15
SAR	6	4.9	6.5	5.4	11	2.1	5.7	4.8	6	0.7	7.6	5.2	5	5.6	8.3	5.9
HCO_3	6	426	631	604	11	112	669	619	6	89	604	518	5	505	668	585
TA	6	431	518	496	11	92	549	507	6	73	513	424	5	414	548	480
SO_4	6	760	1333	1070	11	210	1030	820	6	57	2080	1035	5	1115	2464	1400
Cl	6	0.0	14	12	11	3.5	14	11	6	1.8	12	6.5	5	11	14	12
F	6	0.2	1.1	1.0	9	0.1	1.1	1.0	4	0.1	0.9	0.7	3	0.7	0.9	0.8
N	6	0.0	0.2	0.02	11	0.02	0.43	0.22	7	0.0	0.3	<.01	5	0.0	0.1	0.0
P	5	<.01	0.11	0.02	11	0.0	0.32	0.02	7	<.01	0.56	0.02	5	<.01	0.78	0.04

NOTE: Measurements expressed in mg/l.

conductance levels in Hanging Woman Creek were between 2.74 times higher in the winter and 4.94 times higher during the runoff season than those in the Tongue near their confluence. The waters in the smaller stream were extremely hard, but they were slightly saline, and TDS concentrations in Hanging Woman Creek were at levels high enough to affect most water uses.

The TSS-turbidity levels of the tributary were low and did not indicate major water quality problems; annual median values of 16 JTU and 40 mg/l would indicate a good-to-moderate fishery (European Inland Fisheries Advisory Committee 1965), given no other limiting factors. Such low TSS-turbidity levels in this tributary correspond to the general absence of distinct downstream increases in these variables in the Tongue River between the dam and Brandenburg. However, the high maximum turbidity value in March-April indicates occasional large slugs of sediment in this tributary. Highest TSS levels in Hanging Woman Creek were obtained during the May-July, high-flow period of the stream, correlating with the season of maximum downstream increase in TSS in the Tongue mainstem.

Although the median BOD_5 levels in Hanging Woman Creek during the winter and the spring were somewhat higher than the BOD_5 levels typical of most streams in the Yellowstone drainage, they were not at levels high enough to suggest organic pollution--only 36 percent and 9 percent of the samples had BOD_5 concentrations in excess of 4 mg/l and 7 mg/l, respectively. High BOD_5 levels occasionally exceeding 4 mg/l and approaching 10 mg/l can be expected to occur even under natural conditions. The high DO concentrations and low fecal coliform levels indicate an absence of pollution inputs to the creek. The concentrations of these variables were generally within the state criteria for a $B\text{-}D_3$ stream during all seasons, as were the pH values, and the fecal counts were well below the permissible level for a surface water supply (USDI 1968). In addition, Hanging Woman Creek does not appear to be in a eutrophic condition at present. Although a few samples were obtained from the creek with high phosphorus concentrations in excess of the EPA's (1974b) reference criteria (0.35 mg P/l), 93 percent of the samples had phosphorus concentrations less than this level, and the median concentrations of this critical nutrient were less than 0.05 mg P/l during all seasons. Because nitrogen concentrations were extremely low, except for a winter peak observed in other streams, only 1 percent of the samples from Hanging Woman Creek would be expected to have both nitrogen and phosphorus in excess of their reference levels. These features, and the water's low suspended sediment concentrations, indicate that salinity is the major water quality problem of the stream.

Sodium and sulfate are the dominant cation and anion in water samples from the creek (table 102). As a result, SAR values were high, indicating a medium sodium hazard for irrigation at the specific conductance levels of the stream. Magnesium concentrations exceeded those of calcium; together, these constituents were the secondary cations. Bicarbonate was the secondary anion, and chloride, fluoride, and potassium were the minor chemical components of the samples. Fluoride concentrations were somewhat higher in Hanging Woman Creek than in most other streams of the Yellowstone Basin, with the exception of those in the upper reach of the Yellowstone mainstem near Yellowstone National Park above Livingston tables 25 and 26). Fluoride levels were also very close to the optimum range for drinking water in Hanging Woman Creek and were generally within the control limits (table 9).

Hanging Woman Creek would provide a very poor class of water for public supply due to its extremely high total dissolved solids, sulfate, and hardness levels. Median sulfate concentrations of the stream exceeded the threshold levels for stock during the winter months and were greater than the limiting levels during the remaining seasons; median bicarbonate concentrations also were in violation of the limiting criteria for stock animals during the entire year (California WQCB 1963). These characteristics would definitely reduce the value of the stream as an agricultural supply even though median TDS concentrations (less than 2500 mg/l) were not at levels high enough to degrade the creek for this use; only 7 percent of the samples from Hanging Woman Creek had TDS concentrations in excess of 3000 mg/l.

This creek would also be a poor source of water for irrigation, as it had a medium sodium hazard and a very high salinity hazard for this use (USDA 1954). The waters in the creek would be designated as a borderline, Class II water for this purpose (tables 15 and 16) due to the high SAR, sulfate, specific conductance, and total dissolved solids levels. As noted by the EPA (1976), waters with TDS concentrations greater than 2000 mg/l ". . . can be used for tolerant plants on permeable soils with careful management practices." These waters, therefore, should probably not be applied to the salinity-sensitive and semi-tolerant species listed in table 17, particularly during the May-July period. Similarly, the high salinity levels of Hanging Woman Creek would be expected to affect the aquatic biota, as 82 percent to 86 percent of the samples had TDS-SC levels greater than 1350 mg/l and 2000 μmhos/cm. Salinities in excess of these levels might be judged to have detrimental influences on the freshwater biota. Hanging Woman Creek, like many prairie streams in eastern Montana, might be considered to have a poor class of water, principally on the basis of its high TDS levels.

Hanging Woman Creek has been designated a B-D_3 stream by the State of Montana, butits waters, as noted above, would definitely not be suitable for "drinking, culinary and food processing purposes" (Montana DHES, undated) without the application of extensive treatment for the removal of total dissolved solids. In addition, the suitability of its waters for the "growth and propagation of non-salmonid fishes and associated aquatic life" and for agricultural supply might be questioned. Thus, although most of the water quality parameters in samples from the creek, such as pH, DO, temperature, and fecal coliforms, were in accord with its B-D_3 designation, salinity would certainly make inappropriate certain of the water-use descriptions associated with a B-D_3 classification, given no accessory treatment. This is true of many streams in eastern Montana. As a result, in order to more accurately describe such streams, some supplementary designation should be applied where water uses are restricted by high salinities but not by pollution inputs or other factors.

Miscellaneous constituent and trace element data are available for Hanging Woman Creek as summarized in table 103. Median silica and TOC concentrations were somewhat greater than the national average or median for surface waters, but these constituents did not suggest pollution problems. The low TOC values were in accord with the low BOD_5 concentrations of the creek and also indicate the absence of organic inputs to the stream. All of the tributaries to the Tongue River, including Otter Creek, had median DO concentrations between 88 percent and 91 percent (tables 101 and 103) of saturation; such consistencies in percentage of saturation among these creeks suggests the natural level of

TABLE 103. Summary of miscellaneous constituent and trace element concentrations measured in Hanging Woman and Otter creeks.

	Hanging Woman Creek near Birney								Otter Creek at Ashland							
	Miscellaneous constituents and total recoverable metals				Dissolved metals[a]				Miscellaneous constituents and total recoverable metals[b]				Dissolved metals[c]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[d]	16	72	104	88					17	63	110	91				
NH_3-N	2	0.02	0.05	0.035					3	0.0	0.06	0.03				
Si	18	6.7	22	16					17	2.1	17	7.3				
TOC	2	11	14	12.5					2	13	16	14.5				
Al	3	0.9	6.4	2.0	3	0.0	.04	.02	3	.16	.78	.23	4	0.0	.50	.25
As	15	0.0	<.01	.002	2	0.0	0.001	<.001	15	0.0	<.01	.001 (.006)	2	.001	.001	.001
B	4	.15	.39	.23	18	.12	.82	.28	4	.36	.53	.40	18	.12	.52	.45
Ba					3	.031	.040	.040					3	.02	.03	.02
Be					3	0.0	<.01	<.005					4	<.003	0.01	<.01
Cd	19	<.001	0.02	<.01	3	0.0	<.035	<.035 (.001)	19	<.001	0.01	<.01	4	0.0	<.05	.001
Cr	10	0.0	.014	<.01	3	<.01	<.02	<.02 (.006)	9	0.0	.09	0.0	4	0.0	<.01	<.01
Cu	19	<.01	0.02	<.01	3	<.003	0.004	<.003	19	0.0	.11	.01	4	.002	.01	.005
Fe	19	.22	3.6	.66	18	0.0	1.5	.04	20	.15	2.9	.49	17	.01	.49	.05
Hg	16	0.0	<.001	<.0002 (.0004)	2	0.0	<.0001	<.0001	15	0.0	<.001	<.0002 (.0008)	2	0.0	<.0001	<.0001
Li					3	.09	.10	.10	1	--	--	.15	4	.13	.15	.13
Mn	18	.04	.39	.11	3	.02	.03	.02	18	.02	.36	.08	4	.02	.04	.04
Mo					3	<.004	0.005	<.005	1	--	--	.007	4	<.006	<.01	<.01 (.004)
Ni					3	<.008	0.01	<.008					4	<.010	<.014	<.010
Pb	12	<.01	0.10	<.10	3	<.01	<.02	<.01	13	<.01	0.10	<.10	4	<.010	<.014	<.010
Se	8	0.0	.002	.001	1	--	--	.001	8	0.0	.003	.001	1	--	--	.001
Sr	3	1.5	2.7	1.6	3	1.3	1.4	1.3	3	1.8	2.7	2.0	3	1.1	1.8	1.1
V	4	<.10	<.10	<.10	3	<.005	<.01	<.005	4	<.10	<.10	<.10	4	<.01	<.01	<.01
Zn	14	<.01	0.02	0.01	3	0.0	.02	.01	14	<.01	0.04	0.01	4	0.0	0.11	.005

NOTE: Measurements are expressed in mg/l.

[a]Ga: <.01, N=1; Bi, Ge, Sn, Tl, Zr: <.02, N=1; Ag: <.002, N=3; Co: <.02, N=3.

[b]Be: 0.01, N=1; Ni: 0.05, N=1.

[c]Ga, Tl: <.01, N=1; Bi, Ge, Sn, Zr: <.02, N=1; Ag: <.002, N=3; Co: <.014, N=3.

[d]DO expressed as percentage of saturation.

DO saturation that characterizes these streams. Like the TOC levels, ammonia concentrations were also low, and they were not at levels high enough to increase the stream's eutrophic potential or to be toxic to aquatic life. This latter feature also applies to most of the trace elements with small TR or dissolved concentrations. Of these constituents, only iron had its maximum dissolved concentration in excess of the reference criteria for drinking water (USDHEW 1962), public supply (USDI 1968), and aquatic life (table 19); this was not the case, however, for its median dissolved concentrations, and only 17 percent of the samples from Hanging Woman Creek had dissolved iron in excess of 0.3 mg/l. As a result, the trace elements did not significantly detract from the quality of water in this stream.

Otter Creek

Otter Creek, another of the major Tongue River tributaries, flows in a northerly direction before joining the Tongue near Ashland (USDI 1968). However, Otter Creek has all of its drainage in Montana. Data for the major parameters are summarized in table 104 for Otter Creek, and data for the trace elements and miscellaneous constituents are presented in table 103.

The TR concentrations of trace elements of most Otter Creek samples did not indicate great water quality problems. This would include, most notably, ammonia, As, Be, Cd, Hg, Li, Mo, Ni, Se, and V; the dissolved concentrations of these 10 constituents were also low or undetectable, as were the dissolved levels of 9 other trace elements which had no TR information--Ag, Ba, Bi, Co, Ga, Ge, Ti, Sn, and Zr. However, some of the trace elements had high median or maximum TR levels. Silica, Al, B, Fe, Mn, and Sr were noticeable in this regard, but also Cr, Cu, Pb, and Zn. Such high TR levels were probably associated with suspended sediment because the dissolved concentrations of most of these constituents were low and below their reference criteria; this would include B, Cr, Cu, Mn, and Pb. Silica and Sr concentrations did not indicate water quality problems. Of the various trace elements, only Al and Fe had dissolved concentrations in excess of certain reference criteria. The median and maximum idssolved levels of Al were greater than the recommendation of the EPA (1973) in relation to aquatic life. In terms of iron, 18 percent of the samples from Otter Creek had dissolved concentrations in excess of the criteria for drinking water (USDHEW 1962), surface water public supply (USEPA 1973, USDI 1968), and aquatic life (USEPA 1973), although the median dissolved level of this constituent was less than these values. In addition, one of the samples from Otter Creek analyzed for zinc demonstrated a dissolved concentration in excess of its reference criteria for the aquatic biota (USEPA 1973). For the most part, however, the trace elements do not appear to be at levels high enough to consistently detract from most of the water uses from Otter Creek.

As suggested by the trace element data (table 103), the water quality in Hanging Woman and Otter creeks was found to be similar, which might be expected considering the proximity of their drainage areas (USDI 1968). Both of these creeks had poor inverse relationships between median seasonal flows and TDS-SC levels. In Hanging Woman Creek (table 102), the highest median TDS-SC levels were obtained during the May-July period of greatest flow. In Otter Creek (table 104), median TDS concentrations were closely equivalent through all seasons regardless of median flows. For example, a maximum difference in

TABLE 104. Summary of the physical parameters measured in Otter Creek at Ashland.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	0.2	4	1	12	1.5E	131	4	6	6.0E	260	12.7	5	0.03	25	6
Temp	7	5.0	24.0	12.0	12	0.0	7.5	0.0	6	0.0	13.0	1.1	5	10.5	22.0	18.2
pH	6	8.1	8.62	8.6	12	7.7	8.5	8.2	6	7.2	8.40	8.35	5	7.9	8.40	8.2
SC	7	2616	3080	2950	12	410	3900	3125	6	370	2961	2355	5	2810	3305	3070
TDS	6	2080	2676	2255	11	240	2861	2390	5	228	2533	2204	5	2110	2786	2290
Turb	2	2	9.0	5.5	5	7	14	8	4	5	37	11	0	--	--	--
TSS	2	13.0	23	18	5	1	35	18.0	4	4	79.5	16	1	--	--	2.0
DO	6	7.4	11.7	8.4	11	10.6	12.4	11.9	6	9.9	13.5	11.6	5	5.0	10.0	9.6 (18.0?)
BOD	1	--	--	3.3	3	2.2	3.3	2.2	4	2.5	3.7	3.0	2	3.9	3.9	3.9
FC	3	0	200	8	4	0	18	7	4	0	100	5	1	--	--	4
Ca	6	57	77	66	11	23	169	99	5	23	92	84	5	73	162	91
Mg	6	150	190	162	11	15	182	170	5	17	171	138	5	160	193	180
TH	6	780	930	843	11	120	1116	960	5	130	934	795	5	840	1199	950
Na	6	378	460	395	11	30	460	420	5	26	400	350	5	360	470	390
K	6	8.1	24	22	9	8.5	27	20	2	10	15	13	3	17	17	17
SAR	6	5.6	6.8	6.0	11	1.2	6.5	5.7	5	1.0	5.7	5.1	5	4.9	6.6	5.4
HCO_3	6	542	670	628	10	110	750	663	5	120	590	528	5	501	628	593
TA	6	488	550	531	11	90	664	539	5	98	497	449	5	411	529	486
SO_4	6	1100	1300	1162	11	100	1500	1290	5	80	1270	1070	5	1200	1530	1300
Cl	6	0.0	16	13	11	3	16	12	5	1.5	10	8.5	5	10	13	11
F	6	0.7	1.0	0.8	10	0.1	0.8	0.8	4	0.2	1.0	0.6	3	0.6	0.7	0.7
N	6	0.01	0.13	0.1	11	0.10	1.6	0.40	6	0.0	0.3	0.1	5	0.0	0.1	0.04
P	6	<.01	0.13	0.04	11	0.0	0.17	0.02	6	<.01	0.68	0.01	5	<.01	0.08	0.04

NOTE: Measurements expressed in mg/l.

median TDS between seasons of only 8 percent was obtained in Otter Creek, with only a 2 percent difference in median TDS between the low- and high-flow periods (August-October to March-April); this contrasts with the 96-percent and 87-percent values obtained for the Yellowstone River near Miles City. Water samples from Otter Creek also had high TDS-SC levels, along with a sodium sulfate composition that characterizes most of the lowland streams in eastern Montana. The waters in Otter Creek were extremely hard and were usually slightly to moderatley saline. TDS concentrations and SC levels were possibly somewhat higher in Otter than in Hanging Woman Creek during most seasons, with annual median TDS and SC values in the first stream (2300 mg/l and 2937 µmhos/cm) about 1.11 and 1.06 times greater than the annual medians in Hanging Woman Creek. TDS concentrations in Otter Creek were between 3.33 times in the winter and 5.47 times during May-July greater than those in Tongue River near Birney. Although the tributary flows were comparatively low, the high TDS concentrations of these two creeks indicate a potential salinity loading to the Tongue mainstem via these sources, corresponding to the downstream increase of TDS in the Tongue below the dam.

The possible effect of Hanging Woman and Otter creeks towards increasing TDS levels in the Tongue River below the dam can be shown in table 105.

TABLE 105. Effects of Hanging Woman and Otter creeks towards increasing TDS levels in the Tongue River below the dam.

	Hanging Woman and Otter creeks		Tongue River from Ashland to Brandenburg[a]		Tongue River from Ashland to Brandenburg[b]	
	cfs Flow	mg/l TDS[c]	mg/l TDS	Increase[d]	mg/l TDS	Increase[d]
Aug-Oct	3	2122	563	3.7%	632	16.4%
Nov-Feb	7	2111	777	8.4%	748	4.3%
March-April	15.6	2177	644	15.2%	773	38.3%
May-July	13	2438	446	6.7%	564	34.9%
Annual	38.6	2249	531	8.4%	640	30.6%

[a]Calculated.
[b]Observed.
[c]Flow weighted.
[d]Percentage increase in TDS over that in the Birney reach (table 90).

As indicated by the above loading calculations, these two tributaries apparently have an influence on the salinity levels of the Tongue River, and they may be able to increase the median TDS concentrations of the mainstem about 3.7 percent to 15.2 percent, depending upon season. The annual increase in median TDS due to these two streams would be nearly 8.4 percent. However, the individual daily effects from these creeks could be greater or less than these values depending upon the specific flow-TDS relationships of the Tongue and its tributaries at that particular time. Except during the winter, mainstem TDS increases attributable to these two creeks were significantly less than the observed increases from the Birney reach to the Ashland-Brandenburg segment of the Tongue. TDS inputs from Otter and Hanging Woman creeks would account for only about 27 percent of the median yearly downstream increase in mainstem salinity below the reservoir. As a result, other features were also apparently contributing to this increase in salt concentrations in the Tongue River. Such features could include, as examples, inputs of other saline tributaries below the dam (i.e., the minor tributaries, such as Cook Creek, summarized in table 100, and others), irrigation diversions and evaporation with the subsequent inputs of saltier return flows, accrual of lowland groundwater with high TDS concentrations, and saline seep (Montana DHES 1975).

The chemical composition of water in Otter Creek was found to be quite similar to that in Hanging Woman Creek. In both cases, sodium and sulfate were the dominant ions, producing high SAR values and a medium sodium hazard for irrigation. Fluoride concentrations in Otter Creek were less than those in Hanging Woman Creek, but fluorides in the first stream were also higher than the values typical of most streams in the middle-lower Yellowstone Basin (generally less than 0.7 mg/l). However, fluoride levels were not high enough to detract from water uses. Magnesium-calcium and bicarbonate were the secondary ionic constituents of Otter Creek, and fluoride, chloride, and potassium were insignificant components. In both streams, calcium concentrations were less than the magnesium levels; this feature was greatest in Otter Creek. Such low Ca:Mg ratios suggest dolomitic formations in the middle Tongue River Basin, in accord with the latitudinal-geographic similarity and orientation of the Otter Creek drainage in relation to other drainages east of the Bighorn River that also had high magnesium concentrations (e.g., Tullock, Sarpy, Armells, and lower Rosebud creeks). The Ca:Mg ratios generally declined downstream in the Tongue River in response to these tributary inputs as follows (based on the annual median Ca and Mg concentrations: Decker reach, 1.51; Birney reach, 1.42; Ashland-to-Brandenburg, 1.31; and the Miles City reach, 1.43.

Salinity and the high concentrations of particular ionic constituents appeared to be the major factors detracting from water quality in Otter Creek; none of the remaining parameters and trace elements (table 103) appeared to have concentrations high enough to consistently alter the creek's quality. Sample pH levels from the stream did not suggest water pollution problems. The pH and DO levels of the stream and the fecal coliform concentrations were consistently in accord with Montana's requirements for a $B\text{-}D_3$ water. With the high DO concentrations (the median value was within 9 percent of saturation) and the low BOD_5, TOC, and fecal levels, Otter Creek was apparently free from significant organic-municipal inputs.

In addition, TSS-turbidity levels did not lower the water quality in the creek. The levels of these variables in the Otter Creek samples were generally less than those obtained from Hanging Woman Creek, and the annual median TSS concentration, 14 mg/l; would suggest an excellent fishery in Otter Creek (European Inland Fisheries Advisory Commission 1965), given no other limiting factors. Similarly, the low phosphorus and nitrogen concentrations indicate no eutrophy problems in Otter Creek. Median phosphorus concentrations were less than its reference level for eutrophy during all seasons; with the exception of a winter concentrational peak, this was also true of nitrogen. Only 7 percent of the samples collected from Otter Creek would be expected to have both phosphorus and nitrogen in excess of their reference levels, and the bulk of these samples would be collected during the less critical winter period. As a result, Otter Creek, like most streams in the Yellowstone Basin, does not appear to be eutrophic at present.

Although measurements of many of the major parameters indicate excellent water quality (table 103), the water in Otter Creek is unfit for most, if not all, beneficial uses due to salinity. Water-use limitations and associated rationale would be the same as those for Hanging Woman Creek. This would necessitate eliminating the stream as a suitable source of water for public supply due to its high TDS, sulfate, and hardness levels. Its very high salinity hazard makes it unsuitable for irrigation (it is a Class II to borderline Class III water for this use), along with its high sulfate concentrations, in excess of limiting levels for stock animals. Also, Otter Creek would provide a poor environment for the freshwater aquatic biota, as 93 percent of the Otter samples had TDS concentrations in excess of 1350 mg/l and 90 percent of the samples had SC levels in excess of 2000 μmhos/cm. The waters in Otter Creek therefore has a poor quality for most beneficial applications.

Pumpkin Creek

Pumpkin Creek is the third major tributary to the Tongue River. It is the most northern of these streams and has a rather extensive drainage area located entirely within Montana. It also flows in a northerly direction before joining the mainstem about 15 miles south of Miles City. Water quality and grab sample flow data for Pumpkin Creek are summarized in tables 106 and 107.

Pumpkin Creek can be characterized by its wide fluctuations in flow, ranging from zero on numerous occasions to daily flows approaching 900 cfs, and instantaneous flows as high as 1660 cfs (USDI 1966-1974b). Zero discharges and low flow values were usually observed from summer to early winter, and the maximum discharges were usually observed during the late winter and spring. However, extremely high flows also occurred during other periods of the year (USDI 1966-1974b). High flows were most consistently obtained between February and mid-July.

Pumpkin Creek is an intermittent stream which measured zero flow on 25 perpercent of the days monitored by the USGS. Although Pumpkin Creek is intermittent, its average annual flows were the same or greater than those in Hanging Woman and Otter creeks. Discharge in Pumpkin Creek averaged 14.3 cfs in water year 1973 and 4.5 cfs in water year 1974; this compares to average flows during these years of 5.2 cfs to 7.8 cfs in the other major tributaries (USDI 1966-1974a). The similarity in mean flows between intermittent and perennial streams of the Tongue River drainage was due to the weighting effect of the large slugs of water that can develop in Pumpkin Creek. The median annual flow of Pumpkin Creek (0.7 cfs) (tables 106 and 107) are considerably less than the median annual flows of Otter (5.2 cfs) and Hanging Woman (3.7 cfs) creeks (tables 102 and 104).

Water quality data for Pumpkin Creek near its mouth (close to Miles City) are available from the state WQB and from the USGS. However, the state WQB data are not very extensive, and the USGS initiated its water quality sampling program on Pumpkin Creek later than it did on the other streams in the Tongue River drainage. As a result, a great deal of chemical data are not yet available.

Data for Pumpkin Creek near Miles City were inadequate for the seasonal classifications applied to Hanging Woman and Otter creeks; but the information was sufficient for a flow-based classification (tables 106 and 107). In

TABLE 106. Summary of the physical parameters measured in the Pumpkin Creek drainage.

	Pumpkin Creek and Little Pumpkin Creek near Volborg				Pumpkin Creek near Miles City[a]				Pumpkin Creek near Miles City[b]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	3	0.09	0.21	0.1 (40)	8	0.05	0.7	0.26	7	1.0	240	25
Temp	4	12.0	17.9	14.7	8	1.1	22.8	8.9	7	0.0	20.5	8.5
pH	4	8.20	8.50	8.35	8	8.20	8.62	8.46	7	6.67	8.49	8.20
SC	3	5400	6570	5840 (1460)	8	1977	3545	3130	7	247	4200	1380
TDS	3	4766	6315	5394	7	1585	3063	2729	7	188	3723	1081
Turb	2	5	5	5	5	6	15	14	7	14	220	175
TSS	3	2.0	10	5.6 (228)	7	11.4	41	20.2	7	11.0	1830	360
DO	4	9.1	10.7	9.9	8	9.3	12.4	10.3	6	7.4	12.7	10.5
BOD	4	2.0	4.0	3.3	7	2.2	5.9	2.8	6	3.0	>12	5.2
FC	2	0	0	0	6	0	12,700	42	5	0	5000	9
Ca	3	139	166	164	7	58	81	67	7	10.4	141	60
Mg	3	218	481	253	7	35	69	58	7	6.1	176	43
TH	3	1314	2390	1391	7	289	484	393	6	51	477	315
Na	3	956	1150	1050	7	325	780	680	7	26	720	195
K	0	--	--	--	4	10	13	12	4	5.8	17	8.8
SAR	3	9.3	13.4	11.5	7	7.1	16.2	14.0	6	1.4	12.0	4.2
HCO_3	3	643	920	673	7	381	582	472	7	73	517	306
TA	3	542	754	572	7	335	477	397	6	60	340	223
SO_4	3	2773	3700	3150	7	720	1580	1320	7	56	2140	535
Cl	3	0.0	16	0.0	7	5.4	12	9.0	7	3.0	12	5.5
F	1	--	--	0.6	5	0.3	0.6	0.5	5	0.1	0.5	0.3
N	4	0.0	0.05	0.01	6	0.0	0.95	0.03	7	0.02	0.45	0.13
P	4	<.01	0.01	<.01	6	0.01	0.05	0.03	7	0.01	0.41	0.02

NOTE: Measurements are expressed in mg/l.

[a]Less than 0.99 cfs.

[b]Greater than 0.99 cfs.

TABLE 107. Summary of the miscellaneous constituent and trace element concentrations measured in the Pumpkin Creek drainage (mg/l).

	Miscellaneous Constituents and Total Recoverable Metals				Dissolved Metals[a]
	N	Min	Max	Med	
NH_3-N	2	0.02	0.04	0.03	
Si	1	--	--	8.4	
TOC	2	10	30	20	
Ag					<.002
Al					0.03
As	6	<.001	0.004	<.01	
B	8	<.10	0.40	0.37	0.34
Ba					0.09
Be					<.003
Bi					<.013
Cd	16	<.001	<.01	<.001	0.0
Co					<.013
Cr					<.013
Cu	16	<.01	0.04	<.01	0.01
Fe	16	<.04	13	0.34	0.07
Ga					<.006
Ge					<.02
Hg	9	<.0002	0.0026	<.001	
Li					0.04
Mn	16	.01	.36	.07	0.01
Mo					<.01
Ni					<.013
Pb	5	<.01	0.05	<.05	<.013
Sn					<.013
Sr	4	1.3	3.7	1.6	1.1
Ti					<.009
V	4	<.10	<.10	<.10	<.013
Zn	16	<.01	0.08	0.01	0.0
Zr					<.030

[a] N = 1 in all cases

addition, some water quality information was collected by the state WQB from the upper reaches of Pumpkin Creek near Volborg (USDI 1968), and these data have also been included in tables 106 and 107. The trace element and miscellaneous constituent data from all reaches were combined for the statistical analyses; this information is also presented in tables 106 and 107.

Pumpkin Creek can also be characterized by its high TDS concentrations and its distinct sodium sulfate water in all reaches during all seasons. The upper reach of Pumpkin Creek also had greater magnesium concentrations than calcium, although this relationship became much less noticeable near the stream's mouth. Fluoride, chloride, and potassium were insignificant constituents of the Pumpkin Creek samples, and magnesium-calcium and bicarbonate were the secondary cations and anion. TDS concentrations were highest in the upper reach of Pumpkin Creek near Volborg; they declined to the creek's mouth, showing a downstream improvement in water quality, particularly during high-flow periods.

The waters in Pumpkin Creek were moderately saline in the upper reach, slightly saline in the lower reach at low flows, and non-saline downstream about 40 percent of the time during the high-flow periods. The waters, however, were very hard in most cases. Annual median TDS-SC levels in Pumpkin Creek near Miles City (1931 mg/l and 2564 μmhos/cm) were slightly less than the median values obtained in Hanging Woman and Otter creeks. TDS-SC levels were about 3.4 times and 3.0 times greater than the annual median levels of the Tongue River near Miles City (table 92). But the effect of Pumpkin Creek on the salinity levels of the mainstem near Miles City is slight. For example, at the median flows of the Tongue River near Miles City and lower Pumpkin Creek (about 0.7 cfs), this tributary would increase the annual median TDS level of the mainstem only about 0.4 percent.

Median phosphorus and nitrogen (including ammonia-N) concentrations were low in Pumpkin Creek and below the reference levels that indicate eutrophy. Only 18 percent of the samples from the stream had phosphorus in excess of the reference criteria, 12 percent had excessive nitrogen, and 6 percent had both phosphorus and nitrogen in excess of the reference criteria. With the exception of salinity (TDS-SC) levels and some of the dissolved constituents, the remaining major parameters did not suggest water quality problems. Pumpkin Creek has been designated a $B\text{-}D_3$ stream by the State of Montana. Sample pH values, although high in correspondence to the high alkalinities, were in accord with the criteria of a $B\text{-}D_3$ classification. Values of pH were lowest at the Miles City station during the high-flow regimes when alkalinities were also low. The DO concentrations of the creek and the median fecal coliform counts were also in accord with the standards for a $B\text{-}D_3$ stream; however, high fecal concentrations were obtained in occasional samples (15 percent) that exceeded the state recommendations for grab samples (Montana DHES, undated) and the NTAC (1968) permissible criteria for a surface water public supply. BOD_5 values were also low in Pumpkin Creek, particularly during low flows, which indicates that no organic pollution reaches the stream. The slightly higher BOD_5 concentrations during the high-flow periods, along with the above average TOC levels, indicate inputs of some organic material during this phase of the hydrologic cycle, but these somewhat higher BOD_5 concentrations were most likely derived from natural sources, such as organic pickup in association with the overland flow that develops during these runoff events.

TSS-turbidity levels were greatest in the lower reach and during the periods of high flow; this has been observed on many streams in the Yellowstone Basin. At low flows, TSS concentrations and turbidity values would not be at levels high enough to significantly degrade the quality of the creek's water. At high flows, TSS and turbidity values were at sufficient levels to detract from the better quality of water characteristic of the stream at this time due to lower salinities. Turbidity during high flows would generally preclude the use of the stream as a public supply (NTAC recommendation, table 9), and the median values of turbidity and TSS during runoff events (tables 106 and 107) could adversely affect the aquatic biota. But on a yearly basis, the annual median TSS and turbidity values of Pumpkin Creek (29.3 mg/l and 15 JTU) would indicate a good fishery (European Inland Fisheries Advisory Commission 1965). As a result, salinity is the major detractor from the water quality in this stream, particularly in an upstream direction.

Pumpkin Creek would provide a poor source of water for public and domestic supply and throughout the entire year in all reaches because of its high TDS levels. Only 12 percent of the samples had TDS concentrations below 500 mg/l, and all of these were obtained at high flows (29 percent of the runoff collections). The high levels of sulfate and the extremely hard nature of the water in Pumpkin Creek would further preclude domestic use. Only 12 percent of the samples, all of which were collected at high flows, had sulfate concentrations less than 250 mg/l, and 88 percent of the samples had very hard waters.

Pumpkin Creek would provide a poor source of water for stock; this would be most apparent in the upper reach near Volborg where the waters would be classified as unfit for most farm animals (Seghetti 1951). According to the EPA (1973), waters in upper Pumpkin Creek would be "permissible for livestock, (but) unacceptable for poultry and lactating animals" (USEPA 1973), and the TDS concentrations would be above the salinity threshold level for pigs (McKee and Wolf 1974). The waters in the lower reach of Pumpkin Creek were somewhat better for this use and applicable to most stock animals (tables 10-14). According to Seghetti (1951), the lower section of the stream can be classified as fair during low flows to good during high flows for agricultural supply. However, concentrations of individual ions would further delimit the value of this water as a source for stock. In upper Pumpkin Creek, sulfate concentrations were well above the limiting levels for stock, with sodium and magnesium slightly in excess of the proposed thresholds above which physiological effects may occur in consuming animals. In the lower reach, sulfate concentrations were also in excess of the limiting levels at low flows; they were greater than the threshold value for a large percentage of the time during the high-flow period. Consequently, the waters in Pumpkin Creek may be considered poor for most beneficial uses.

Samples from Pumpkin Creek indicate that it has a very high salinity hazard for irrigation in its upper reach and also in its lower reach during low flows. In addition, the upper reach and the lower reach of Pumpkin Creek at low flows would also have a high-to-very high sodium hazard for irrigation due to the sodic nature of the water and the high SAR values. Because of this latter feature, Pumpkin Creek would be less suitable as a source of water for irrigation at low flows than Hanging Woman or Otter creeks, which have lower sodium hazards.

Low discharges may preclude the use of Pumpkin Creek for irrigation through a large part of the year, judging from the fact that its flows were less than 1.0 cfs on about 62 percent of the days monitored by the USGS (USDI 1966-1974a). With such a high proportion of low-flow days, Pumpkin Creek would have a poor class of water for a major part of the year. Nevertheless, about 3600 acres of land are irrigated from Pumpkin Creek (USDI 1974), but this usually occurs during the high-flow periods when water quantity and quality is greater.

Waters in the upstream reach would probably be unacceptable for irrigation due to its extremely high TDS-SC and sulfate levels. The concentrations of these variables generally exceeded the minimum limits prescribed for a Class III water, and the TDS concentrations were greater than the maximum level listed by the EPA (1976) for application to tolerant plants. The best water quality for irrigation develops in Pumpkin Creek at high flows, which occur over about 38 percent of the year. It would seem that the lower TDS-SC and sulfate concentrations downstream near Miles City at low flows would indicate a Class II water at these times, but the lower reach probably would retain its Class III water at low flows due to the high SAR values (tables 106 and 107). The median SAR, sulfate, and TDS-SC values indicate that the water is more appropriately Class II also, but water with TDS concentrations between 1000 mg/l and 2000 mg/l "may have adverse effects on many crops and requires careful management practices" (USEPA 1976). Careful management practices would therefore be necessary in the use of this water for irrigation, even though it would be applicable to a wider variety of crop and forage species as a result of its lower salinities.

Trace element levels in Pumpkin Creek did not generally suggest water quality problems (tables 106 and 107); TR concentrations of most constituents were typically below the reference criteria. This includes Si (concentrations were below the national average), NH_3-N (at non-toxic levels), As, B, Cd, Cu, Pb, Sr, V, and Zn. Almost all of these constituents had low dissolved concentrations. Although based on only one sample analysis, low dissolved concentrations eliminate the following trace elements as potential causes of water quality problems: Ag, Al, Ba, Be, Bi, Co, Cr, Ga, Ge, Li, Mo, Ni, Sn, Ti, and Zr. Only Fe and Mn had TR concentrations high enough to exceed water quality criteria; the dissolved levels of Fe and Mn were well below the reference criteria for water use. Additional analyses are necessary in order to adequately judge the potential effects of TR and dissolved concentrations of trace elements in Pumpkin Creek.

POWDER RIVER DRAINAGE

Powder River Mainstem

The Powder River is the most eastern of the major tributaries that join the Yellowstone River in Montana. Its headwaters are on the eastern slopes of the Bighorn Mountains in Wyoming; it has an extensive reach in Wyoming and an extensive prairie reach and drainage in Montana before it joins the Yellowstone near Terry (USDI 1968). Poor water quality might be expected in the Powder River due to its long length, providing opportunities for accessory inputs.

On the basis of average annual discharge, the Powder River is about 1.44 times larger than the Tongue River, but only 16 percent as large as the Bighorn River (USDI 1974). However, on certain days, flows in the Tongue River exceed those in the Powder. The Powder River has an average annual discharge equal to about 5 percent of that in the Yellowstone River at Miles City. As a result, the Powder could have a significant effect on mainstem quality, particularly if it has significantly poorer quality than the lower Yellowstone. However, very little water quality information is available on the Powder River. Since 1965, the USGS has sporadically sampled two stations on an upper reach of the Powder River above Broadus (table 3), and the USGS has initiated a monthly sampling program on this segment near Moorhead and at a downstream station near its mouth close to Locate. Also, the state WQB has collected several samples from the river at various locations along its length in Montana. The available USGS data and the state WQB data were combined to represent two segments of the stream--an upper reach from near Broadus to Moorhead close to the Montana-Wyoming border, and a lower reach below Broadus from near Locate to near Terry. With this combination of data, water quality information were sufficient for a seasonal classification of the two segments as summarized in tables 108 and 109.

Of the major streams in the Yellowstone River Basin, the Powder River is unusual to have a definite sodium sulfate water with high TDS-SC levels, even in its upper Montana segment. Many of the other large streams in the Yellowstone Basin have calcium bicarbonate water, the Clarks Fork and Tongue rivers have calcium-sodium bicarbonate water, and the Bighorn River has calcium-sodium sulfate water.

The major tributaries to the Yellowstone above Billings, including the Clarks Fork River, usually have TDS-SC levels less than 300 mg/l and 400 μmhos/cm in the upper reaches, and TDS-SC levels typically less than 500 mg/l and 600 μmhos/cm near their mouths (Karp et al. 1976a). The major streams below Billings (the Little Bighorn, Bighorn, and Tongue rivers) have SC levels ranging between 350 and 950 μmhos/cm in the upper reaches, depending upon season and the particular stream, and between 550 and 1025 μmhos/cm in the lower segments. TDS concentrations in these rivers range between 200 and 625 mg/l in the upper segments and between 300 and 700 mg/l in the lower sections of the streams, depending upon season and drainage. The TDS-SC levels of the Powder were significantly greater than these values; TDS levels varied between 950 and 1650 mg/l, and SC levels between 1260 and 2175 μmhos/cm. The Powder River near its mouth had median TDS levels 2.74 to 4.18 times greater, and SC levels 2.30 to 3.62 times greater than those of the Yellowstone River near Miles City, depending upon reach and season.

Evidence of the greatest differences between the Powder and Yellowstone rivers was obtained during the low-flow August-October period and the May-July runoff period of the year. The high TDS concentrations of this major Yellowstone tributary may be related to its long length from its headwaters in Wyoming to its mouth in Montana. The Bighorn River, which also has an extensive drainage system, also had comparatively high TDS levels (table 48).

Flow patterns in both reaches of the Powder River (tables 108 and 109) were generally similar to those of the other large streams in eastern Montana. Flow was low in the late summer-early fall. Peak flows occurred during the May-July period due to runoff from the river's mountainous headwaters. Median seasonal flows consistently increased from the summer low through the winter and spring months to the May-July maximum, and a secondary peak in flow became

TABLE 108. Summary of the physical parameters measured in the Powder River near Moorhead-Broadus.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	18	7.7	302E	109	16	87	1520	234	8	340E	4930	664	14	486	12,060	845
Temp	19	2.0	28.5	14.2	21	0.0	5.0	0.0	10	0.5	10.0	3.0	15	9.0	26.0	17.5
pH	19	7.7	8.6	8.30	19	7.53	8.6	7.9	8	7.5	8.3	7.85	15	7.5	8.40	8.0
SC	18	1525	5000	2175	20	775	2800	2040	9	850	2300	1750	15	624	2950	1350
TDS	18	1240	4080	1635	22	584	1710	1369	9	642	1755	1390	15	461	2230	954
Turb	10	5.2	390	30	12	20	300	68	5	125	1100	300	7	180	8120	220
TSS	5	12.0	972	112	6	66	644	165	2	1240	2910	2075	4	1223	8900	1914
DO	18	7.6	11.6	9.4	18	3.0	12.6	10.4	9	7.0	12.0	10.4	14	5.2	9.6	7.8
BOD	12	0.7	4.1	2.0	12	1.5	8.1	3.1	6	2.1	10.6	3.9	11	1.8	9.0	2.4
FC	9	0	100	24	11	0	270	20	5	20	180	100	11	20	4100	350
Ca	15	105	228	150	19	79	160	130	9	58	143	130	14	52	130	90
Mg	15	56	132	73	19	25	72	56	9	25	64	56	14	12	50	35
TH	18	493	1110	720	18	431	700	565	9	248	619	560	15	196	1220	370
Na	12	190	300	220	16	66	310	240	8	62	320	250	10	58	200	139
K	10	6.0	17	8.3	10	3.4	7.3	6.1	5	5.3	8.0	6.4	6	3.1	6.3	4.6
SAR	10	3.0	5.4	4.1	13	4.1	5.3	4.5	7	1.5	5.9	5.1	9	1.8	4.2	3.5
HCO_3	9	231	294	261	12	254	427	314	5	150	295	272	8	116	189	162
TA	12	190	246	217	12	209	350	259	5	123	242	223	10	95	160	139
SO_4	16	570	1240	820	17	280	730	570	9	260	850	660	15	193	690	439
Cl	13	35	230	93 (2.0?)	19	36	260	160	9	10	180	120	14	23	100	75
F	12	0.3	0.5	0.4 (2.2?)	12	0.3	0.5	0.4	7	0.2	0.7	0.6	8	0.0	0.6	0.4
N	16	0.0	0.40	0.03	20	0.18	0.64	0.3	9	0.20	0.5	0.40	15	0.0	0.93	0.25
P	16	0.0	1.9	0.04	20	0.01	0.82	0.08	9	0.02	1.7	0.40	15	0.01	2.9	0.3

NOTE: Measurements expressed in mg/l.

TABLE 109. Summary of the physical parameters measured in the Powder River near Locate-Terry.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	8	33	265	166	6	154	700	308	4	732	4296	1520	7	67	3600	1670
Temp	7	4.5	19.5	17.3	7	0.0	2.5	0.0	4	1.0	18.0	4.3	7	10.5	24.5	17.5
pH	8	8.17	8.4	8.3	7	7.7	8.5	8.20	4	7.80	8.3	8.20	8	7.68	8.20	8.10
SC	8	1483	2250	2020	7	1700	2400	2140	4	1220	2998	2025	8	882	2309	1268
TDS	8	1142	1870	1529	7	1210	1800	1460	3	993	2205	1530	7	629	1797	1050
Turb	7	4	5800	160	7	10	200	40	3	1000	>1000	1150	8	41	2150	505
TSS	7	33	740	282	5	92	1750	206	4	4130	62,800	4965	7	1070	10,600	5530
DO	6	8.0	12.4	10.3	7	11.2	12.8	11.9 (2.7?)	4	5.1	10.8	7.3	7	6.4	9.9	7.6
BOD	1	--	--	6.1	1	--	--	4.6	2	2.9	5.9	4.4	4	2.1	6.4	5.7
FC	6	30	7900	141	5	3	66	10	3	23	3100	27	7	65	1300	360
Ca	8	74	145	113	7	97	160	120	3	77	190	120	7	62	131	81
Mg	8	53	80	56	7	43	74	54	3	35	79	56	7	20	62	36
TH	8	470	615	517	7	420	680	520	3	340	802	530	7	236	580	350
Na	8	150	350	273	7	210	340	260	3	190	375	260	7	98	350	180
K	7	6.4	8.6	7.5	6	6.1	8.7	6.8	2	7.4	8.1	7.8	6	4.3	10	5.3
SAR	8	3.0	6.3	5.2	7	4.0	5.9	4.7	3	4.5	5.8	4.9	7	2.7	6.5	4.2
HCO_3	9	218	345	258	6	267	454	303	3	179	265	254	7	123	238	217
TA	8	179	241	215	7	219	372	250	3	147	217	209	7	101	195	178
SO_4	8	545	970	745	7	500	740	600	3	490	1190	720	7	300	935	450
Cl	8	36	140	78 (4.5?)	7	106	220	150	3	72	116	100	7	21	97	81
F	7	0.2	0.4	0.3	6	0.3	0.4	0.4	2	0.4	0.5	0.5	7	0.4	0.5	0.4
N	7	0.0	0.2	0.02	7	0.2	0.57	0.3	4	0.07	0.74	0.47	7	0.0	0.38	0.18
P	7	0.01	0.72	0.10	7	0.03	0.62	0.10	4	0.01	1.1	0.51	7	<.01	1.5	0.04

NOTE: Measurements expressed in mg/l.

evident during the March-April period, probably due to runoff from the lowlands area. At Locate, this secondary flow peak was almost equivalent to the May-July runoff value. Median flows also increased significantly in a downstream direction in the Powder, from Moorhead to Locate, with this increase greatest during the two runoff periods. The downstream percentage increases by season were: August-October, 52.3 percent; November-February, 31.6 percent; March-April, 128.9 percent; and May-July, 97.6 percent. The Powder drainage in Montana therefore appears to contribute significantly to the volumes of water at the river's mouth.

Although the Powder River had an average annual discharge equal to about 5 percent of that in the Yellowstone upstream of its confluence, this percentage varied considerably between seasons as follows: August-October, 1.8 percent; November-February, 4.1 percent; March-April, 16.6 percent; and May-July, 6.3 percent. These variations in flow and the high TDS concentrations indicate that the Powder River could have a significant salinity loading effect on the mainstem, particularly during the March-April period.

The potential effect of the Powder and Tongue rivers in increasing mainstem salinities is shown in table 110.

TABLE 110. Calculated percentage increases in TDS of the Yellowstone River from Miles City to below the confluence of the Powder River.

	Powder River	Powder plus Tongue Rivers	Tongue River
Aug-Oct	5.1	5.9	0.8
Nov-Feb	8.1	9.1	1.0
March-April	28.9	28.7	-0.2
May-July	18.2	19.4	1.2
Annual Median	14.5	15.2	0.7

As indicated in table 110, the effects of the Tongue River would be negligible during the March-April season and small through the rest of the year. The Tongue would increase the annual median TDS level of the mainstem by only 0.7 percent, but the Powder would increase it by 14.5 percent. The effects of the Powder are apparently smallest between August and February when flows in the tributary would be low, and these effects would increase through those months from summer to winter in correspondence to the increase in Powder flows. The influences of the Powder on mainstem salinities are greatest during the March-April period when its discharge would be high with high TDS concentrations. Intermediate effects would be obtained during the May-July runoff period when TDS levels in the Yellowstone River are low.

Except during the March-April season, the median seasonal TDS concentrations in both reaches of the Powder River were inversely related to flow. The unusually high TDS-SC levels of the March-April season corresponded to the secondary peak in flow; the high salinities at this time probably reflected inputs from lowland runoff with an inferior water quality. Median TDS and SC levels tended to increase downstream in the river from Moorhead to Terry, although increases were not totally consistent in all seasons or for both parameters. They were highest during the November-April period, and slightly lower in the August-October season. Overall, downstream changes in Powder salinity were small. An annual median increase of 1852 mhos/cm to 1872 mhos/cm (1.1 percent) was evident downstream in SC from the Moorhead to the Locate reach. An annual median increase of 1335 mg/l upstream to 1387 mg/l (3.9 percent) near Locate in TDS also was evident between the two segments. TDS:SC ratios were 0.72 near Moorhead-Broadus and 0.74 at Locate-Terry. Although TDS loads increased greatly downstream in the Powder River because of accessory TDS inputs (from 1546 tons per day to 3067 tons per day annually), the overall TDS concentrations of the Montana input waters would not be very much higher than those of the mainstem, or significantly different from the TDS concentrations of small prairie streams. The following measurements were determined from the TDS load differences between reaches: August-October, 1326 mg/l; November-February, 1748 mg/l; March-April, 1639 mg/l; May-July, 1148 mg/l; and annually, 1444 mg/l. A fairly large percentage of the salt load in the Powder River was apparently obtained in Wyoming. Median values were between 70 percent and 71 percent during low flows, between 40 percent and 46 percent during the high flows, and 50 percent annually.

Waters in the Powder River were extremely hard (Bean 1962, Durfor and Becker 1964) and slightly saline (Robinove et al. 1958) in both reaches in all seasons; 83 percent of the samples collected from the Powder had TDS concentrations in excess of 1000 mg/l. Sulfate and sodium, the dominant cation and anion, accounted for 60 percent to 62 percent of the annual median TDS concentration. Calcium and bicarbonate were the secondary ions, and fluoride and potassium were insignificant constituents.

The Powder River had high chloride concentrations, an unusual occurrence in the Yellowstone Basin. A large proportion of the chloride loading in the Powder was apparently derived from its Wyoming drainage, judging by the high chloride levels obtained from the Moorhead-Broadus samples (table 108). Chloride concentrations then tended to decrease slightly downstream to the Locate reach. But the significant increases in chloride loads below Moorhead indicated supplemental inputs of chloride from the Montana portion of the river's drainage. Calculations based on the differences of chloride loads between reaches indicated that these Montana inputs would have overall chloride concentrations ranging between 49 mg/l and 118 mg/l, depending upon season.

Calcium and magnesium tended to decrease slightly downstream, as did total hardness, contrasting to the river's significant downstream increase in sodium levels. As a result, the Powder River tended to become more sodic in character towards its mouth after passing through its prairie drainage, showing a definite downstream decline in its Ca:Na ratios. Sulfate and bicarbonate concentrations remained fairly constant throughout the river, and $HCO_3:SO_4$ ratios did not decrease downstream in the Powder River as they did in the Yellowstone River and most other streams. Calcium concentrations exceeded magnesium levels in both reaches of the Powder River. Ca:Mg ratios tended to increase from the low- to the high-flow periods, and they tended to decline slightly downstream.

The slightly saline nature of the Powder River and the high concentrations of some ionic constituents would be expected to lower the value of this stream for many water uses. Obviously, the river would not be expected to be a good source of water for public supply due to its high TDS, sulfate, and hardness

(Ca + Mg) levels. About 99 percent of the samples from the Powder had TDS and sulfate concentrations in excess of the permissible criteria, recommendations, and standards established by the NTAC (1968) and the EPA (1973) for surface water public supply, and by the Public Health Service (1962) for drinking water (table 9). About 66 percent of the Powder samples had turbidity levels in excess of the permissible level recommended for public supply (NTAC 1968). These levels were most common during the March-to-July high-flow season and they were highest in a downstream direction.

The water in the Powder River would not be of ideal quality for irrigation because of a high salinity hazard during most of the year, along with a medium sodium hazard at certain times of the year due to the river's high sodium concentrations and SAR values. The sodium hazard was greatest in the lower segment near Locate and most common during the August-April period.

As indicated by tables 15, 16, 108, and 109, the water in the Powder would be mostly Class II and should consequently be used for irrigation with certain restrictions. As noted by the EPA (1976), waters like those in the Powder with salinities typically between 1000 and 2000 mg/l of TDS--as in 75 percent of the samples from the Powder River--". . . may have adverse effects on many crops . . . (requiring) careful management practices." The best water quality for irrigation from the Powder occurs, of course, during the high-flow, low TDS runoff period of May-July; however, the high TSS concentrations typical of this season may complicate irrigation use (USEPA 1973).

Salinities in the Powder River may have some detrimental effects on the stream's aquatic biota since TDS concentrations and SC levels commonly exceeded 670 mg/l and 1000 mhos/cm, and were often greater than 1350 mg/l and 2000 mhos/cm, as shown in table 111.

TABLE 111. Percentage of Powder River samples with TDS and SC concentrations in particular ranges.

	Upper Reach			Lower Reach		
	Low Flow	March-April	Runoff	Low Flow	March-April	Runoff
TDS (mg/l)						
<670	3	11	20	0	0	29
670-1350	23	33	67	33	33	43
>1350	75	56	13	67	67	29
SC (μmhos/cm)						
<1000	5	22	20	0	0	38
1000-2000	37	33	73	40	50	38
>2000	58	44	7	60	50	25

However, suspended sediment and turbidity levels of the Powder River may affect the stream's biota more than its salinity. The Powder should provide a good quality water for all livestock (USEPA 1973, McKee and Wolf 1974, Seghetti 1951), but the river's sulfate concentrations appeared to be at levels that would detract from this good quality. As in many eastern Montana streams, sulfate concentrations were commonly in excess of the threshold levels for domestic animals (California WQCB 1963). TDS concentrations would not affect animals physiologically, but the sulfate levels of the Powder samples may do so, conceivably reducing stock production.

Of the major parameters summarized in tables 108 and 109, salinity (TDS-SC), suspended sediment, turbidity, total hardness (calcium plus magnesium), SAR (sodium), sulfate, and possibly the critical nutrients (phosphorus and nitrogen) indicated water quality problems in the Powder River. None of the remaining major parameters (fluoride, chloride, bicarbonate-total alkalinity, and potassium) appeared to be significant.

The Powder River has been designated a $B\text{-}D_3$ warm-water stream by the State of Montana. This classification is appropriate considering the high maximum water temperatures obtained from the stream during warm-weather periods; the pH values and DO concentrations were also in accordance with a $B\text{-}D_3$ classification. Low DO levels were measured in a few of the samples from the stream, but they were generally obtained in conjunction with high TSS levels. For the most part, the river was very close to oxygen saturation throughout its length, with median DO levels within 5 percent to 6 percent of saturation (table 112).

The high DO levels of the Powder River suggest that no substantial organic pollution reaches the stream; and this was substantiated in the upper reach by the low BOD_5 concentrations. BOD_5 values tended to increase downstream to the lower reach during all seasons, which suggests organic inputs between Moorhead and Terry. This was also indicated by the associated downstream increase in TOC levels and by the slight downstream decline in median DO saturation. These downstream increases in BOD_5 were small, and occasionally high values approaching 10 mg/l can be expected as a natural occurrence. The downstream BOD_5 concentrations near Locate were at insufficient levels to indicate that extensive organic pollution reaches the river. The small organic inputs to the Powder River seem to be more like those obtained from natural sources than from municipal effluents, although the town of Broadus may contribute (USDI 1968). The annual median BOD_5 loading to the Powder River would amount to about 8 tons per day, or only 8 mg/l.

Fecal coliform concentrations also increased downstream in the Powder River, but not consistently through all seasons. Annual median fecal concentrations increased slightly from 117 colonies per 100 ml near Moorhead-Broadus to 133 colonies per 100 ml near Locate-Terry. Coliform concentrations were not noticeably high in either reach, except during the runoff season, and seasonal median concentrations were within the state's average criteria in all months except May to July. About 16 percent of the samples had coliform concentrations in excess of the state's criteria for grab samples. This percentage was slightly greater than the 10 percent leeway prescribed by the state for a 30-day period (table 8). However, 78 percent of these grab sample excesses occurred during the high-flow period when high fecal counts would result from overland runoff. Only 7 percent of the grab samples had fecals in excess of the NTAC (1968) and the EPA (1973) recommendations for public supply. Fecal strep levels in the Powder River were also low (table 112), and the annual median fecal coliform:fecal strep ratio (0.83) indicates a "predominance of livestock and poultry

TABLE 112. Summary of miscellaneous constituent and trace element concentrations measured in the Powder River.

	Near Moorhead-Broadus								Near Locate-Terry							
	Miscellaneous constituents and total recoverable metals[a]				Dissolved metals[b]				Miscellaneous constituents and total recoverable metals				Dissolved metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Color	4	9	45	20												
CN	8	0.0	.01	0.0												
DO[c]	15	35	108	95					15	20	104	94				
Fecal strep									12	31	970	110				
MBAS	12	0.0	.06	.005												
NH_3-N	33	0.0	0.61	0.08												
Si	20	3.3	12	6.8					15	5.5	12	8.3				
TOC	1	--	--	6					5	6.6	53	33				
Ag					14	0.0	<.003	0.0 (.002)								
Al	6	3.6	270	14	4	0.0	.03	.02								
As	10	<.001	0.350	0.006	13	0.0	.006	0.0	9	<.001	0.060	0.008	5	0.0	.002	.001
B	6	<.10	0.42	0.19	28	.10	.89	.26	6	<.10	0.20	0.18				
Ba					6	0.0	.07	0.0								
Cd	23	0.0	0.02	.003	14	0.0	.002	0.0	15	<.001	0.01	<.01	5	0.0	.001	0.0
Co					6	0.0	<.025	.001	5	<.05	0.15	<.05	4	0.0	.001	.0005
Cr	12	0.0	0.50	<.01					6	0.0	.10	.03	5	0.0	.01	0.0
Cu	25	<.01	0.90	0.02	16	0.0	.030	.009	15	<.01	0.22	0.02	5	.003	.008	.005
Fe	23	0.09	600	6.7	19	0.0	.399	.030	15	0.03	170	6.3	5	.02	.15	.06
Hg	12	0.0	.0011	<.001	11	0.0	.0009	.0002	9	<.0002	<.001	0.0002	5	0.0	.0003	.0001
Li					2	.06	.06	.06								
Mn	21	<.01	6.8	0.26	15	0.0	.240	.017	14	0.03	14.0	0.46	5	0.0	.01	0.0
Mo					13	0.0	.031	.003								
Ni					14	0.0	.030	.005								
Pb	11	<.01	0.80	<.10	16	0.0	.008	.0005	10	<.10	0.20	<.10	5	0.0	.004	.002
Se	9	0.0	.008	.002	10	0.0	.011	.002	5	.001	.005	.002	5	.001	.003	.002
Sr					6	1.20	2.43	1.43	3	.50	1.5	1.4				
V					6	0.0	<.006	.0017	3	<.05	<.10	<.05				
Zn	21	<.01	5.0	0.05	16	0.0	.180	.020	15	<.01	1.8	0.05	5	.02	.04	.02

NOTE: Measurements are expressed in mg/l.

[a]V: 0.05, N=1.

[b]Be: <0.01, N=11; Cr: <.01, N=9.

[c]DO expressed as percentage of saturation.

wastes in mixed pollution" (Millipore Corporation 1972). Data presented here indicate that bacterial contamination of the Powder River, including that from human sources, is not a major water quality problem.

Phosphorus concentrations were high in both reaches of the Powder River (tables 108 and 109); the median concentration exceeded the reference criteria for eutrophication in 75 percent of the seasonal periods. About 60 percent of the samples from the Powder had phosphorus levels in excess of 0.05 mg P/l, and 49 percent of the samples had concentrations greater than the reference levels established by the EPA (1974b) for eutrophication. The high phosphorus levels were possibly related to the river's high TSS concentrations as the median phosphorus values tended to increase downstream from Moorhead to Locate except during the May-July period.

Nitrogen concentrations were also high in the Powder River except during the summer. Nitrogen concentrations showed warm-weather low median values in August-October and high concentrations during winter and spring. However, the river was nitrogen-limited, with median nitrogen concentrations lower than or closer to the reference level than was phosphorus. About 32 percent of the samples from the Powder River had nitrogen concentrations in excess of 0.35 mg N/l, but only 1.2 percent had levels in excess of the EPA's (1974b) more stringent criteria for eutrophication. The river was non-eutrophic during the critical summer season due to the low median nitrogen concentrations, but if median ammonia concentrations are considered (table 112), the river was potentially eutrophic during the less critical and cooler November-to-April period because both median phosphorus and nitrogen levels would exceed reference levels at this time. During the May-July period, the river was limited in either nitrogen (Moorhead reach) or in both nitrogen and phosphorus (Locate reach), although the upper reach had median concentrations approaching eutrophic levels. The Powder River came closer to eutrophy than most of the streams and reaches in the Yellowstone Basin. On a yearly basis, about 29 percent of the samples from the Powder River would be expected to have both nitrogen and phosphorus in excess of their reference criteria, but only 0.4 percent of the samples would have both of these nutrients in excess of the reference levels established by the EPA (1974b).

Probably the most distinctive water quality features of the Powder River in all reaches are its high suspended sediment concentrations and its high turbidity values. At low flows median TSS concentrations in the Powder near Locate were between 3.3 and 8.9 times greater than those in the Yellowstone River near Miles City in comparable seasons. Median turbidities were between 4.4 and 13.9 times greater in the Powder than in the mainstem. Maximum TSS concentrations in the Powder near Locate during the low-flow seasons were as much as 9.7 times higher than the maximums recorded at low flows in the Yellowstone above the confluence of the Powder.

Such high TSS concentrations were most noticeable during the March-July high-flow periods at which times high median TSS-turbidity values were obtained in excess of 2000 mg/l and 200 JTU and particularly high values were obtained from some grab samples. The 62,800 mg/l value recorded in table 109 is especially noticeable; 33 percent of the sample volume was due to settleable solids (Karp et al. 1975). At high flows, median TSS levels in the Powder near its mouth were between 64 times (during March-April) and 12 times (during May-July) higher than those in the Yellowstone near Miles City, and maximum values were between 149 times and 9.3 times higher than the maximums obtained from the mainstem. High flow turbidities were between 3.6 times (during March-April) and 32 times (during May-July) higher than those in the Yellowstone near Miles City, and maximum values were between >1.3 times and 11 times higher than the maximums obtained from the mainstem. Consequently, the Powder River would be expected to have a considerable influence on mainstem water quality.

The potential of the Powder and Tongue rivers to increase mainstem suspended sediment concentrations is shown through the loading calculations presented in table 113.

TABLE 113. Calculated percentage increases in TSS in the Yellowstone from near Miles City to below the confluence of the Powder.

	Powder River	Powder plus Tongue Rivers	Tongue River
Aug-Oct	14.2	13.2	-1.0
Nov-Jan	9.2	6.3	-2.9
March-April	900.0	863.0	-37.0
May-July	66.7	63.6	-3.1
Annual Median	84.6	80.8	-3.8

These percentages suggest that the Tongue River should have a negligible effect on the TSS levels of the Yellowstone mainstem. Comparisons of the TSS data in tables 57 and 92 indicate that inputs from the Tongue River would reduce the TSS concentrations in the mainstem below the confluence (between 0.6 percent and 2.7 percent) since the Tongue had lower TSS levels than the Yellowstone near Miles City during all seasons. As shown in table 113, the Tongue, through the addition of water volume, would negate the subsequent effects of the Powder on mainstem TSS concentrations. The Powder River would significantly increase mainstem TSS levels, but this increase would be small during the August-to-October period when flows and TSS concentrations would be low. The most significant effects would be obtained during the March-April season (the secondary runoff peak) when flows of the Powder would be high in comparison to those of the mainstem. Intermediate effects would be observed during the May-July season because the high flow-high TSS inputs from the Powder would be less noticeable due to the high Yellowstone flows and the high TSS levels already developed in the mainstem from upstream sources. On a yearly basis, the Powder River could increase the annual median TSS level of the Yellowstone about 85 percent; the Tongue would decrease TSS levels by about 4 percent. The Powder River is therefore responsible for a net annual median accrual in TSS of nearly 81 percent from Miles City to Fallon.

Suspended solids concentrations were related to flow in the Powder River (tables 108 and 109). Median TSS concentrations consistently increased downstream through all seasons, indicating a downstream degradation in water quality. Median TSS concentrations increased by the following percentages from the Moorhead-Broadus to the Locate-Terry reach in each season: August-October, 152 percent; November-February, 25 percent; March-April, 139 percent; May-July, 189 percent. Annual median TSS levels increased from 914 mg/l upstream to

2365 mg/l near Locate, an increase of 159 percent. Median TSS loads in the upper reach of the Powder ranged from 33 tons per day to 104 tons per day during low flows (August-February) and ranged from 3720 tons per day to 4367 tons per day during high flows (March-July). Median TSS loads were significantly higher in the lower reach, ranging between 126 tons per day and 171 tons per day and between 20,376 tons per day and 24,935 tons per day for the same seasonal periods. This marked downstream increase in TSS loading in the river suggests significant inputs of suspended sediment from the Montana portion of its drainage. Comparisons of the TSS loads in the two reaches indicate that the Wyoming portion of the Powder drainage would contribute only 18 percent to 26 percent of the suspended sediment in the river between March and October and 61 percent during the winter. The drainage above Moorhead would contribute between 40 percent and 71 percent, depending upon flow, of the river's TDS levels.

Loading calculations indicate that inputs of water from the Montana drainage would require median TSS concentrations between 336 mg/l and 507 mg/l during low flows, and between 7207 mg/l and 9234 mg/l during high flows in order to account for the increase in suspended sediment in the Powder from Moorhead to its mouth. Such high calculated concentrations indicate that some of the TSS in the river probably comes from natural bank and stream bottom erosion and from channel redefinition in addition to surface water confluences. During low-flow periods with a stable discharge and reduced surface runoff, suspended sediment levels in the Powder are significantly lower and are probably derived from these autochthonous actions. This type of scouring continues throughout the year and would be greatly increased during periods of greater discharge. However, during the high-flow periods, the marked increases in TSS that occur are also probably due in part to inputs from overland flow and surface runoff with the associated erosion of adjacent lands. In any event, the high TSS levels of the Powder indicate readily erodible soils in the region.

The high salinities of the Powder River indicate poor water quality, restricting many beneficial uses of the stream. This is reinforced by the high suspended sediment levels of the stream which further restrict water uses. The Powder would be a poor source of water for public supply because of its high turbidities and its high TDS levels. About two-thirds of the samples collected from the Powder had turbidities in excess of the 75 JTU permissible level for this parameter (NTAC 1968). The high TSS concentrations of the stream could also cause indirect problems and expense to irrigation use by tending ". . . to fill canals and ditches, causing serious cleaning and dredging problems" (USEPA 1973). In addition, the application of irrigation waters with high TSS concentrations could tend ". . . to further reduce the already low infiltration characteristics of slowly permeable soils . . ." (USEPA 1973), assuming that such soils are present in the Powder drainage. The apparent erodibility of the adjacent lands, attested to by the high TSS levels of the river, indicates that this is the case. This in turn further complicates irrigation and other agricultural pursuits through the need for more careful management practices.

The high TSS level of the Powder River would be expected to adversely affect the aquatic biota. The annual median TSS concentrations of the stream suggest a very poor fishery (European Inland Fisheries Advisory Commission 1965). A resident fishery in the Powder might be somewhat different from the rest of the Yellowstone Basin because of its requisite adaptation to high silt loads; the unique occurrence of the sturgeon chub in the Powder drainage is possibly related to this fact (Karp et al. 1975). However, migrant warm-water game fish have been observed in the river, and this stream is apparently used as a spawning ground by various species originating in the Yellowstone (Peterman 1977).

The high TSS-turbidity levels of the Powder may have added effects on the biota by reducing primary production in the stream through the sediment's scouring action on the benthos and through decreased light penetration. Klarich (1976) observed that the high turbidities of the Clarks Fork River apparently kept production below the potential inherent in the river's nutrient concentrations. This could also apply to the Powder River, which had significantly greater turbidities than the Clarks Fork (Karp et al. 1976a). Such restrictions of primary production could affect other aspects of the river's biota.

The Powder River also had high TR concentrations of several trace elements in both reaches (table 112). High TR concentrations of Al, Fe, and Mn have been observed in the Yellowstone River and many other streams, but they were much higher in the Powder samples. The TR concentrations of Co, Cr, Cu, Pb, and Zn were also high in the Powder collections, unlike those in most of the other waters of the Yellowstone Basin.

The low dissolved concentrations of many of the trace elements--Al, Ag, As, B, Ba, Be, Cd, Cr, Co, Cu, Li, Mo, Ni, Pb, Se, and V--indicate no potential water quality problems; maximum and median dissolved concentrations were well below the reference criteria. The high TR levels of the Powder samples were probably related to their high TSS concentrations, and because the Powder had significantly greater suspended sediment levels than most of the other streams, higher TR concentrations might be expected as a natural development. In addition, Si, Sr, MBAS, ammonia, and cyanide were not at levels high enough to indicate water quality problems or pollution inputs. However, the Powder River was somewhat colored (i.e., color greater than 10 units), and this, along with the high turbidities, would indicate aesthetic degradation of the stream.

Therefore, color, Fe, Hg, Mn, and Zn appear to be the greatest potential water quality problems in the Powder River. In the upper reach, the maximum dissolved concentrations of Fe and Mn exceeded the reference criteria for public supply and drinking water (USEPA 1973, NTAC 1968, USDHEW 1962), and, along with zinc, also exceeded the criteria for aquatic life (USEPA 1973). Such problems would be expected to be occasional in the upper segment, however, since the median dissolved concentrations were below the reference levels. In the Locate-Terry reach, Fe, Mn, and Zn concentrations did not indicate water quality problems at any time. Of the metals, mercury appears to be the greatest continual problem to aquatic life and municipal supply; the median and grab sample dissolved concentrations often equalled or exceeded water-use criteria in both reaches (tables 9 and 19). Of the samples from the Powder analyzed, 44 percent had dissolved Hg equal to or greater than 2.0 µg/l, and 56 percent had dissolved Hg equal to or greater than 1.0 µg/l.

Little Powder River

The Little Powder River and Mizpah Creek are the Powder River's two major tributaries in Montana. Mizpah Creek has a rather extensive drainage area located entirely in Montana adjacent to Pumpkin Creek drainage; it joins the Powder from the southwest about 37 miles upstream from Terry near Mizpah (USDI 1968). The Little Powder River has most of its drainage in Wyoming, with only a short 34-mile segment located in Montana before it joins the mainstem from the southeast near Broadus (USDI 1968). Both of these tributaries tend towards intermittency with extremely low flows recorded through part of the year; zero flows have been observed in both streams (USDI 1966-1974a). This intermittency, however, is greatest in Mizpah Creek, particularly in the upper reaches. Montana's Little Powder is probably more perennial than intermittent because it is ponded throughout the year. The annual average discharge of both streams is low--39.6 cfs in the Little Powder River (USDI 1966-1974a). The volume of water in these two tributaries is not at adequate levels to account for a very large percentage of the 290 cfs annual median downstream increase in mainstem flows from Moorhead to Terry. Some water quality data are also available from the USGS on the Little Powder (USDI 1966-1974b) as a result of a past sampling program (table 3). These USGS data, combined with several state WQB collections from the stream, were adequate for a seasonal classification (table 114).

The chemical composition of the Little Powder's water was similar to that of the mainstem. TDS concentrations and SC levels were generally the same in both streams, although they were slightly higher in the smaller river (27 percent to 39 percent on an annual basis). This correlates with the downstream increase in TDS in the Powder. Waters of both streams were extremely hard and slightly saline (Bean 1962, Durfor and Becker 1964, Robinove et al. 1958). The Little Powder River also had a definite sodium sulfate water, and calcium and bicarbonate were the secondary ions. As a result, SAR values were also high. As in the Powder River, calcium concentrations exceeded magnesium levels, and potassium and fluoride were insignificant constituents of the samples. Chloride concentrations were significantly lower than those of the Powder, and potassium concentrations were slightly higher. The critical nutrient concentrations in the Little Powder were also significantly lower than those in the mainstem, and the smaller stream was obviously non-eutrophic during all seasons. TSS-turbidity levels were high in the Little Powder River, but not as high as those in the Powder River. This tributary would apparently not contribute significantly to the downstream increases in TSS loads that characterize the mainstem; the median TSS concentrations were only between 14 percent and 46 percent of those in the Powder near Broadus. TSS concentrations and flow were directly related in the Little Powder, but the maximum flows and TSS levels were obtained during the March-April season, suggesting an early prairie runoff.

The Little Powder River has been classified a B-D_3 stream by the State of Montana, which is appropriate considering the high maximum warm-weather temperatures obtained in conjunction with grab samples. Values of pH and concentrations of DO and fecal coliforms were also in accord with this B-D_3 designation (table 8). Although median BOD_5 levels were slightly higher in the Little Powder samples than in most water samples from the Yellowstone Basin, maximum values were not very different from those obtained in Beauvais Creek. Median BOD_5 values were also high in the lower Powder River (table 109). The low maximum BOD_5 values suggest natural lowland prairie streams rather than organic

TABLE 114. Summary of the physical parameters measured in the Little Powder River near the Montana-Wyoming state line and near Broadus.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	0.0E	0.40	0.06E	6	0.0E	17	0.80	6	<.1E	95	35.5	11	1.4	55	8.8
Temp	7	10.2	26	19.4	3	0.0	3.3	0.1	3	1.0	11.0	9.0	9	13.8	28.5	20.0
pH	7	7.5	8.4	8.30	5	6.95	8.20	7.87	4	7.27	8.17	8.03	9	7.8	8.6	8.24
SC	7	2245	4056	3210	5	789	4950	1846	4	564	3050	2557	9	1300	3003	2049
TDS	7	1818	3386	2810	5	609	4487	1420	4	389	2163	1615	9	924	2364	1630
Turb	4	6	31	22	2	7	49	28	3	24	225	150	6	28	260	88
TSS	2	24.2	54	39.1	4	9.8	122	76	5	42	5100	485	6	74.5	950	276
DO	3	7.6	8.9	8.2	2	11.6	12.3	12.0	2	10.2	11.5	10.9	5	6.0	9.9	9.5
BOD	2	3.2	4.2	3.7	2	5.2	>11.6	>5.2	2	5.9	9.6	7.8	3	3.0	6.6	4.9
FC	4	0	880	89	3	0	380	0	1	--	--	0	4	25	340	138
Ca	7	42	160	138	5	30	258	93	4	25	114	106	9	75	170	102
Mg	7	39	159	115	5	16	162	57	4	12	78	62	9	39	122	102
TH	7	326	922	831	5	143	1310	467	4	109	586	520	9	374	926	516
Na	7	410	720	580	5	125	910	247	4	72	430	302	9	151	456	282
K	7	7.5	20	19	4	4.5	23	15	4	8.0	14	8.8	8	12	18	14
SAR	7	6.6	10.9	9.9	5	4.1	11.3	5.0	4	3.0	7.7	5.8	9	3.4	7.5	5.2
HCO_3	7	189	473	390	5	148	732	320	4	123	431	317	9	165	472	337
TA	4	251	388	347	3	121	423	262	3	101	354	290	3	212	371	278
SO_4	7	820	2160	1740	5	250	2620	686	4	106	980	855	9	540	1240	800
Cl	6	1.0	28	15	5	4.1	35	17	4	9.0	123	45	9	4.2	45	8.4
F	7	0.2	0.6	0.4	4	0.1	1.2	0.6	4	0.2	2.1	0.4	8	0.3	1.4	0.5
N	6	0.02	0.05	0.02	4	0.04	0.17	0.08	4	0.08	0.14	0.10	9	0.0	0.18	0.01
P	5	0.0	0.01	0.01	2	<.01	0.03	<.03	3	0.02	0.19	0.02	6	<.01	0.10	0.035

NOTE: Measurements expressed in mg/l.

inputs from pollution sources. This supposition is supported by the low TOC concentration of one sample from the Little Powder River (table 115). The major water quality problems in the Little Powder River appear to be essentially the same as those in the Powder River but not nearly as severe.

Water quality problems evident in the Little Powder were salinity (with high TDS-SC levels), hardness (with high magnesium and calcium concentrations), SAR (with high sodium levels), sulfate (with high concentrations), and possibly turbidity and suspended sediment (with high levels). The associated water-use restrictions can be summarized as follows:

1) For use as a surface water public supply and drinking water, the waters had high hardness and turbidity. Also, TDS and sulfate levels were generally in excess of reference criteria (table 9).

2) For livestock watering, the water had high sulfate concentrations commonly in excess of the threshold (November to July) or the limiting (August to October) levels. This may produce physiological effects (California WQCB 1963), but the TDS concentrations indicated a fair-to-good/very satisfactory class for all livestock (tables 10-14).

3) For irrigation, the water had a high-to-very high salinity hazard and a medium sodium hazard (USDA 1954), and a Class II water due to the high SAR, sulfate, and TDS-SC levels (tables 15 and 16) that ". . . may have adverse effects on many crops (table 17) (requiring) careful management practices . . ." (USEPA 1976).

4) For aquatic life, the water had high TDS and SC levels commonly in excess of 1350 mg/l and 2000 µmhos/cm (Ellis 1944). This was true in 72 percent of the Little Powder samples in which TDS was measured and in 68 percent of the samples in which SC was measured. Annual median TSS-turbidity levels (62 JTU and 186 mg/l) suggest a fair warm-water fishery in the stream (European Inland Fisheries Advisory Commission 1965).

High TR concentrations of Al, Fe, and Mn were obtained in correspondence with high TSS levels. Low TR and dissolved concentrations of As, B, Be, Cr, Li, Mo, Ni, Pb, Sb, Se, V, and Zn were obtained, indicating no water quality problems. Low dissolved concentrations of Al, Cd, and Cu were obtained, but their TR levels exceeded various reference criteria. However, only Fe and Mn levels were high enough to adversely affect at least two water uses--public supply/drinking water and aquatic biota.

Mizpah Creek Drainage

Not much historical water quality and flow information is available on Mizpah Creek (USDI 1966-1974a, USDI 1966-1974b); however, the USGS has initiated a sampling program on this stream (table 3) (USDI 1976). The state WQB has also sampled this stream as a part of two water quality inventories (Karp et al. 1975, Montana DNRC 1974). Combining the data from these two agencies allowed for a flow-based (although not a seasonal-based) classification of

TABLE 115. Summary of miscellaneous constituent and trace element concentrations measured in tributaries to the Powder River.

	Little Powder River near the Montana-Wyoming state line and near Broadus								Mizpah Creek drainage[a]							
	Miscellaneous constituents and total recoverable metals[b]				Dissolved metals				Miscellaneous constituents and total recoverable metals				Dissolved metals			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
DO[c]									2	58	69	64				
NH_3-N	4	0.0	.13	.04												
Si	12	3.0	14	10					2	14	15	15				
TOC	1	--	--	12												
Al	4	0.32	5.00	3.15	2	0.0	0.0	0.0	1	--	--	.05				
As	6	<.001	0.020	0.002	2	0.0	0.0	0.0	4	0.0	0.016	<.001				
B	16	<.10	0.26	0.18	4	.08	.24	.175	6	<.10	0.4	0.19	2	.27	.35	.31
Be					2	0.0	<.01	<.01								
Cd	16	<.001	0.010	0.001	2	0.0	0.001	<.001	15	<.001	<.01	<.001 (.004)				
Cr	5	0.0	.01	0.0	2	0.0	0.0	0.0	1	--	--	0.0				
Cu	16	<.01	0.06	0.01	2	.002	.003	.0025	15	<.01	0.06	<.01				
Fe	24	.04	7.8	.64	4	0.0	1.10	0.55	15	.28	6.5	.68	2	.03	.32	.175
Hg	6	0.0	<.001	.0004	2	0.0	0.0001	<.0001	6	<.001	<.001	<.001				
Li	4	.03	.04	.04	2	.03	.05	.04								
Mn	16	.03	1.3	.23	2	.05	.11	.08	15	.02	.97	.13				
Mo	4	.001	.005	.002	2	.02	.05	.035								
Ni	4	<.05	0.05	<.05	2	.005	.007	.006								
Pb					2	.001	.004	.0025	1	--	--	<.100				
Sb	1	--	--	0.0	1	--	--	0.0								
Se	4	.001	.002	.001	2	.001	.001	.001	1	--	--	0.0				
V	1	--	--	.10	2	.0006	.0020	.0013	1	--	--	.80				
Zn	16	<.01	0.08	0.01	2	0.0	0.010	0.005	15	<.01	0.05	0.01 (.21?)				

NOTE: Measurements are given in mg/l.

[a]Sand and Sheep creeks, upper Mizpah Creek near Volborg, lower Mizpah Creek near Mizpah.

[b]Be: <.01, N=4; Pb: <.100, N=5.

[c]DO expressed as percentage of saturation.

water quality information available on the lower segment of the stream near Mizpah. Statistical summaries of the data from the upper reach of Mizpah Creek and from the two Mizpah tributaries are presented in table 116.

The high maximum warm-weather temperatures, pH values, and DO and fecal coliform concentrations in samples from the Mizpah Creek drainage were generally in accord with the B-D_3 designation applied to these waters (Montana DHES undated). In 15 percent of the samples high fecal counts in violation of the state's coliform standards were obtained, particularly in the upper reach, but for the most part, fecal concentrations were well within permissible criteria for a surface water public supply (NTAC 1968). This and the fact that BOD_5 concentrations were low indicates that no municipal-organic pollution reaches the drainage.

The streams in the Mizpah drainage had very low critical nutrient concentrations, indicating that they are probably non-eutrophic. The major water quality problems and water-use restrictions appear to be related primarily to salinity and to the high concentrations of particular ionic constituents. Iron and manganese could detract from the quality of their water, and TSS-turbidity levels could restrict certain water uses, primarily municipal-public supply. However, levels of these parameters were below those in the Little Powder River, and they were not remarkable compared to other streams of the Yellowstone Basin. In general, therefore, suspended sediment and turbidity do not suggest water quality problems in Mizpah Creek except during portions of the high-flow periods. Mizpah Creek near Mizpah did not have TSS levels or flows high enough to contribute to the marked downstream increases in suspended sediment loads observed on the Powder mainstem.

The TDS-SC levels of the Mizpah Creek samples and their chemical compositions were similar to those obtained from the Little Powder River, although ionic concentrations were significantly higher in the two Mizpah tributary streams. The waters were extremely hard (Bean 1962, Durfor and Becker 1964) in the Mizpah drainage; they were slightly saline in Mizpah Creek and moderately saline in the tributaries (Robinove et al. 1958). These streams had a definite sodium sulfate water with high SAR values, and calcium-magnesium and bicarbonate were the secondary ions. Fluoride, chloride, and potassium were observed in very low concentrations.

Water quality problems and water-use restrictions in Mizpah Creek would be generally the same as those in the Little Powder. The low chloride levels of both the Little Powder River and Mizpah Creek were well below the calculated overall chloride concentrations of input waters to the Powder (49 mg/l to 118 mg/l); this suggests that other significant sources of water reach and affect the mainstem (possibly groundwater).

TABLE 116. Summary of the physical parameters measured in the Mizpah Creek drainage.

	Sand and Sheep creeks (Mizpah Creek tributaries)				Upper Mizpah Creek near Volborg				Lower Mizpah Creek near Mizpah (<1.0 cfs)				Lower Mizpah Creek near Mizpah (>1.0 cfs)			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	2	0.0	0.0	0.0	4	0.0	0.1	0.05	5	<.1E	0.9	0.4	6	1.5	95	18
Temp	2	11.0	16.0	13.5	4	1.0	9.3	1.9	4	10.3	23.3	15.0	6	0.3	29.2	5.4
pH	2	8.41	8.50	8.46	4	7.62	8.20	7.75	5	8.30	8.73	8.70	6	7.24	8.58	8.15
SC	2	5010	5530	5270	4	1923	3752	2770	5	2092	8391	3020	6	440	2370	1832
TDS	2	4098	4819	4459	3	1960	3307	1970	4	1695	3923	2414	6	310	2029	1410
Turb	2	25	180	103	4	2	18	3	4	7	40	33	5	18	170	36
TSS	1	--	--	55	2	2.6	25	13.8	5	15	70	46.0	6	25.0	6000	105
DO	1	--	--	6.9	4	6.6	9.8	8.5	4	7.5	10.0	9.0	6	7.6	12.2	10.3
BOD	1	--	--	3.2	2	1.5	4.7	3.1	3	1.5	5.9	3.1	6	3.2	11.2	5.9
FC	2	56	60	58	2	10	4080	2045	5	0	480	196	4	0	145	5
Ca	2	36	115	76	3	130	256	140	4	38	114	46	6	16	87	60
Mg	2	40	121	81	3	70	241	72	4	38	83	50	6	2.4	58	43
TH	2	256	784	520	3	610	1632	650	4	282	626	308	6	79	457	323
Na	2	1160	1188	1171	3	375	420	420	4	410	1090	507	6	56	430	302
K	1	--	--	9.7	2	8.8	9.1	9.0	3	11	14	12	4	3.6	10	7.3
SAR	2	18.5	31.6	25.1	3	4.0	7.4	7.2	4	8.6	26.2	13.3	6	2.7	8.8	7.4
HCO_3	2	756	923	840	3	470	621	608	4	349	548	519	6	89	416	331
TA	2	628	783	706	3	385	509	499	4	310	507	444	6	73	343	272
SO_4	2	2086	2456	2271	3	1000	1945	1000	4	814	2141	1171	6	132	1020	670
Cl	1	--	--	3.3	3	7	20	9	4	0.5	8.9	8.1	6	0.8	6.2	4.0
F	1	--	--	1.2	2	0.3	0.3	0.3	3	0.5	0.7	0.5	4	0.1	0.4	0.4
N	1	--	--	0.0	3	0.0	0.02	0.0	3	0.0	0.03	0.0	6	0.01	0.42	0.17
P	1	--	--	0.02	3	0.0	0.01	0.0	3	0.01	0.02	0.02	6	0.01	0.36	0.03

NOTE: Measurements expressed in mg/l.

YELLOWSTONE RIVER
POWDER RIVER TO MONTANA-NORTH DAKOTA BORDER

YELLOWSTONE MAINSTEM

The USGS has maintained a single water quality irrigation network station on the lower Yellowstone River near Sidney for several years (USDI 1974), and the state WQB has also made collections from various sites on the lower river in recent years. Appropriate data from these two agencies were combined and seasonally classified to represent a reach of the Yellowstone River near Sidney. These data confirm that between Corwin Springs and Miles City, the Yellowstone River had significant and consistent downstream increases in TDS and ionic constituent concentrations during all seasons. Calculations of potential TDS loading to the mainstem from the Tongue and Powder rivers suggested that such concentration increases would continue below Miles City to the river's mouth near Fairview. Also, salinity-related water quality problems and associated water-use restrictions probably would be greatest and most critical in the lower reach of the river.

State WQB data from the upstream locations below Miles City were separately combined to represent another river reach west of Sidney between Terry and Intake (USDI 1968); in this manner, the water quality data from the Terry-to-Intake sampling sites could also be seasonally classified. Information from the Sidney reach was the most extensive due to the USGS's longer sampling period, and the data were therefore directly comparable to the Yellowstone River data near Miles City (table 57). Less valid comparisons can be made between the Terry-Intake reach and the Miles City or Sidney segments because little data is available on the Terry-Intake reach. Statistical summaries of data on the major water quality parameters are presented in table 117 for the Terry-to-Intake reach and in table 118 for the Sidney segment. Data for the miscellaneous constieuents and trace elements were not seasonally classified, but they were separated by reach as shown in table 119.

The lower Yellowstone River had definite seasonal variations in nitrogen levels. Extremely low nitrogen concentrations were noted during the warm late summer-early fall season of high biological activity. High nitrogen concentrations developed in conjunction with the colder temperatures of the dormant winter season. However, no distinct downstream trends became evident from Miles City to Sidney.

Phosphorus concentrations tended to increase downstream in the lower river during the March-to-July period and remained constant through the remainder of the year. Like nitrogen, phosphorus also demonstrated a seasonal variation in concentration, but the higher concentrations were recorded during the high-flow, high TSS periods of the year (March-July). At least some phosphorus variations in the lower Yellowstone were probably correlated with alterations in suspended sediment levels.

The river was apparently non-eutrophic and usually N-limited in all reaches during most seasons; this was most noticeable during the critical August-October period. During the winter, the median total soluble inorganic nitrogen concentrations in the lower river (including the median ammonia-N levels) exceeded the

TABLE 117. Summary of the physical parameters measured on miscellaneous sites on the Yellowstone River between Terry and Intake.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	9	8300	14,700E	10,800	6	6000E	10,200	8295	4	9430	15,500	13,300	10	9760E	61,500E	26,200
Temp	10	6.5	22.8	19.0	9	0.0	3.5	0.0	4	0.5	16.5	9.0	17	10.5	24.6	16.1
pH	12	8.0	8.8	8.5	9	7.97	8.6	8.3	4	7.70	8.3	8.15	17	7.5	8.40	8.09
SC	11	478	840	570	10	686	910	760	4	560	1144	878	16	290	910	475
TDS	9	315	508	418	8	467	564	535	4	441	847	609	17	173	514	349
Turb	6	6	230	15	5	10	45	30	2	190	>1000	--	11	40	280	205
TSS	8	12	147	24.5	3	8	84	78	2	61.4	118	84.7	13	90	1930	740
DO	12	8.0	12.0	9.4	9	11.3	13.8	12.6	4	7.4	11.2	10.1	17	7.1	10.0	9.0
BOD	5	0.9	2.5	2.5	3	2.9	3.8	3.0	2	1.6	3.9	2.3	13	0.6	6.3	3.9
FC	4	2	29,400	22,350	3	10	32	19	1	--	--	104	10	<10	855	300
Ca	9	39	59	51	8	58	75	63	4	50	71	70	17	25	59	41
Mg	9	15	23	20	9	15	28	25	4	23	38	30	17	7.8	23	16
TH	9	161	240	210	8	212	300	254	4	220	333	295	17	95	240	170
Na	9	40	70	55	8	56	75	65	4	65	123	90	17	19	66	44
K	7	2.8	4.0	3.4	8	3.4	4.1	3.7	3	4.3	4.8	4.5	13	2.0	3.6	2.7
SAR	9	1.4	2.0	1.6	8	1.5	2.0	1.8	4	1.9	2.9	2.3	17	0.9	1.8	1.4
HCO_3	9	145	195	177	8	184	235	196	4	169	214	213	17	93	174	140
TA	8	119	160	146	9	151	193	158	4	139	176	175	17	76	143	115
SO_4	9	120	191	180	8	175	270	210	4	190	372	280	17	57	220	136
Cl	9	5.5	13	8.2	8	5	15	13	4	15	31	20	17	3.2	13	8.0
F	7	0.1	0.4	0.4	8	0.3	0.4	0.4	3	0.4	0.6	0.6	17	0.2	0.7	0.3
N	9	0.0	0.21	0.02	7	0.2	0.5	0.36	4	0.18	0.32	0.25	16	0.03	0.52	0.27
P	9	0.0	0.28	0.03	7	0.0	0.06	0.04	4	0.01	1.4	0.30	17	<.01	1.5	0.41

NOTE: Measurements expressed in mg/l.

TABLE 118. Summary of the physical parameters measured in the Yellowstone River near Sidney, Montana.

	August-October				November-February				March-April				May-July			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	56	2804	17,000	9395	78	3080	18,200	7408	44	4900	35,800	10,050	72	3737	73,200	23,750
Temp	34	4.5	25.0	15.3	41	0.0	8.5	1.5	23	0.5	12.0	6.1	38	10.0	26.0	19.5
pH	62	7.4	8.9	8.0	84	7.3	8.9	8.1	47	7.4	8.5	8.0	77	6.4	8.6	7.9
SC	56	440	939	678	74	460	1050	817	41	562	1050	844	72	274	934	509
TDS	55	271	629	434	72	280	719	545	41	404	684	570	69	158	647	309
Turb	14	4	70	24	15	4	70	8	9	28	920	100	17	30	680	195
TSS	18	20	2910	274	14	44	270	117	14	79	3120	300	23	82	4630	676
DO	25	7.4	11.6	9.2	27	9.2	12.6	11.4	15	7.2	11.6	9.8	26	7.0	9.8	8.1
BOD	14	1.0	3.5	2.0	15	0.7	5.3	1.5	10	1.2	3.2	2.1	17	0.7	4.5	1.9
FC	21	0	13,400	36	22	0	108	10	15	0	400	20	26	0	2500	165
Ca	27	40	62	54	37	41	89	65	22	46	78	62	35	23	63	40
Mg	29	15	27	22	37	14	36	26	21	13	33	26	38	7.9	29	14
TH	52	164	291	222	68	160	363	279	37	170	330	259	63	90	283	165
Na	48	42	100	60	68	39	97	73	35	47	100	78	64	20	96	42
K	26	2.8	6.7	3.7	41	2.7	5.8	4.2	26	3.9	6.4	4.7	36	2.1	5.5	3.0
SAR	50	1.3	2.6	1.8	68	1.4	2.3	1.9	37	1.5	3.1	2.1	62	0.9	2.5	1.4
HCO_3	50	145	220	187	64	126	275	221	37	153	236	204	63	90	277	156
TA	17	121	175	140	18	144	204	168	7	126	185	164	17	77	167	105
SO_4	50	120	224	180	71	100	305	233	38	139	304	240	68	47	288	124
Cl	29	4.4	19	9.4	37	6.6	20	13	25	8.4	21	15	38	3.6	23	7.0
F	26	0.2	0.8	0.4	37	0.3	0.6	0.5	25	0.3	0.8	0.4	38	0.2	0.6	0.4
N	36	0.0	0.39	0.02	44	0.0	0.60	0.30	30	0.0	0.6	0.16	51	0.0	0.69	0.15
P	33	0.0	0.24	0.06	38	0.0	0.17	0.04	21	0.01	1.4	0.18	34	0.01	2.7	0.30

NOTE: Measurements expressed in mg/l.

TABLE 119. Summary of miscellaneous constituent and trace element concentrations measured in the Yellowstone River between Terry and near the Montana-North Dakota border.

	Miscellaneous sites between Terry and Intake								Yellowstone River near Sidney							
	Miscellaneous constituents and total recoverable metals				Dissolved metals				Miscellaneous constituents and total recoverable metals[a]				Dissolved metals[b]			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
COD									16	11	64	20				
Color									34	1	20	5				
DO[c]	22	79	104	95					47	63	109	91				
Fecal strep									22	5	700	27				
MBAS									11	0.0	.04	0.0				
NH_3-N	7	0.01	0.20	0.09 (1.27)					55	0.0	.26	.06				
Si	21	5.8	12	9.8					109	5.9	19	10				
TOC	6	8	15	11					54	2.0	27	4.9				
Ag					0	--	--	--								
Al	7	.30	34	4.9	5	0.0	0.01	<.01	4	.45	42	11	9	.0001	.02	.0002
As	6	<.01	.014	.007	5	0.0	.007	.004	6	.003	.034	.007	5	.001	.005	.003
B	19	<.10	0.52	0.10	12	.070	.160	.145	9	<.10	0.30	0.10	80	0.0	.23	.15
Ba					2	<.10	<.10	<.10								
Be					5	0.0	0.01	<.01								
Cd	23	<.001	0.01	<.001	3	0.0	.002	0.0	15	<.001	0.01	<.01	5	0.0	.003	0.0
Cr	6	<.01	0.56	0.02	5	0.0	.01	0.0	7	0.0	0.05	0.01	5	0.0	.01	0.0
Cu	26	<.01	0.08	0.01	4	.002	.003	.003	14	<.01	0.14	0.02	5	.002	.010	.004
Fe	23	.03	93	8.4	14	0.0	.08	.02	14	.04	53	1.5	81	0.0	2.6	.04
Hg	15	0.0	0.0017	<.0002					12	0.0	0.0008	<.0002	5	0.0	.0007	.0002 (.0046?)
Li					3	.02	.05	.04					3	.02	.05	.03
Mn	21	.01	3.8	.35	16	0.0	.02	0.0 (.26?)	15	.02	.97	.06	39	0.0	.12	.008
Mo					3	.001	.002	.002					3	.001	.003	.002
Ni					3	.002	.007	.002					3	0.0	.003	.003
Pb	25	<.01	0.100	<.05	4	.001	.004	.002	14	<.01	0.100	<.05	5	0.0	.003	.002 (.015?)
Se	7	0.0	.004	.002	6	.001	.003	.002	6	.001	.003	.002	5	.001	.002	.001
Sr	14	.06	3.1	.50	2	.59	.61	.60	8	.06	1.3	.44				
V	15	<.05	<.10	<.10	6	0.0	.002	.001	6	<.05	0.10	<.10	3	.0003	.002	.002
Zn	27	<.01	0.47	0.04	6	0.0	.06	.02	14	<.01	0.33	0.05	5	.01	.02	.01

NOTE: Measurements expressed in mg/l.
[a]Co: <.05, N=2.
[b]Be: <.01, N=3. Co: 0.0, N=2.
[c]DO expressed as percentage of saturation

reference criteria, and phosphorus was limiting with median concentrations below its reference point. Throughout the entire year, 64 percent of the samples from the lower river had phosphorus concentrations exceeding the reference levels, and 47 percent of the samples had phosphorus greater than the EPA's (1974b) criteria for eutrophication. None of the samples had nitrogen in excess of the EPA's (1974b) criteria, and only 25 percent of the collections had nitrogen levels greater than or equal to 0.35 mg N/l. Only 16 percent of the lower river samples suggest eutrophy.

The high maximum grab sample temperatures obtained from the lower reach during warm-weather seasons (22°C to 26°C) are in accord with its $B\text{-}D_3$ designation (Montana DHES, undated). The lower Yellowstone is a warm-water fishery (Perman 1977), and except during the winter, median grab sample temperatures tended to increase downstream from Miles City to Sidney. Dissolved oxygen concentrations and pH values were also appropriate for a $B\text{-}D_3$ classification. Median seasonal pH values in the Sidney reach were measured at 8.0 units, and a slightly lower median pH was measured during the runoff season in correlation with greatly reduced alkalinities. With two exceptions (both from the Terry-to-Intake reach with its reduced sample sizes), median fecal coliform concentrations were also within the state's average criteria. Near Sidney (table 118), only 12 percent of the collections had fecal counts in excess of the state's criteria for grab samples, very close to the 10 percent monthly leeway that is allowed by state standards (table 8). Only 5 percentof the samples exceeded the permissible criteria for surface water public supply (table 9).

In the Terry-to-Intake reach, however, the somewhat higher median fecal values and the extremely high grab sample concentrations obtained on occasion (table 117) suggested pollution problems, possibly derived from municipalities (Miles City, Terry, and Glendive). In the Terry-to-Intake reach, 38 percent of the samples exceeded the state's grab sample criteria for fecals (far above the 10 percent leeway factor), and 14 percent had concentrations greater than the recommendation of 2000 colonies per 100 ml for public supply (USEPA 1973, NTAC 1968). Apparently the problem lessens towards Sidney with flow time and associated die-off. In addition, although the annual median fecal strep concentration of samples from the river near Sidney were low and did not suggest pollution inputs (table 119), the annual median fecal coliform:fecal strep ratio (2.1) indicated municipal contamination and human wastes in mixed pollution (Millipore Corporation 1972). Consequently, municipal-bacteriological pollution is a mild water quality problem in some segments of the lower Yellowstone with a subsequent recovery further downstream.

Although the biological parameters suggested pollution inputs to the lower river, this was not reflected in the oxygen data. DO concentrations were always well above the state's minimum requirement for a $B\text{-}D_3$ stream. Median DO concentrations were with 5 percent to 9 percent of saturation, and 67 percent of the grab samples from the lower river had DO levels within 10 percent of saturation; only 12 percent of the samples had DO levels less than 80 percent of saturation. The seasonal variations in median DO concentrations were probably inversely related to seasonal changes in temperature. Low median DO levels were measured during the May-July period (8.1 mg/l to 9.4 mg/l) in relation to the high median temperatures (15.3°C to 19.5°C). High median DO levels were obtained between November and April (9.8 mg/l to 12.6 mg/l) in conjunction with the low median temperatures of this period (0.0°C to 9.0°C).

DO levels, the low TOC concentrations (the median value was near the national average for surface waters), and the low COD and BOD_5 concentrations indicate that there is no extensive organic input to the lower stream. For example, the maximum BOD_5 concentrations obtained from the lower river were only 5.3 mg/l in the Sidney reach and 6.3 mg/l in the Terry-to-Intake segment; much higher natural BOD_5 concentrations have been obtained from unpolluted streams in eastern Montana. Of the lower Yellowstone samples, 89 percent had BOD_5 levels less than 4.1 mg/l; 89 percent of the high values occurred during the May-July runoff season. Much higher BOD_5, TOC, and COD concentrations, and much lower dissolved oxygen concentrations and percentages of DO saturation would have been expected considering the marked organic pollution entering the lower Yellowstone River.

TDS concentrations and SC levels increased downstream in the Yellowstone River from Miles City to Sidney during all seasons, as seen in table 120.

TABLE 120. Percentage increases in TDS concentrations and SC levels downstream in the Yellowstone River from Miles City to Sidney.

	Total Dissolved Solids	Specific Conductance
August to October	11.0	13.0
November to February	13.1	9.4
March to April	12.6	11.0
May to July	19.8	24.1

Downstream increases in salinity were fairly similar through a large part of the year in the lower Yellowstone (August to April) and much greater during the low TDS runoff period. The percentages given in table 120 for TDS increases indicate that the loading calculations made for the Tongue and Powder rivers to the Yellowstone were underestimated for the August-to-February low-flow periods at 5.9 percent and 9.1 percent, and they were greatly overestimated for the March-to-April early runoff season at 28.7 percent. The 19.4 percent calculation was fairly accurate for the May-to-July period. Annual median TDS concentrations increased by 13.8 percent from Miles City to Sidney, close to the 15.2 percent value predicted from the loading calculations. The calculated concentrations confirmed that the Tongue and Powder rivers have significant effects on mainstem salinity.

Discrepancies between the actual and calculated percentage increases of TDS might have been caused by incomparability of station data due to different periods of collection. A shorter sampling period, and thus a smaller sample size was obtained on the Powder River (table 109) than on the Yellowstone near Miles City and Sidney (table 3). The downstream increases in TDS suggest a degradation of water quality in the lower Yellowstone River to Sidney, and a large proportion of this degradation appears traceable to the confluences of the Tongue and the Powder rivers. However, the marked effect on the Yellowstone predicted during the March-to-April high-flow/high TDS period apparently did not occur in the mainstem.

The Yellowstone tends to become progressively more sodium sulfate downstream due to inputs originating from the lowland sodium sulfate tributary streams. As a result, Ca:Na and HCO_3:SO_4 ratios consistently declined downstream until the river, for all practical purposes, became sodium sulfate in its Sidney reach; annual median Ca:Na and HCO_3:SO_4 ratios were less than 1.0 in this segment. The river's sodium sulfate character was greatest in the lower Yellowstone during the March-April season in correlation with the secondary peak in mainstem flow originating from lowland runoff (adding sodium sulfate, high TDS waters); the river's sodium sulfate character was least obvious during the May-July runoff period from the basin's mountainous headwaters regions, which had predominantly calcium bicarbonate, low TDS inputs.

Salinity in the lower Yellowstone was also greatest during the March-April period of lowland runoff, and, as a result, the inverse relationship between flow and TDS-SC was poorly defined through this season. However, calcium-sodium and bicarbonate-sulfate concentrations were not as dissimilar in the lower Yellowstone as they were upstream; magnesium, therefore, can be considered the secondary ionic constituent in the lower reach. Fluoride, chloride, and potassium had insignificant concentrations. Chloride levels were somewhat higher in the Sidney than in the Miles City segment, possibly resulting from Powder River inputs (table 109).

In addition to the mild coliform problem described previously and the potential water quality problems from certain trace elements, the major features detracting from water quality in the lower Yellowstone River were related to TSS and TDS. The waters in the lower river were hard during the runoff season and very hard between August and April. They were non-saline throughout the year. Except for TDS, total hardness, and sulfate, none of the remaining dissolved ionic constituents, including fluoride, appear at levels that would preclude water use. Median TDS concentrations in the lower river from November to April were greater than the permissible criteria and standards for public supply and drinking water in both the Terry-to-Intake and Sidney reaches (table 9). During this six-month period, 81 percent of the samples from the lower river had TDS levels in excess of 500 mg/l. From August to October, 22 percentof the collections had TDS levels exceeding 500 mg/l, compared to only 10 percent of the runoff samples. As a result, the lower Yellowstone, judging from salinity levels, would be a poor source of water for public supply from late fall through spring, but may have an acceptable water quality from May to October.

The high turbidities of the lower Yellowstone would further degrade and probably preclude the use of the water for municipal supply during the March-April season and also during the May-to-July period of low TDS levels. Median turbidities during these two periods in both reaches exceeded the 75 JTU permissible criteria for public supply (NTAC 1968), and 82 percent of the grab samples from the lower river had individual turbidities greater than this level. Thus, the August-to-October season, with its low TDS concentrations and low turbidities, would appear to be the only season in which the lower Yellowstone might be directly applicable as a public supply without extensive treatment. Water hardness and high sulfate concentrations would also detract from the value of the lower river as a municipal supply, as sulfate concentrations were occasionally in excess of the recommended levels for this use (USEPA 1973, NTAC 1968, USDHEW 1962).

The lower Yellowstone River at present has an excellent water quality for agricultural use, including the watering of all stock animals. The lower river also has a medium-to-high salinity hazard for irrigation, depending upon season, and a low sodium hazard. It has a Class I water for irrigation due to the low boron (table 119), SAR, chloride, sulfate, and TDS-SC levels (tables 15 and 16). Waters with TDS concentrations less than 500 mg/l are generally those ". . . from which no detrimental effects will be usually noticed . . ." (USEPA 1976) on plants after irrigation, including salinity-sensitive species. About 45 percent of the samples from the lower segment had TDS concentrations in excess of 500 mg/l, which would indicate that the above description does not apply to the lower Yellowstone much of the time. However, a significant number of samples with such high TDS levels were collected during the winter season, which had high median TDS values; the river usually would not be used for irrigation during this period. The proportion of high TDS samples was much lower during the irrigation season in correlation with the lower median TDS concentrations as follows: May to July, 10.5 percent and August to October, 11.9 percent, as opposed to November to February, 80.0 percent and March to April, 82.2 percent. Therefore, effects of salinity on irrigation would be expected to occur mostly during the March-April period.

Although the EPA's (1976) description of an excellent irrigation water applies to the lower Yellowstone, the water has annual median TDS values of 472 mg/l in the Terry-to-Intake reach, and 463 mg/l in the Sidney reach. The lower river, therefore, appears to have borderline quality for irrigation and is particularly susceptible to future degradation that might result in salinity increases. For example, an overall increase factor of only 1.5 in salinity could significantly reduce the lower river's value as an irrigation supply, particularly during the August-October season, by greatly increasing the proportion of samples with TDS concentrations in excess of 500 mg/l. Sensitive crop and forage species would then be affected (table 17).

Salinity levels in the lower Yellowstone River should have mild, if any, effects on the aquatic biota judging from the small percentage of samples which had TDS concentrations in excess of 670 mg/l (3.3 percent) and SC levels in excess of 1000 µmhos/cm (2.1 percent). None of the samples from the lower river had TDS and SC levels greater than the more critical 1350 mg/l and 2000 µmhos/cm values for freshwater biota, and 30.5 percent and 32.3 percent of the samples had TDS and SC levels less than 400 mg/l and 600 µmhos/cm. Most collections had TDS-SC levels between 400 and 670 mg/l and between 600 and 1000 µmhos/cm (66.2 percent and 65.5 percent) which, according to Ellis (1944), are acceptable levels of salinity for the support of viable and mixed fish fauna in western alkaline streams. However, the high suspended sediment concentrations of the lower Yellowstone and the associated high turbidities could have a much more significant effect on the stream's biota than would salinity, particularly in the Sidney reach.

TSS-turbidity levels in the lower Yellowstone usually varied directly in response to the magnitude of flow; extremely high median and maximum values were obtained in both reaches of the lower stream during the May-July runoff period. TSS concentrations in excess of 1000 mg/l and approaching 5000 mg/l were obtained in some samples, with turbidities in excess of 100 JTU. In the Sidney reach, high median TSS-turbidity levels were also observed during the early spring secondary runoff phase, and high levels were noted even during the August-to-February low-flow periods. However, TSS concentrations and turbidities were significantly lower in the upstream Terry-to-Intake reach from August to April. The annual median TSS-turbidity levels in the Terry-to-Intake segment of the lower Yellowstone (231 mg/l and 70 JTU) would indicate a poor-to-fair fishery, and the higher values in the Sidney reach (327 mg/l and 74 JTU) would suggest a poor fishery in the extreme lower reach of the river.

The high turbidities of the lower river could also affect the aquatic biota by reducing light penetration and retarding primary production (Klarich 1976). The high TSS levels of the water could also indirectly affect the use of the lower Yellowstone for irrigation by reducing soil permeability and clogging ditches and canals, which would lead to the extra expense of periodic dredging (USEPA 1972). The lower Yellowstone River would thus appear to have only fair water quality, at best, leading to curtailment of various water uses because of its high suspended sediment levels.

Such high suspended sediment concentrations in the lower Yellowstone were deemed likely on the basis of the high TSS levels in the Powder River with the associated TSS loadings to the mainstem. Distinct increases in TSS were predicted for the reach of the river below Miles City, and comparisons between tables 57, 117, and 118 indicate that TSS-turbidity levels did in fact consistently and significantly increase from the Miles City reach, through the Terry-to-Intake segment of the stream. Percentage increases in TSS through the lower river from Miles City to Sidney can be summarized by season: August-October, 764 percent; November-February, 88.7 percent; March-April, 287 percent; and May-July, 48.2 percent. Annual median TSS levels increased by 108 percent from Miles City to Sidney, slightly higher than the 81-percent increase predicted by the Tongue-Powder loading calculations. These comparisons indicate that the Powder does have a significant effect in degrading mainstem quality through the introduction of suspended sediment, although the slight discrepancy between the observed annual median concentration and the calculated TSS level indicates the operation of other influential factors and inputs.

The Tongue-Powder loading calculations (6.3 percent and 13.2 percent) for TSS were considerably less than the observed increases below Miles City during the low-flow August-February period, and calculations were considerably greater (863 percent) than the actual increase during the March-April season. The observed and calculated (64 percent) values were similar during the May-July runoff period. Marked downstream increases in TSS were observed during all seasons in the lower Yellowstone River, with a significant portion of this increase attributed to inputs from the Powder River.

As observed in the Powder River and several other streams, the TR concentrations of Al, Fe, and Mn were generally greater in the lower Yellowstone than those from upstream sites on the mainstem. The maximum TR concentrations of Cr, Du, and An were also high. Suspended sediment levels also increased downstream in the Yellowstone in correlation with the greater TR values of the lower reach samples. In turn, the dissolved concentrations of most of the trace elements were low, and they did not suggest water quality problems. Only iron and manganese indicated occasional water quality problems; a few of the samples from the Sidney reach (less than 8 percent) had dissolved concentrations in excess of most reference criteria listed in tables 9-14 and 19. Mercury was a more continuous problem in the lower segment, as its median and maximum concentrations exceeded the reference criteria for public supply and aquatic life.

In general, the dissolved levels of Al, As, B, Ba, Be, Ca, Co, Cr, Cu, Li, Mo, Ni, Pb, Se, Sr, U, and Zn in the lower Yellowstone would not be expected to degrade the water quality in the stream. This may be said also of the stream's miscellaneous constituents: Si had concentrations close to the national average for surface waters; TOC-COD-fecal strep levels indicated no problems; ammonia was at non-toxic levels but was at levels high enough to be a potential eutrophicant; MBAS indicated no synthetic detergent inputs; color was generally absent, indicating no aesthetic degradation except by turbidity; and the insecticides-herbicides were generally undetectable--species were detected in only 4 percent of the analyses performed by the USGS (1966-1974b) in concentrations ranging from 0.01 μg/l to 0.05 μg/l.

O'FALLON CREEK DRAINAGE

The Yellowstone River has a rather extensive reach about 150 miles below the confluence of the Powder River before it leaves Montana and enters North Dakota near Fairview, Montana. No large tributaries enter the river through this segment, but numerous small streams do (USDI 1968), many of which are intermittent in nature. This probably accounts for the absence of distinct and consistent increases in TDS-SC between the Terry-to-Intake and Sidney reaches of the mainstem (tables 117 and 118). For example, the Terry-to-Intake segment had an annual median TDS concentration of 472 mg/l, and the downstream Sidney reach had the very similar value of 463 mg/l. O'Fallon Creek, with its small flows, is representative of the small tributaries entering the extreme lower segment of the Yellowstone (table 121). Individual TDS loading effects on the Yellowstone mainstem from streams of this nature would be expected to be small, although a number of them could produce a cumulative effect.

Due to the distance of O'Fallon Creek from the currently active coal fields, and due to its rather inconspicuous nature, very little water quality information is available on this small drainage basin. The state WQB, however, has made several collections from near the stream's mouth near Fallon plus a few collections from the upper reaches of the creek near Ismay. The state WQB has also obtained a few samples from two of O'Fallon's major tributaries, Sandstone and Pennel creeks. These data were insufficient for a seasonal classification, and a flow-based separation of data from O'Fallon Creek near its mouth failed to reveal the occurrence of definite flow-related trends found to occur in Mizpah Creek (table 116). The data on this small drainage were separated by stream and reach, but were statistically summarized without the application of additional classifications (table 121).

O'Fallon Creek and its tributaries are lowland streams, and this is generally reflected in the chemical composition of their waters. Like many of the prairie streams, O'Fallon, Sandstone, and Pennel creeks have a distinct sodium sulfate water with high SAR values and dissolved solids concentrations; calcium-magnesium and bicarbonate were the secondary cations and anion of the waters. In most cases, calcium and magnesium concentrations were closely equivalent, and chloride, fluoride, and potassium were found in insignificant proportions. The waters in the O'Fallon Creek drainage were generally extremely hard (Bean 1962,

TABLE 121. Summary of the physical parameters measured in the O'Fallon Creek drainage.

	Upper O'Fallon Creek near Ismay				Lower O'Fallon Creek near Fallon				Sandstone Creek near Plevna				Pennel Creek near Ismay			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	4	0.05	6.6	0.28	7	0.1	85.E	15.4	3	0.0	3.5	<.1E	1	--	--	<.2E
Temp	5	9.0	21.0	14.3	10	0.2	26.2	13.5	3	7.5	18.5	14.8	1	--	--	20.0
pH	6	8.20	9.24	8.35	12	7.60	8.65	8.25	4	7.60	8.70	8.08	1	--	--	8.50
SC	6	2458	3440	3000	12	685	2890	1623	4	1380	3993	3440	1	--	--	4530
TDS	5	1943	2505	2235	12	522	2290	1326	3	1084	3171	2645	1	--	--	3796E
Turb	4	21	88	36	12	<1	750	33	3	62	96	74	0	--	--	--
TSS	4	26	170	94.3	11	0.0	4550	59	3	37.5	228	180	0	--	--	--
DO	2	9.5	9.8	9.7	11	7.5	12.3	9.7	2	7.3	9.4	8.4	0	--	--	--
BOD	1	--	--	2.3	11	1.6	11.6	4.8	0	--	--	--	0	--	--	--
FC	3	0	430	80	10	0	6000	105	3	20	120	90	0	--	--	--
Ca	5	33	80	60	12	25	83	54	3	45	79	53	1	--	--	370
Mg	5	0.0	74	61	12	19	75	50	3	28	98	61	1	--	--	70
TH	5	180	450	400	12	140	514	320	3	230	602	384	1	--	--	1214
Na	5	410	650	540	12	81	500	283	3	235	750	650	1	--	--	688
K	3	8.2	10	9.6	10	1.8	11.0	7.9	2	9.7	10.8	10.3	1	--	--	10
SAR	5	8.4	18.3	11.7	12	2.1	9.6	7.3	3	6.7	14.4	13.3	1	--	--	8.6
HCO_3	5	403	583	549	12	147	437	273	3	255	582	500	1	--	--	342
TA	5	350	502	460	12	121	390	256	3	209	477	410	1	--	--	320
SO_4	5	925	1177	1075	12	222	1177	591	3	510	1560	1370	1	--	--	2251E
Cl	5	0.2	15	6.0	12	0.8	25	11.7	3	0.0	90	9.0	1	--	--	30
F	4	.4	.5	.5	11	0.1	0.5	0.4	3	0.3	0.6	0.5	0	--	--	--
N	4	0.06	0.99	0.19	12	0.0	0.99	0.13	2	0.04	0.27	0.16	1	--	--	0.29
P	3	0.01	0.02	0.01	12	0.01	0.09	0.04	2	0.06	0.07	0.07	0	--	--	--

NOTE: Measurements expressed in mg/l.

Durfor and Becker 1964) and usually slightly saline (Robinove et al. 1958). Judging by TDS and dissolved constituent concentrations, water quality was better in O'Fallon Creek than in its tributary streams, and improved towards the downstream reaches as a result of the 41 percent to 46 percent reductions in TDS-SC levels.

Due to similarities in chemical composition, the water-use restrictions in the O'Fallon Creek drainage would be essentially the same as those noted in the Little Powder River and Mizpah Creek, and for the same reasons. This would preclude the use of the water as a surface water public supply due to the high TDS, sulfate, and hardness levels of the stream. Also, various agricultural uses and the aquatic biota could also be affected. Such restrictions, of course, would be greatest in the tributary streams and in the upper reaches of O'Fallon Creek as a result of the greater salinities and dissolved constituent concentrations.

The streams in the O'Fallon Creek drainage were obviously non-eutrophic; nitrogen and phosphorus concentrations were well below the reference levels. High TSS-turbidity levels were occasionally obtained in conjunction with runoff events; this was most noticeable in the lower reach of O'Fallon Creek. However, the median concentrations of these constituents were not particularly high, and they were not significantly higher than those in other prairie streams. Turbidities occasionally may be too high for municipal use without extensive treatment for dissolved and suspended solids, but the median TSS-turbidity levels of the streams suggest a fair fishery.

The O'Fallon Creek drainage does not appear to be affected by marked municipal-organic pollution at present, as its BOD_5 concentrations were not particularly high. BOD_5 values and fecal coliform concentrations were generally similar to the ranges obtained from Beauvais Creek and other small prairie streams. The TOC concentration of a single sample from lower O'Fallon Creek (table 122) also suggested no organic inputs entering the streams.

Like most of the small creeksin eastern Montana, O'Fallon Creek and its tributaries have been classified as $B\text{-}D_3$ streams by the State of Montana. With the exception of a few runoff samples, fecal counts from these waters were generally within the coliform standards prescribed for this class of stream (table 8). In addition, the high maximum temperatures from the creeks were in accord with the $B\text{-}D_3$ designation, as were the grab sample DO concentrations. Values of pH were also typically within the maximum-minimum, $B\text{-}D_3$ criteria, although high pH values were occasionally obtained, and one reading from upper O'Fallon Creek exceeded the maximum standard. For the most part, however, temperature, pH, TSS-turbidity, DO, BOD_5, and fecal coliforms did not suggest significant water quality problems in the O'Fallon drainage.

Nitrogen, phosphorus, fluoride, chloride, potassium, and most of the trace elements monitored from O'Fallon and Sandstone creeks (table 122) were not detected in levels high enough to detract from the streams' quality. The TR concentrations of As, B, Cd, Cr, Cu, Pb, U, and Zn were consistently below the associated reference criteria. Of the metals, only the presence of iron and manganese suggested problems, as median TR levels exceeded the criteria for public supply-drinking water and aquatic life. However, the magnitude of the

TABLE 122. Summary of trace element and miscellaneous constituent concentrations measured in the O'Fallon Creek drainage and in small tributaries to the Yellowstone River below Fallon, Montana.

	Upper O'Fallon Creek near Ismay				Lower O'Fallon Creek near Fallon				Sandstone Creek near Plevna				Cabin, Cedar, Hay, and Sevenmile creeks between Fallon and Glendive				Glendive Creek at Glendive				Fox Creek near Sidney			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
As	2	<.001	<.01	<.01	3	<.001	<.01	<.001	2	<.01	<.01	<.01	2	<.001	0.006	--	2	0.004	0.01	0.007	3	<.001	<.01	<.01[a]
B	1	--	--	0.32	8	0.10	0.30	0.15	1	--	--	0.67	1	--	--	0.49								
Cd	3	<.001	<.01	<.001	11	<.001	<.01	<.001[b]	3	<.001	<.01	<.001	3	<.001	<.01	<.001	2	<.001	<.01	<.01	3	<.001	<.01	<.001
Cr					1	--	--	<.01					1	--	--	<.01	1	--	--	<.01	1	--	--	<.01
Cu	3	<.01	0.01	<.01	11	<.01	0.04	<.01	3	<.01	0.01	<.01	3	<.01	0.03	<.01	2	0.01	0.03	0.02	3	<.01	<.01	<.01
Fe	3	0.31	1.1	0.49	11	0.02	17.2	0.95	3	0.70	1.9	1.2	3	0.42	1.9	1.4	2	1.2	1.7	1.45	3	0.27	0.32	0.30
Hg					1	--	--	<.001																
Mn	2	0.08	0.11	0.095	10	0.03	0.77	0.05	2	0.20	0.26	0.23	3	0.1	0.17	0.15	1	--	--	0.06	2	0.04	0.06	0.05
Pb	1	--	--	<.01	2	<.01	0.01	--	1	--	--	0.02	1	--	--	<.01	2	<.01	<.01	<.01	2	<.01	<.01	<.01
TOC					1	--	--	9																
V	1	--	--	0.13					1	--	--	0.14	1	--	--	0.35								
Zn	3	<.01	0.02	<.01	11	<.01	0.09	0.01	3	<.01	0.02	0.02	3	<.01	0.02	0.01	2	<.01	0.02	--	3	<.01	<.01	<.01

NOTE: Measurements are expressed in mg/l; all metals are total recoverable metals.

[a]Also, .002 was obtained.

[b]Also, .007 was obtained.

potential Fe-Mn problem, and that of mercury, cannot be definitely assessed because dissolved concentration data is unavailable.

In conclusion, the salinity-related factors--TDS-SC, hardness, sodium, and sulfate--appear to be the major factors detracting from the water quality in the O'Fallon Creek drainage.

TRIBUTARY STREAMS

In addition to O'Fallon Creek, numerous other small tributaries join the Yellowstone River below the confluence of the Powder River (USDI 1968). Except for a few collections completed by the state WQB on seven of the larger tributaries, very little water quality information is now available on these streams. The data were too sparse for a season- or flow-based classification; to increase the data base for the statistical summaries, the streams were combined geographically wherever possible (major parameters are summarized in table 123). Trace element data are presented in table 122.

Most Yellowstone tributaries in the lower drainage, like the mainstem, have been classified as $B\text{-}D_3$ streams; only Fox Creek is classified as $B\text{-}D_2$. These tributaries generally have lower water quality than those in the mainstem; samples from some streams in the lower basin had the lowest water quality in the entire Yellowstone region. For example, samples from Lonetree, Hay, Cedar, and Cabin creeks had TDS concentrations in excess of 8000 mg/l and specific conductance levels greater than 9000 µmhos/cm.

The small Fox Creek tributary near Sidney, however, had high water quality. Fox Creek is largely perennial, and it had a sodium bicarbonate water. It also had low suspended and dissolved solids concentrations, low SC levels and SAR values, and cool temperatures. Fox Creek supports a small viable trout fishery (Karp et al. 1975), which is unique for eastern Montana and in accord with its $B\text{-}D_2$ classification (Montana DHES, undated).

The remaining small streams draining the region below the O'Fallon Creek subbasin are intermittent in nature and have the sodium sulfate water characteristic of lowland streams. The TDS, SC, and SAR values were high and more typical of prairie streams than those in Fox Creek. Suspended sediment concentrations and turbidities were low except in Glendive Creek, where they were quite high. This would preclude the use of Glendive Creek for public supply and as a fishery.

Saline seep degradation of agricultural lands is becoming a prevalent problem in many areas of Montana, including the northern counties of the lower Yellowstone drainage (Kaiser et al. 1975). This can affect the surface water quality in other streams in such saline seep regions. Surface runoff and groundwater return from afflicted areas could contribute to the high TDS-SC levels observed in some streams in the lower Yellowstone area--Hay Creek in Dawson County, Cabin Creek in Prairie and Fallon counties, Cedar Creek in Dawson and Wibaux counties, and Lonetree Creek in Richland County. All five of these counties have recognized saline seep acreages (Kaiser et al. 1975). The high nitrate-N concentrations shown in some of the samples from the region (table 123)

TABLE 123. Summary of the physical parameters measured in small tributaries to the Yellowstone River below Fallon, Montana.

	Cabin, Cedar, Hay, and Sevenmile Creeks between Fallon and Glendive				Glendive Creek at Glendive				Fox Creek near Sidney				Lonetree Creek at Sidney			
	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med	N	Min	Max	Med
Flow	7	0.0	1.0E	0.01	3	1.2	4.5	2.7	3	1.8	4.1	4.0	1	--	--	0.0
Temp	6	4.0	26.5	17.4	2	14.1	15.5	14.8	2	8.0	11.5	9.8	0	--	--	--
pH	7	7.90	8.60	8.30	3	8.20	9.20	8.80	3	8.10	8.40	8.30	1	--	--	7.80
SC	7	980	17,500	3670	3	1134	2264	2200	3	1137	1185	1163	1	--	--	9125
TDS	7	953	15,302	2899	3	1257	1895	1877	3	1004	1127	1087	1	--	--	9127
Turb	1	--	--	30	2	44	8900	--	1	--	--	1	0	--	--	--
TSS	3	12	121	24	3	26	66,000	972	2	5	8.5	6.8	0	--	--	--
DO	2	10.9	11.0	11.0	3	6.9	11.1	9.8	2	9.8	10.8	10.3	0	--	--	--
BOD	0	--	--	--	2	1.2	3.3	2.3	2	3.6	5.6	4.6	0	--	--	--
FC	2	2	247	125	2	0	17,000	--	2	640	>1000	--	0	--	--	--
Ca	7	20	495	71	3	9.6	88	13.9	3	63	77	76	1	--	--	184
Mg	7	14	677	69	3	4.4	5.8	5.8	3	61	74	67	1	--	--	939
TH	7	108	4025	460	3	42	244	58	3	434	495	439	1	--	--	4328
Na	7	212	3550	730	3	280	555	536	3	107	145	118	1	--	--	1225
K	2	11	15	13	2	4.0	9.5	6.8	2	5.2	6.5	5.9	0	--	--	--
SAR	7	7.1	26.0	13.4	3	7.8	37.3	30.5	3	2.2	3.0	2.3	1	--	--	8.1
HCO_3	7	151	527	293	3	441	800	767	3	379	578	428	1	--	--	122
TA	7	124	466	240	3	361	794	707	3	319	474	351	1	--	--	100
SO_4	7	265	8400	1698	3	402	505	438	3	275	412	317	1	--	--	6656
Cl	7	0.0	1893	30	3	0.5	30	1.0	3	1.0	10	7.7	0	--	--	--
F	3	0.2	0.6	0.4	2	0.9	0.9	0.9	3	0.3	0.8	0.4	0	--	--	--
N	5	0.04	2.01	0.38	3	0.06	0.19	0.15	3	0.0	0.68	0.07	0	--	--	--
P	4	0.01	0.22	0.06	3	0.02	0.06	0.03	3	<.01	0.04	0.02	0	--	--	--

NOTE: Measurements expressed in mg/l.

were also symptomatic of saline seep inputs to the waters, but they were not at levels that would affect surface water public supply (table 9) and livestock watering (tables 10-14).

The waters in these creeks were extremely hard except in some of the Glendive Creek samples, and slightly saline. The saline seep-affected streams had samples moderate to high in salinity (Robinove et al. 1958). These waters would have a very high salinity hazard for irrigation and a high-to-very high sodium hazard (Fox Creek would have a high salinity hazard and a low sodium hazard) (USDA 1954).

The chemical compositions of the waters varied considerably. Calcium and magnesium levels were usually fairly equal, although the Lonetree Creek sample had noticeably high magnesium concentrations; this may reduce its value as a source of water for stock. Glendive Creek had low calcium-magnesium concentrations and hardness levels, and Lonetree Creek had low bicarbonate concentrations. Chloride concentrations were particularly high in a few of the samples collected between Fallon and Glendive, further restricting the water's use for public supply, irrigation, and livestock watering. For the most part, however, chloride, fluoride, potassium, and magnesium were minor constituents and did not suggest water quality problems. Sodium and sulfate were the dominant ions in the samples.

High sodium (SAR), sulfate, TDS-SC, and hardness levels would restrict many water uses, and such restrictions would be much greater in the streams with moderate-to-high salinity. In fact, waters with extremely high TDS-SC levels might be classified as unuseable even for livestock (Seghetti 1951). The major water-use restrictions for most of these streams can be briefly summarized as follows:

1) For use as surface water public supply, all streams had high TDS, sulfate (table 9), and hardness levels, and Glendive Creek had high turbidities.

2) For irrigation, Fox Creek had Class II waters, and other streams had Class III waters due to high sulfate and TDS-SC levels or high SAR and chloride values (tables 15 and 16).

3) For the aquatic biota (not in Fox Creek), major effects were evident with TDS-SC levels commonly in excess of 1350 mg/l and 2000 μmhos/cm, and in the high TSS levels in Glendive Creek.

4) For the aquatic biota in Box Creek, some mild salinity effects were evident, as TDS concentrations were greater than 660 mg/l and SC levels were greater than 1000 μmhos/cm.

5) For livestock watering, sulfate levels were high and sometimes TDS levels were high, except in Glendive and Fox creeks.

Apart from salinity-related factors (and TSS-turbidity in Glendive Creek), most of the remaining major parameters did not suggest water quality degradation or water-use restrictions. BOD_5 concentrations were not at levels high enough to indicate that organic pollution reaches the streams, and pH levels (with the exception of one sample) and DO concentrations were within the state standards for a $B\text{-}D_3$ stream (table 8). Stream temperatures also suggested $B\text{-}D_3$ waters

($B\text{-}D_2$ waters in Fox Creek). Fecal coliform concentrations were high in the stream samples, and they were in excess of state criteria in several instances. However, with only six analyses for fecals available, additional collections would be necessary in order to fully assess the problem. Because of high salinity levels, these waters are unsuitable for public supply anyway except in Fox Creek.

Summary of existing situation

YELLOWSTONE RIVER MAINSTEM

TDS CONCENTRATIONS

The Yellowstone River in Montana shows an obvious downstream change in water quality from its entrance to the state near Corwin Springs (from Yellowstone National Park) to its exit into North Dakota near Fairview, Montana. Such downstream changes in water quality are common in many streams, and are best seen in the Yellowstone by the increase in TDS concentrations towards the river's mouth. Figure 3 shows the median TDS concentrations for various sites on the river having adequate post-1966 USGS and state WQB records. Data in figure 3 were grouped by month to correspond to the seasons of the year, a high-flow period (May to July), warm- and cold-weather low-flow periods, and the March-April spring season.

As indicated in figure 3, downstream increases in TDS occurred through all seasons of the year along the Yellowstone River. At all sites, lowest concentrations occurred during the late spring/early summer runoff period. However, the greatest increase in TDS between Corwin Springs and Sidney was noted during this high-flow season with a factor increase of 3.6 during May-July, and between 2.85 and 3.15 over the remainder of the year. The greatest increase in TDS occurred through the Billings-to-Miles City segment, which includes the confluence of the Bighorn River. This increase was observed during all seasons. Negligible alterations were recorded from Corwin Springs to Livingston, where small tributaries with excellent water quality join the mainstem. Moderate increases in TDS were recorded for the Livingston-to-Billings reach (including the confluence of the Clarks Fork River) and in the reach below Miles City (including the confluences of the Tongue and Powder rivers).

Differences in TDS levels between seasons were greatest at sites on the lower reach of the river. Much higher concentrations of TDS were observed in the March-April and November-February periods than in the late spring/early summer; intermediate concentrations were observed during the August-October season. In the upper river, seasonal differences in TDS were much less noticeable, although the high TDS:low TDS seasonal ratios were similar throughout the mainstem. Maximum changes in median TDS at sites on the Yellowstone River above Custer occurred between the high-flow period and the cold-weather low-flow season, and ranged from factors of 2.0 to 2.2. Seasonal changes in TDS at sites on the river below Custer ranged from factors of 1.8 to 2.0 and occurred between the high-flow period and the March-April early spring season. Seasonal TDS changes occurred at a factor of 1.6 in the river at Custer. Consequently, it may be concluded that the effect of the Bighorn River on the quality of the Yellowstone River was greatest during the early spring season.

CHANGES IN CHEMISTRY

Downstream changes in the Yellowstone River's water quality are also evident through alterations in the stream's chemistry (table 124). Near Yellowstone

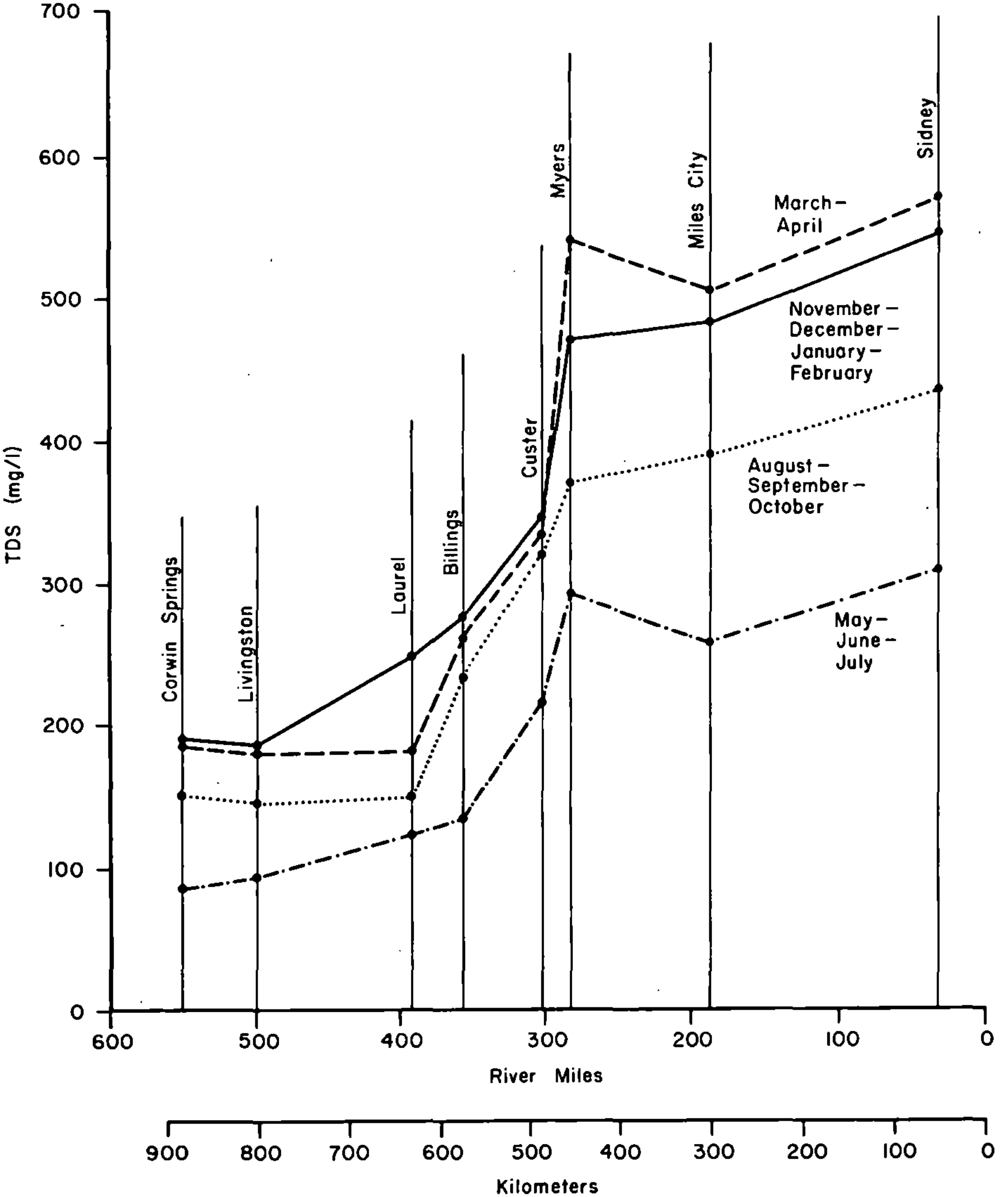

Figure 3. Median TDS concentrations at various sites on the Yellowstone River during four seasons of the year.

TABLE 124. Ratios of median calcium to sodium concentrations and median bicarbonate to sulfate concentrations at various sites on the Yellowstone River through four seasons of the year.

	August-October		November-February		March-April		May-July	
	Ca:Na	$HCO_3:SO_4$	Ca:Na	$HCO_3:SO_4$	Ca:Na	$HCO_3:SO_4$	Ca:Na	$HCO_3:SO_4$
Corwin Springs	0.79	2.17	0.75	1.98	0.83	--	1.00	5.08
Livingston	1.19	3.76	1.20	3.14	1.10	3.06	1.40	5.25
Billings	1.42	2.38	1.59	2.01	1.48	1.99	1.73	3.83
Custer	1.13	1.51	1.41	1.63	1.56	2.20	1.60	2.72
Myers	1.07	1.22	1.10	0.98	1.00	0.87	1.19	1.35
Forsyth	0.92	1.10	1.13	1.03	0.97	0.88	1.14	1.31
Miles City	0.96	1.09	1.00	0.96	0.98	0.88	1.27	1.31
Fallon	0.93	0.98	0.96	0.93	0.78	0.76	0.93	1.03
Sidney	0.90	1.03	0.89	0.95	0.79	0.85	0.95	1.26

National Park the river has a definite sodium-bicarbonate water during most of the year. However, tributaries to the Yellowstone above Billings typically have a calcium-bicarbonate composition, and this is reflected in the chemistry of the mainstem which gradually becomes calcium-bicarbonate from Corwin Springs to Billings. With river inputs below Billings, the water then tends to become progressively more sodium-sulfate because Ca:Na and HCO_3:SO_4 ratios decline to Custer. This, in turn, reflects tributary inputs to the mainstem because the tributary streams below Billings tend to have sodium-sulfate compositions. This alteration in the Yellowstone chemistry becomes very noticeable below the confluence of the Bighorn River, with its large volume of flow. The Yellowstone River tends to retain its calcium-bicarbonate composition at high-flow periods in the lower river from May to July due to the influence of the upstream calcium-bicarbonate tributary streams which have their peak flows then. The sodium-sulfate streams below Billings tend to have peak flows earlier in the year, and this is reflected in the low Ca:Na and HCO_3:SO_4 ratios obtained during the March-April season at some locations. However, in the extreme lower river below Fallon, the Yellowstone River is mainly a sodium-sulfate stream.

CHANGES IN WATER QUALITY

Although there is a general deterioration in water quality and an alteration in chemistry downstream from Corwin Springs, the water quality in the upper Yellowstone River above Billings appears to be quite good, and suitable for all potential uses. This quality degradation is primarily due to increases in stream salinity.

There is no evidence of marked pollution inputs to the stream. None of the concentrations of common constituents exceed recommended levels for human consumption and use, for stock water, or for irrigation. Fluoride concentrations were high near Corwin Springs due to the Yellowstone Park drainage, but rapidly becomes diluted downstream in Montana. Dissolved oxygen concentrations are usually near saturation, and BOD levels do not indicate organic pollution. Most of the dissolved metals do not appear to be in toxic concentrations. Possible exceptions are arsenic, apparently derived from Yellowstone Park, and mercury, which had grab sample concentrations occasionally in excess of water use criteria. The critical nutrients in the upper river are not generally at levels characteristic of eutrophy, although the Yellowstone comes close to this condition in the segment near Custer. Temperatures in the Yellowstone River above Billings are generally comparable to those of a cold-water fishery. Of the water quality parameters, the fecal coliforms and possibly the phenols occur at concentrations that could indicate pollution problems. Concentrations of these two pollutants occur in the river near Billings, which has a number of industrial and wastewater discharges.

Although the water quality in the lower river remains generally good, it shows a degradation due to increasing salinities which continues in the river as it flows from Billings to its confluence with the Missouri River in North Dakota; this is most obvious below the confluence of the Bighorn River (figure 3). A few specific parameters reach potential problem levels.

Temperatures in the river below Billings are typical of a warm-water fishery and of a cold-water/warm-water transition zone between Big Timber and Bighorn.

Dissolved oxygen levels remain very close to saturation but occur in lower concentrations than levels observed upstream. BOD levels indicate no organic pollution, and fecal coliform concentrations do not indicate water quality problems. Dissolved metals usually do not approach toxic levels, but iron, manganese, and mercury have dissolved concentrations occasionally in excess of water use criteria.

There is no evidence that the waters become eutrophic in the segment of the stream below Billings. The lower river's water therefore appears to be suitable for most beneficial uses. Drinking water may be the only exception. In the extreme lower segment of the river below Miles City, median TDS concentrations and sulfate levels exceed recommended criteria for drinking water (500 mg/l and 250 mg/l) from November to April, the seasonal low-flow period (figure 3).

As illustrated in figure 4, turbidity and high levels of TSS may cause water quality problems below Miles City. A definite increase in TSS occurs downstream through all sites during the high-flow period with concentrations in the river exceeding 100 mg/l below Laurel. At periods of low flow, however, TSS concentrations are typically less than 80 mg/l above Miles City. A marked increase in TSS occurs below this point through all seasons, and median TSS concentrations exceed 100 mg/l through most of the year below Fallon (below the confluence of the Powder River). Such high TSS levels in the lower river degrade its quality and could restrict certain beneficial water uses, such as a particular fishery or a source of public supply.

In general, the water quality in the Yellowstone River is best at upstream sites and at high-flow periods, although the increase in TSS during this period detracts from its value. There is a general degradation in the river's quality downstream to Sidney, and TDS, sulfate, and TSS levels appear to be the main reasons. However, there is no evidence of extensive pollution inputs through most of the river's length. Water quality is generally good above Miles City and suitable for most uses.

Below Miles City, sediment, TDS, and sulfate levels may restrict some water uses because of the lower water quality through this segment. Nonpoint tributary inputs of inferior quality are the major contributors to downstream degradation of mainstem waters.

ASSOCIATED DRAINAGES

TDS CONCENTRATIONS

TDS concentrations were found to be variable among the tributary streams of the Yellowstone Basin. High values were obtained in some cases and a wide range of SC levels was measured, varying from 250 to 17,500 µmhos/cm, depending on the stream and season of collection. TDS concentrations were generally greater in the primary, secondary, and tertiary tributary streams than at their points of juncture with the mainstem of the Yellowstone River. For the most part, TDS concentrations and SC levels increased downstream in these tributaries, and they were usually higher in the smaller streams of any particular subbasin.

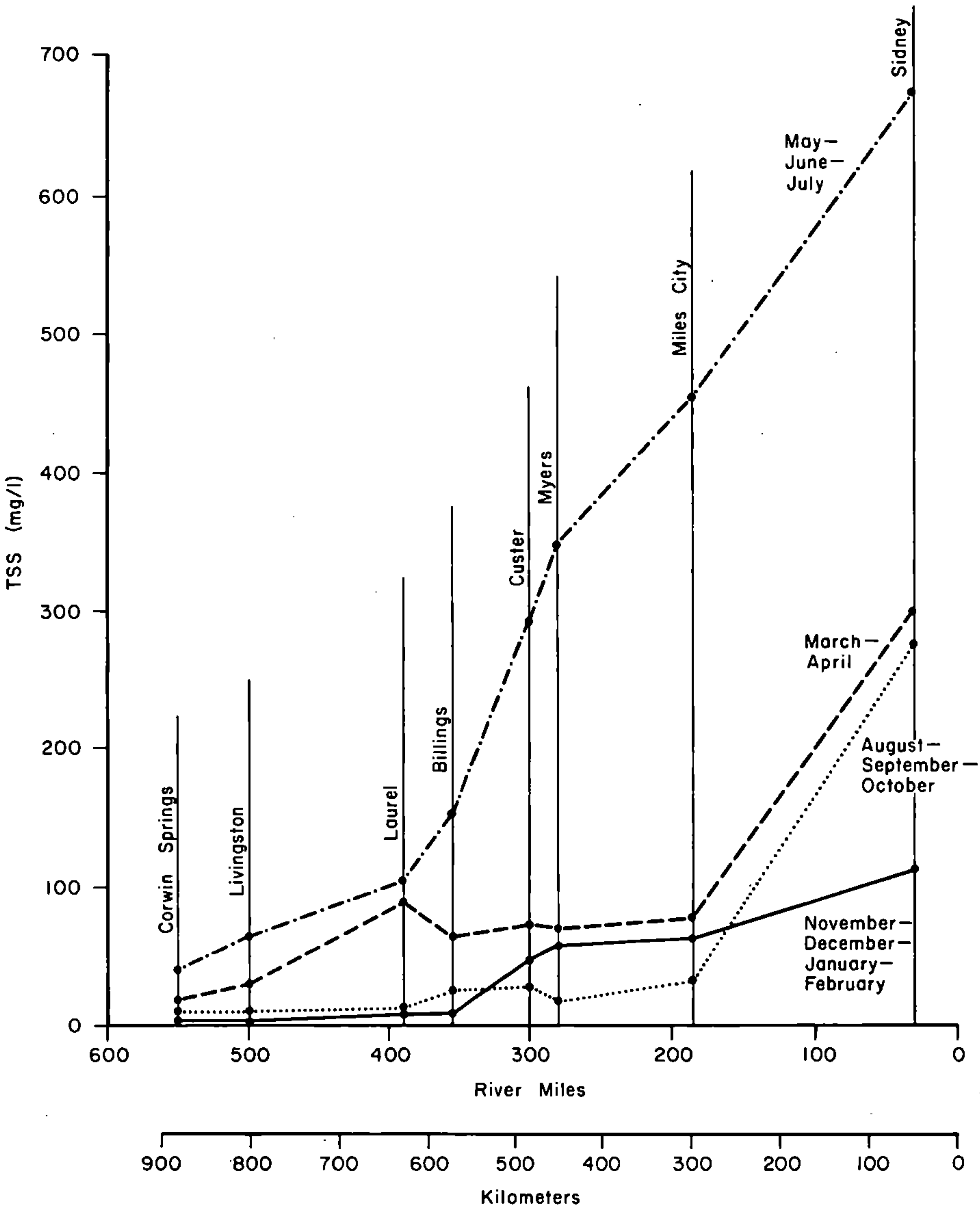

Figure 4. Median TSS concentrations at various sites on the Yellowstone River during four seasons of the year.

TDS concentrations in the streams of the study area were high and exceeded the recommended public water supply and drinking water standards in many cases. The waters in many of the smaller streams and in the Powder River were usually slightly saline. Concentrations were consistently highest in the smaller streams such as Armells, Little Porcupine, Reservation, Otter, and Pumpkin creeks which have their headwaters directly in the basin. Values greater than 1000 mg/l were typical. In some instances, TDS concentrations exceeded the threshold concentrations for stock water.

Rosebud Creek and most of the larger streams had TDS concentrations typically ranging between 500 and 1000 mg/l, although the Powder River had TDS concentrations greater than 1000 mg/l. Of the other large streams, the Yellowstone and the Little Bighorn rivers had the lowest TDS concentrations in the basin. They were generally followed in order by the Bighorn River, the Tongue River and Pryor Creek, tributaries of the Little Bighorn and Bighorn rivers, and Rosebud Creek and the Powder River drainage.

SALINITY

Water quality in the Yellowstone Basin, judging by salinity levels, generally declined in an eastward and downstream direction. Quality was generally inversely related to the size of the stream; that is, the smaller streams typically had lesser water quality. Numerous exceptions, however, became evident. Some prairie streams, such as Sarpy Creek, actually showed downstream improvements in water quality. Also, the west-flowing Bighorn River, one of the larger streams in the Yellowstone Basin, had comparatively poor water quality, and the smaller east-flowing Fox Creek had comparatively good water quality.

PH VALUES

Values of pH in the various streams of the basin typically ranged between 7.8 and 8.5 units. In some cases, field readings were above or below these values. Values greater than 9.0 were obtained in a few of the smaller streams, but readings outside the recommended limits in tables 8-14 were rare. With few exceptions, pH values were well within the range recommended by the Committee on Water Quality Criteria for aquatic systems (USEPA 1973).

TEMPERATURE

Stream temperatures in the basin generally varied from near 0 C in the winter to between 20 C and 29 C during the summer. This range and the warm summer temperatures are typical of warm-water habitats in the Northern Great Plains. An extreme temperature of 28.5 C was noted in the Powder River; high temperatures were more common in the smaller streams than in the Yellowstone River. In general, warm-weather water temperatures are in accord with the $B\text{-}D_2$ and $B\text{-}D_3$ designations applied to the tributary streams in the Yellowstone Basin below Laurel (Montana DHES, undated). The only inappropriate classification, in terms of temperature, may be Pryor Creek, with its $B\text{-}D_1$ designation.

DISSOLVED OXYGEN

Dissolved oxygen (DO) is a critical water quality parameter related more to biological and ecological factors than to human use. However, low DO content in surface waters may indicate that it is organically polluted and therefore unfit for human consumption. Groundwaters are often naturally devoid of oxygen; waters lacking oxygen generally have a "flat" taste, especially after boiling.

From a biological point of view, game fish require DO concentrations of at least 5 ppm to reproduce, and they generally die if DO falls below 3 ppm (Salvato 1958). Montana criteria for oxygen in B-D_1, B-D_2, and B-D_3 class streams are listed in table 8. With few exceptions, DO concentrations within the streams of the basin were at or near saturation levels during the period of sampling. DO levels ranged from about 6.0 to 13.5 mg/l; the higher values were obtained during the winter, with water temperatures approaching 0.0°C. As a result, DO values in the basin were typically greater than the minimum Montana requirements for salmonid propagation. The few exceptions were in the smaller streams, such as Sarpy Creek.

ORGANIC POLLUTION

Consistently high DO values in the streams of the study area indicate a general absence of major organic pollution in the basin. This is confirmed by data from the numerous BOD_5 determinations, typically less than 6 mg/l in most of the stream samples, but ranging up to about 11.5 mg/l. Even the higher values are not particularly high considering those taken from sewage outfalls. In a well-operated and functional lagoon system, values were generally between 40 and 80 mg/l, but approached 140 mg/l, and, in some instances, exceeded 200 mg/l in poorly managed or nonfunctional systems. Yegen Ditch in Billings is an example of an organically polluted flowing stream with BOD_5 levels between 20 and 25 mg/l during some periods. Here, a BOD_5 level of 11.5 mg/l is not indicative of a gross organic pollution.

The general absence of municipal pollution in the middle Yellowstone River Basin is indicated by the bacteriological data. Fecal coliform counts varied widely at any given site between sampling dates and between streams. This data demonstrated a positive correlation with flow. Fecal counts were usually much lower than the permissible criteria listed in table 9, but often were higher than that level deemed desirable by the National Technical Advisory Board (NTAC 1968) for public supply. Because fecal counts were only occasionally greater than the standards established by the State of Montana for B class waters, they would not suggest water quality problems or indicate that extensive municipal inputs enter the Yellowstone tributaries.

CHEMICAL COMPOSITION

The larger streams varied considerably in their chemical compositions, but the smaller prairie creeks were usually sodium sulfate in character. Magnesium was an abundant cation in almost all of the tributaries and small streams; it often exceeded calcium on a weight and/or equivalence basis, suggesting dolomitic formations in the basin. Generally, however, calcium was the major primary or secondary cation. As a result of the high calcium and magnesium concentrations, the waters in the Yellowstone Basin were usually extremely hard.

With a few exceptions, fluorides in the surface waters were below the upper limits for drinking water, and should therefore not prevent stock or human use. Chlorides, like potassium, were at negligible levels, and bicarbonate-carbonate and sulfate were the dominant anions. The major exceptions were in Sunday Creek and the Powder River, where sulfate exceeded the recommended criteria for human use in many cases; in some of the smaller streams, both of the dominant anions exceeded the threshold or limiting concentrations for livestock.

Like sulfate, sodium was a common ion in all waters of the basin and was the dominant cation in many streams, but it exceeded threshold values for livestock in only a few samples. A review of the SAR data in the samples taken also indicates that waters from most of the larger streams of the Yellowstone River Basin--the Yellowstone, Little Bighorn, Bighorn, and Tongue rivers, and Rosebud Creek--are safe for irrigation. These data also indicate that most of the smaller streams (Tullock, Pryor, and Fly creeks, and the Little Powder River) of the basin and the Powder River could have sodium hazards for irrigation.

Standards have been established (table 9) for nitrate in municipal supplies according to infant toxicities. None of the samples collected from the streams in the Yellowstone Basin exceeded or approached this limit. Phosphate standards for public supply and drinking water have not yet been established by the EPA or the U.S. Public Health Service. However, phosphate and nitrate even at such low concentrations remain critical parameters because they play critical roles in the development of toxic or nuisance algae and macrophyte blooms in surface waters, which influence human use. Data on nitrogen and phosphorus from the Yellowstone Basin indicate that none of the streams are obviously eutrophic, and that most are nitrogen-limited. Locations most likely to develop eutrophic conditions were the Yellowstone River near Custer and Sidney, the Bighorn River near Hardin, the Powder River, and various small streams in the extreme eastern portion of the basin.

TURBIDITIES, TSS, AND FLOW

Turbidity, TSS, and flow were found to be positively related. TSS values showed wide fluctuations between dates and streams. For example, in the Yellowstone River TSS ranged from 8.8 to 992 mg/l on different dates at Forsyth in correlation with flows of 7400 to 33,800 cfs. Similar wide fluctuations were evident in the smaller streams: Starved-to-Death Creek, 6.5-220 mg/l and 0.01-0.9 cfs; Pumpkin Creek, 13.0-1016 mg/l and 0.6-42.7 cfs; and Moon Creek, 4.5-482 mg/l and 0.2-1.3 cfs. Rosebud Creek, Pryor Creek and the Powder River were unusual to have consistently high TSS values through the lower reaches regardless of flow. Pryor Creek also had extremely high TSS values in some of its samples (values of 1720 and 3436 mg/l). Consequently, extremely high TSS concentrations were also obtained in some of the streams of the lower basin; values exceeding 1000 mg/l were found in the Yellowstone and Powder rivers and in Sunday and Glendive creeks. Extreme values of 62,800 mg/l were obtained in the Powder River and 66,000 mg/l in Glendive Creek. In the Yellowstone, TSS values of 2600 and 9450 mg/l were obtained. Such high TSS concentrations obviously degrade the quality of these streams, most noticeably in the Powder River.

Turbidities varied greatly within and between the streams of the lower Yellowstone Basin. Such fluctuations were apparently related to flow, judging from data from the Yellowstone River in which values varied from 6 JTU at 9300 cfs to 220 JTU at 35,100 cfs. During an extended rain in Sunday Creek, turbidities varied from 4 JTU at 0.6 cfs to 210 JTU at 75 cfs. Although turbidities less than 30 JTU were measured in almost all of the streams at appropriate seasons, values in the Little Powder and Powder rivers were consistently greater than 30 JTU. Fox Creek had turbidities consistently less than 10 JTU, possibly accounting for its value as a minor trout fishery.

WATER QUALITY DEGRADATION

It may be concluded that because of high TDS and TSS concentrations in some of the streams of the Yellowstone River Basin, the water quality in many of the tributaries and associated waters are poor, with a variety of water-use restrictions. The main problems contributed by TDS concentrations are bicarbonate and sulfate as anions and sodium as a cation; TSS levels are particularly detrimental to water quality at high-flow periods.

Concentrations of iron, manganese, and mercury may detract somewhat from water quality, but the remaining water quality parameters--dissolved oxygen, BOD, bacterial counts, pH, temperature, and nutrients (nitrate and phosphate)--apparently do not.

WATER QUALITY INDEX

The water quality index (WQI) of samples provides a valuable tool for assessing the relative water quality status of a stream. The WQI, developed by the National Sanitation Foundation (Brown et al. 1970, Brown et al. 1973, Brown and McClelland 1974, McClelland 1974), has been applied to several of the samples collected by the state WQB from the Yellowstone Basin in Montana from the mainstem and from numerous of the tributary streams (table 125).

Waters in the upper Yellowstone above Laurel can be considered good on the basis of their WQI's (Brown and McClelland 1974), but they show a general downstream decline in quality from Laurel to the North Dakota border. Brown and McClelland (1974) have developed the following relationships for the WQI: 0-25, very bad; 26-50, bad; 51-70, medium; 71-90, good; and 91-100, excellent. In these terms, the Laurel-to-Bighorn reach of the Yellowstone has water quality ranging from medium (51-70) to good (71-90); according to the mean WQI, a good quality is most typical. The same analysis applies to the Bighorn-to-Miles City reach, although a few samples with a bad rating (26-50) were also obtained there. In the extreme lower reach, a medium-minus classification (with a mean WQI equal to 55) would best describe its type of water.

The quality of waters in the Yellowstone Basin as a whole ranged from bad-to-good according to the WQI values. On the basis of average WQI's, the waters

TABLE 125. Water quality index (WQI) of samples collected by the state WQB from various streams, stream reaches, and drainage areas in the Yellowstone Basin.

Points of Collection	Number of Samples	Range of WQI	Mean WQI
Yellowstone River above Laurel	10	72.6-85.1	79.4
Yellowstone, Laurel to Bighorn	11	53.5-81.1	68.8
Yellowstone, Bighorn to Miles City	17	48.9-81.1	66.1
Yellowstone, Miles City to mouth	10	50.3-69.7	54.9
Pryor drainage	7	49.7-75.4	62.8
Arrow and Fly creeks	4	62.7-70.8	67.3
Little Bighorn River tributaries	13	60.4-84.3	72.2
Little Bighorn River	9	64.4-81.9	74.3
Bighorn-Yellowtail tributaries	6	76.7-91.3	85.7
Tullock Creek	7	61.7-75.9	68.9
Other Bighorn tributaries	7	57.3-75.7	65.4
Bighorn River	10	58.3-76.3	70.2
Sarpy and Armells creeks	20	44.5-83.2	69.7
Other small streams	14	54.3-83.6	73.4
Rosebud Creek tributaries	7	55.7-80.0	71.0
Upper Rosebud Creek	6	55.1-78.3	67.7
Middle Rosebud Creek	6	57.7-75.0	66.2
Lower Rosebud Creek	7	46.6-72.0	58.3
Tongue River tributaries	12	62.3-81.6	72.9
Pumpkin Creek	7	44.5-89.0	74.0
Upper Tongue River	3	77.4-78.5	77.8
Middle Tongue River	6	70.6-81.1	77.3
Tongue River-Miles City	6	55.0-80.2	69.8
Sunday Creek	4	56.9-82.9	62.9
Little Powder River	5	54.4-74.1	63.2
Mizpah Creek drainage	7	56.0-77.6	67.8
Upper Powder River	6	50.5-75.9	61.7
Lower Powder River	6	50.8-64.6	58.4
O'Fallon Creek	8	49.3-79.5	65.8
Basin Averages	--	57.2-78.8	68.8
Totals	241	---	--
Extremes	--	44.5-91.3	54.9-85.7

ranged from medium-to-good, with a medium-plus designation (a mean WQI equal to 69) most representative of the entire basin. The best water quality was obtained from the Yellowtail-Bighorn tributaries and from the upper Yellowstone River above Laurel. The lesser water quality was obtained from lower Rosebud Creek, from lower Powder River, and from the extreme lower reach of the Yellowstone River below Miles City. The tributaries to the Yellowstone and the associated streams typically had medium-to-good water quality.

The water quality in Rosebud Creek, the Tongue River, and the Powder River also declined to some extent downstream. In most cases, the tributary streams had slightly lesser water qualities than the mainstem, but the Yellowstone River had a lower quality than most of its tributaries at their points of confluence, according to the WQI. On the basis of a nationwide comparison made possible through the use of a standardized WQI, the waters of the Yellowstone Basin, including those in many of the small prairie tributaries and the Powder River, apparently have a fairly good quality according to the WQI.

However, the description of a good water quality in terms of the variables considered in the WQI is obviously not appropriate to water uses of the Yellowstone Basin as outlined throughout this report. The WQI designation of Sarpy and Armells creeks as having "almost" a good water quality (i.e., a mean WQI of 69.7 compared with the standard of 71) and a better quality than the Yellowstone seems ludicrous, but this is apparently true on a national scale of comparison. The development of a more specific WQI that relates directly to the Yellowstone drainage and its particular water uses and water quality problems may resolve such discrepancies.

POTENTIAL WATER QUALITY PROBLEMS IN RELATION TO WATER USE

The most obvious water-use restrictions throughout the Yellowstone Basin would be directed towards using the streams for surface water public supply and for drinking water. This is due primarily to the high TDS, sulfate, and hardness levels (table 9). Turbidity and the occasionally high fecal coliform, iron, manganese, and mercury concentrations could also restrict use for surface water public supply and for drinking water during some or all seasons in several of the streams. The unsuitability of water for public supply was found in almost all of the smaller streams in the primary study area of the basin and in many of the larger streams, including the lower reach of the Yellowstone River below Miles City.

The waters in the Yellowstone Basin, for the most part, should provide a good quality of water for stock animals (Seghetti 1951), and it should be excellent for all types of livestock (USEPA 1973). In some cases, however, particularly in the smaller streams, sulfate concentrations exceeded the limiting or threshold levels of livestock, which could affect the animals adversely. In a very few instances, other dissolved constituents, e.g., magnesium and bicarbonate, exceeded reference levels. Most commonly, TDS concentrations and sulfate exceeded the theshold-limiting levels; these waters were considered fair for livestock and not applicable to poultry. Highly saline waters termed poor and unfit were collected from a few of the smaller streams. Their use would be even more restricted. In general, though, the waters in the Yellowstone Basin appear to be highly suitable for livestock.

Restrictions to aquatic life in the Yellowstone Basin were also caused primarily by TDS concentrations. Temperature, of course, naturally regulates types of fisheries in the streams of the basins by providing warm-water and cold-water salmonid fisheries. The Yellowstone River gradates from a cold-water stream above Big Timber near the mountains to a warm-water stream below Bighorn in the lowlands (Berg 1977, Peterman 1977). There is no evidence that man's activities through point-source inputs disrupt or alter these natural changes to any great extent, except possibly through the industrialized Billings area (Karp et al. 1976b). Nonpoint influences would be much more likely in the Yellowstone Basin, but these would be difficult to recognize and quantify.

On the whole, dissolved oxygen, pH, temperature levels, and fecal coliform concentrations were within the criteria and standards established by the State of Montana (table 8) for stream designations applied to the waters of the Yellowstone drainage (Montana DHES, undated). The effects of salinity and suspended solids on the aquatic biota are expected to be much greater than the influences of most of the other water quality variables. However, iron and mercury had dissolved concentrations occasionally (and, in one case, the phenols) in excess of the reference criteria for aquatic life in some streams and reaches, including the Yellowstone River (table 19).

The effects of salinity on the aquatic biota would probably vary among the streams of the Yellowstone Basin, corresponding to the highly variable salinity levels of the region. In many instances, no effects or only mild influences are anticipated, with TDS and SC levels less than 670 mg/l and 1000 μmhos/cm. Ellis (1944) claims that these salinity levels are acceptable in western alkaline streams supporting a viable and mixed fish fauna. This is probably true in most of the large streams in the study area.

In many of the smaller lowland creeks, more adverse effects might be expected with TDS and SC levels greater than the values specified by Ellis (1944). In a few instances, salinity would be more detrimental to the freshwater biota, with TDS and SC levels greater than 1350 mg/l and 2000 μmhos/cm. Although salinity in many of the basin's streams was not at adequate levels to exert a marked influence over the aquatic biota, high suspended solids concentrations in their waters could act in this manner. This could result in a degradation of the stream's fishery potential (USEPA 1973, European Inland Fisheries Advisory Commission 1965, Bishop 1975, Peters 1962) and a reduction in its productivity (Klarich 1976) regardless of the low TDS levels. Many of the larger streams in the Yellowstone drainage would be affected in this way, including Pryor Creek, the Little Bighorn River, the lower Bighorn, Tongue, and Yellowstone rivers, and Rosebud Creek. In some cases, especially in the Powder River and in certain of the smaller streams, the dissolved and suspended solids would act together to degrade the aquatic environment.

Salinity was at adequate levels to reduce the value of some of the waters in the Yellowstone Basin for irrigation (Allison 1964, USEPA 1973, California WRCB 1974, USDA 1954, USEPA 1976). But this influence and its associated restrictions would vary considerably throughout the basin because of the variable TDS and SC levels among the streams. Some of the streams in the drainage would have an excellent source of water for application to all crop and forage species with minimal risk, and other streams would be unsuitable for a variety of plant types, particularly the salinity-sensitive species (table 17).

Overall, restrictions on water use are due to the high TDS-SC levels and their high sulfate concentrations rather than from high boron, chloride, or SAR (sodium) levels. The concentrations of the various trace elements (tables 15 and 16) generally do not reduce the value of a particular water for irrigation. The Powder River drainage and a few of the smaller streams have a high sodium hazard for irrigation because of the water's high sodium concentrations and SAR values, and its high salinity hazard. But in most instances, salinity is the major deterrant to irrigation, and the better water quality for irrigation is usually found in the larger streams which have lower salinity levels.

TABLE 126. Summary of water quality in the Yellowstone River Basin of Montana for surface water public supply and drinking water.

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions	pH (R) (NTAC permissible criteria)	Most streams in the Yellowstone Basin
	pH (R) (EPA recommendation)	Upper Sarpy, upper O'Fallon, and Glendive creeks
	Chloride (R)	Small Yellowstone tributaries below the Bighorn River, and the upper Powder River
	Chloride (O)	Sunday Creek
	Fluoride (R)	Small Yellowstone tributaries between the Bighorn and Powder rivers; Little Powder River
	Total hardness[b] (R)	Yellowstone-Big Timber to Laurel
	Total hardness[b] (F)	Yellowstone-Laurel to Custer; Sunday and Glendive creeks
	Total hardness[b] (C)	Yellowstone-Bighorn to mouth; remaining streams in the Yellowstone Basin
	TDS (R)	Upper Little Bighorn River; Bighorn-Yellowtail tributaries
	TDS (O)	Sage Creek; Yellowstone-Myers to Miles City
	TDS (F)	Lower Little Bighorn River; Yellowstone below Miles City; Tongue River
	TDS (C)	Pryor drainage; Arrow and Fly creeks; Little Bighorn tributaries; Bighorn River; remaining Bighorn tributaries; Sarpy and Armells creeks; Sunday Creek; small Yellowstone tributaries below Laurel; Rosebud drainage; Tongue tributaries; Powder and O'Fallon drainages

Table 126 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions (continued)	Sulfate (R)	Bighorn-Yellowtail tributaries; Yellowstone-Myers to Miles City
	Sulfate (O)	Little Bighorn River and tributaries; Yellowstone-below Miles City; Rosebud tributaries; Tongue River
	Sulfate (F)	Pryor drainage; Arrow Creek; upper Bighorn River; Sunday Creek
	Sulfate (C)	Fly Creek; lower Bighorn River; other Bighorn tributaries (except Sage Creek); Sarpy and Armells creeks; small Yellowstone tributaries below Laurel; remaining Rosebud Creek (except the upper Rosebud); Tongue tributaries; Powder and O'Fallon drainages
Physical factors	Turbidity-TSS (R)	Yellowstone-Laurel; Little Bighorn tributaries; Bighorn-Yellowtail tributaries; upper Tongue River; Hanging Woman Creek; possibly Otter Creek
	Turbidity-TSS (O)	Yellowstone-Billings to Intake; Arrow Creek; Little Bighorn River; lower Bighorn River; Bighorn tributaries (Soap, Rotten Grass, and Tullock creeks); Sarpy and Armells creeks; small Yellowstone tributaries below Bighorn; upper Rosebud Creek; small Tongue tributaries; Pumpkin Creek; Little Powder River; Mizpah Creek; O'Fallon drainage
	Turbidity-TSS (F)	Beauvais Creek; Sunday Creek; middle and lower Rosebud Creek; lower Tongue River (except below the dam); upper Powder River; lower Yellowstone River-Sidney
	Turbidity-TSS (C)	Pryor drainage; lower Powder River
Toxic-Harmful substances and health hazards	Fecal coliforms (R)	Lower Bighorn River; Yellowstone-Myers to Miels City; Sunday Creek; upper Rosebud Creek; upper and lower Tongue (not the middle Tongue below the dam); Pumpkin Creek; Powder River; Mizpah Creek; O'Fallon Creek, small Yellowstone tributaries below the Powder River and between Laurel and Custer

Table 126 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Fecal coliforms (O)	Yellowstone-Billings and Custer; Pryor drainage; Yellowstone-Terry to mouth
	Fecal coliforms (F)	Yellowstone River-Huntley
	Arsenic (R) U.S. Public Health Service standard	Yellowstone-Huntley to Miles City; middle Rosebud Creek
	Arsenic (O) U.S. Public Health Service standard	Yellowstone-Laurel to Billings
	Arsenic (F) U.S. Public Health Service standard	Yellowstone above Laurel
	Arsenic (R) U.S. Public Health Service rejection and NTAC criteria	Yellowstone-Laurel to Billings
	Selenium (R?)	Beauvais Creek
	Selenium (R)	Yellowstone-Laurel to Billings
	Cadmium (R?)	Sarpy and Armells drainages
	Iron (R)	Yellowstone River; Fly Creek; lower Bighorn River; Sarpy and Armells drainages; Hanging Woman and Otter creeks; upper Powder River
	Iron (R?)	Other Yellowstone tributaries between Laurel and Custer and below the Powder River; Bighorn-Yellowtail tributaries; Pumpkin Creek; lower Powder River; Mizpah Creek; O'Fallon drainage
	Iron (O)	Upper Tongue River
	Iron (O?)	Most Bighorn tributaries (Soap, Rotten Grass, Sage, and Tullock creeks); small Yellowstone tributaries between the Bighorn and Powder rivers; Sunday Creek

Table 126 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Iron (F)	Beauvais Creek; little Powder River
	Manganese (R)	Yellowstone River; little Bighorn River; upper Bighorn River; upper Tongue River and below the dam; small Tongue tributaries; upper Powder River
	Manganese (R?)	Little Bighorn tributaries, lower Bighorn River, Bighorn-Yellowtail tributaries, lower Tongue River (except, possibly, Tongue-Miles City); lower Powder River; Mizpah Creek; O'Fallon drainage; Yellowstone tributaries below the Powder River
	Manganese (O)	Sarpy Creek; east and west fork Armells Creek; small Yellowstone tributaries between the Bighorn and Powder rivers
	Manganese (O?)	Bighorn tributaries (Soap, Rotten Grass, Sage, and Tullock creeks); Sunday Creek
	Manganese (F)	Fly Creek; Beauvais Creek; lower Armells Creek, little Powder River
	Manganese (F?)	Other Yellowstone tributaries between Laurel and Custer
	Mercury (R)	Yellowstone-Myers to Miles City; small Yellowstone tributaries between the Bighorn and Powder rivers; upper Tongue River and Tongue-Miles City; lower Powder River; little Powder River
	Mercury (R?)	Yellowstone-Huntley to Custer; Bighorn River; Beauvais Creek; Armells Creek
	Mercury (O)	Yellowstone River above Huntley and the lower Yellowstone near Sidney; upper Powder River
	Mercury (O?)	Upper Sarpy Creek (possibly not lower Sarpy)
	Nitrite-Nitrate	No streams in the Yellowstone Basin

Table 126 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Ammonia (R)	Yellowstone-Laurel to Custer; upper Bighorn River; upper Powder River
	Ammonia (O)	East fork Armells Creek
	Ammonia (C)	Upper Sarpy Creek
	Phenols (F)	Yellowstone-Laurel to Custer[c]

NOTE: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]Waters were classified as hard-very hard.

[c]This stream reach was the only one with available phenol data.

TABLE 127. Summary of water quality in the Yellowstone River Basin of Montana for livestock.

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions	TDS (threshold)[b] (R)	Small Yellowstone tributaries between the Bighorn and Powder rivers; small Tongue tributaries
	TDS (threshold)[b] (O)	Small Yellowstone tributaries between Laurel and Custer; lower Sarpy Creek; Hanging Woman, Otter, and lower Pumpkin creeks; Little Powder River; O'Fallon drainage
	TDS (threshold)[b] (F)	Upper Sarpy Creek
	TDS (threshold)[b] (C)	Armells drainage; upper Pumpkin Creek; Mizpah drainage; small Yellowstone tributaries below the Powder River (except Fox and Glendive creeks)
	TDS (limiting)[c] (R)	East fork Armells Creek; small Tongue tributaries; Mizpah Creek
	TDS (limiting)[c] (O)	Upper Sarpy Creek; west fork Armells Creek; small Yellowstone tributaries below the Powder River (except Fox and Glendive creeks)
	TDS (limiting)[c] (F)	Upper Pumpkin Creek
	TDS (limiting)[c] (C)	Mizpah Creek tributaries
	pH (threshold) (NTAC permissible criteria	Most streams in the Yellowstone Basin
	pH (limiting) (EPA recommendation)	Upper Sarpy, upper O'Fallon, and Glendive creeks
	Bicarbonate (R)	Fly Creek; minor little Bighorn tributaries; small Yellowstone tributaries below Bighorn; Sunday Creek; lower Rosebud Creek; little Powder River

Table 127 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions (continued)	Bicarbonate (O)	Tullock and lower Pumpkin creeks; O'Fallon drainage
	Bicarbonate (F)	Lower Sarpy Creek; Armells drainage; Rosebud and small Tongue tributaries; Mizpah drainage
	Bicarbonate (C)	Upper Sarpy, Hanging Woman, Otter, and upper Pumpkin creeks
	Fluoride (threshold) (R)	Yellowstone above Huntley; Beauvais Creek; small Yellowstone tributaries between the Bighorn and Powder rivers; Sunday and lower Rosebud creeks; little Powder River
	Fluoride (threshold) (O)	Upper Sarpy Creek; small Tongue tributaries
	Fluoride (R) (EPA recommendation)	Small Yellowstone tributaries between the Bighorn and Powder rivers; little Powder River
	Magnesium (threshold) (R)	Small Tongue tributaries
	Magnesium (threshold) (O)	Upper Sarpy and upper Armells creeks
	Magnesium (threshold) (F)	Upper Pumpkin Creek
	Magnesium (limiting) (R)	Cedar Creek
	Sodium (threshold) (R)	Upper Sarpy Creek; Armells drainage; Lonetree Creek
	Sodium (threshold) (F)	Upper Pumpkin Creek
	Sodium (threshold) (C)	Mizpah Creek tributaries
	Sodium (limiting) (R)	Cedar and Second Hay creeks
	Sulfate (threshold) (R)	Arrow, Sunday, and lower Rosebud creeks
	Sulfate (threshold) (O)	Rotten Grass Creek

Table 127 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions (continued)	Sulfate (threshold) (F)	Lower Tullock Creek; small Tongue tributaries
	Sulfate (threshold) (C)	Small Yellowstone tributaries-Laurel to mouth; Fly, Beauvais, and Sarpy creeks; Armells drainage; major Tongue tributaries; Powder and O'Fallon drainages
	Sulfate (limiting) (R)	Beauvais and lower Tullock creeks; Powder River
	Sulfate (limiting) (O)	Fly Creek; small Yellowstone tributaries below Bighorn; small Tongue tributaries; little Powder River
	Sulfate (limiting) (F)	Lower Sarpy, Hanging Woman, and lower Pumpkin creeks
	Sulfate (limiting) (C)	Small Yellowstone tributaries between Laurel and Custer; upper Sarpy Creek; Armells drainage; Otter and upper Pumpkin creek; Mizpah and O'Fallon drainages
	Chloride (threshold) (R)	Cedar Creek
Toxic-Harmful substances and health hazards	Nitrite-Nitrate	No streams in the Yellowstone Basin
	Vanadium (R?)	Lower Sarpy and Armells creeks; small Yellowstone tributaries below Bighorn

NOTES: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted. No apparent problems were noted for stock from trace elements and metals in the basin.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]Fair-to-poor waters for stock.

[c]Generally unfit waters for stock.

TABLE 128. Summary of water quality in the Yellowstone River Basin of Montana for irrigation.

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions	High salinity hazard[b] (R)	Yellowstone-Myers to Forsyth; upper Little Bighorn River
	High salinity hazard[b] (O)	Lower little Bighorn River; Yellowstone-Miles City to Intake
	High salinity hazard[b] (F)	Upper Tongue River and below dam; lower Yellowstone River near Sidney
	High salinity hazard[b] (C)	Pryor drainage; Arrow and Fly creeks; little Bighorn tributaries; Bighorn River; Bighorn tributaries (Beauvais, Soap, Rotten Grass, and Tullock creeks); Sunday and Rosebud creeks; Rosebud tributaries; lower Tongue River; small Tongue tributaries; lower Pumpkin Creek; Powder River; Fox Creek
	Very high salinity hazard[c] (O)	Fly and lower Tullock creeks; Powder River
	Very high salinity hazard[c] (F)	Small Yellowstone tributaries (except Fox Creek); small Tongue tributaries; lower Pumpkin Creek
	Very high salinity hazard[c] (C)	Sarpy and Armells drainages; Hanging Woman, Otter, and upper Pumpkin creeks; little Powder River; Mizpah and O'Fallon drainages
	Medium-high sodium hazard[d] (R)	Upper Sarpy and east fork Armells creeks; small Tongue tributaries (except Deer Creek)
	Medium-high sodium hazard[d] (O)	Upper Powder River
	Medium-high sodium hazard[d] (F)	Small Yellowstone tributaries-Laurel to Custer; Fly and Tullock creeks; Deer Creek; lower Powder River

Table 128 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions (continued)	Medium-high sodium hazard[d] (C)	Lower Sarpy and west fork Armells creeks; lower Armells Creek; small Yellowstone tributaries between the Bighorn and Powder rivers; Sunday, Hanging Woman, and Otter creeks; little Powder River; Mizpah and O'Fallon drainages
	High-very high sodium hazard[e] (R)	Lower Armells and Sunday creeks
	High-very high sodium hazard[e] (O)	Mizpah Creek
	High-very high sodium hazard[e] (F)	Pumpkin Creek; O'Fallon drainage; small Yellowstone tributaries below the Powder River (except Fox Creek)
	High-very high sodium hazard[e] (C)	Mizpah tributaries
	Potential chloride problems (R)	Small Yellowstone tributaries between the Bighorn and Powder rivers; Powder River; Cedar Creek
	Potential chloride problems (O)	Sunday Creek
	Minor sulfate problems[f] (R)	Sunday Creek
	Minor sulfate problems[f] (O)	Beauvais and lower Tullock creeks; small Tongue tributaries (except Deer Creek); upper Powder River; O'Fallon Creek
	Minor sulfate problems[f] (F)	Small Yellowstone tributaries-Laurel to the Powder River; Fly Creek; lower Pumpkin Creek; lower Powder River; Mizpah Creek

Table 128 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions (continued)	Minor sulfate problems[f] (C)	Sarpy, Hanging Woman, and Otter creeks; little Powder River
	Major sulfate problems[g] (R)	Otter Creek
	Major sulfate problems[g] (O)	Lower Sarpy, Hanging Woman, and lower Pumpkin creeks; little Powder River; Mizpah Creek
	Major sulfate problems[g] (F)	Upper Sarpy and Deer creeks; O'Fallon tributaries
	Major sulfate problems[g] (C)	Armells drainage; upper Pumpkin Creek; Mizpah tributaries; small Yellowstone tributaries below the Powder River (except Fox and Glendive creeks)
	Fluoride (threshold) (R)	Yellowstone above Huntley; Beauvais Creek; small Yellowstone tributaries between the Bighorn and Powder rivers; Sunday and lower Rosebud creeks; little Powder River
	Fluoride (threshold) (O)	Upper Sarpy Creek; small Tongue tributaries
Toxic-Harmful substances and health hazards	Boron	Does not appear to be an affecting factor in the Yellowstone Basin
	Cadmium (R?)	Sarpy and Armells drainages
	Manganese (R)	Yellowstone above Livingston; Beavais Creek; Armells drainage; upper Powder River
	Manganese (R?)	Soap, Rotten Grass, and Tullock creeks
	Molybdenum (R)	Beauvais Creek

Table 128 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Physical factors	Molybdenum (O)	Upper Bighorn River
	Selenium (O)	Yellowstone-Laurel to Billings
	Vanadium (R?)	Sarpy and Armells creeks; small Yellowstone tributaries below the Bighorn River
	Flow	Many of the smaller streams are restricted to flood irrigation during high-flow runoff periods
	TSS[h] (R)	Yellowstone-Laurel to Custer; upper Pryor and Sarpy creeks; Armells drainage; Yellowstone tributaries between the Bighorn and Powder rivers; Mizpah and O'Fallon drainages
	TSS[h] (R,O)	Yellowstone-Myers to Miles City; Tongue River near Miles City
	TSS[h] (O)	Little Bighorn and lower Bighorn rivers; Rotten Grass, Soap, lower Tullock, Sunday, lower Rosebud, and Pumpkin creeks; Yellowstone-Terry to Intake
	TSS[h] (F)	Lower Pryor Creek; Beauvais Creek; upper Powder River; little Powder River; lower Yellowstone River near Sidney; Glendive Creek
	TSS[h] (C)	Lower Powder River

NOTE: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

Table 128 (continued)

[b]Based on TDS concentrations and SC levels; waters are most typically Class II.

[c]Based on TDS concentrations and SC levels; waters are most typically Class III.

[d]Based on SAR values; waters are most typically Class II.

[e]Based on SAR values; values are most typically Class III.

[f]Most typical of Class II waters.

[g]Most typical of Class III waters.

[h]There is an indirect effect on irrigation by silting ditches and the potentially reduced soil permeability; 300 mg/l is used as a general guide.

TABLE 129. Summary of water quality in the Yellowstone River Basin of Montana for aquatic biota.

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions	Potential effects[b] (R)	Little Bighorn and upper Tongue rivers; Yellowstone-Powder River to mouth
	Potential effects[b] (O)	Pryor and Arrow creeks; Bighorn River; upper Rosebud Creek; lower Tongue River
	Potential effects[b] (F)	Fly Creek; small Tongue tributaries; Fox Creek
	Potential effects[b] (C)	Beauvais, Soap, Rotten Grass, Tullock, Sunday, and lower Rosebud creeks; Rosebud tributaries; Pumpkin Creek; Powder River; lower O'Fallon Creek
	Detrimental effects[b] (R)	Beauvais Creek
	Detrimental effects[b] (O)	Fly Creek; small Tongue tributaries
	Detrimental effects[b] (F)	Lower Tullock and Pumpkin creeks; Powder River; lower O'Fallon Creek
	Detrimental effects[b] (C)	Small Yellowstone tributaries (except Fox Creek); Sarpy Creek; Armells drainage; Hanging Woman and Otter creeks; little Powder River; Mizpah drainage; upper O'Fallon Creek and tributaries
	pH ($B\text{-}D_1$ stream) (R)	Yellowstone River above Laurel; lower Pryor Creek
	pH ($B\text{-}D_2$, $B\text{-}D_3$ streams (R)	Upper Sarpy and O'Fallon creeks; Glendive Creek
Physical factors-TSS (Turbidity)[c]	Poor fishery (R)	Yellowstone-Custer to Miles City; little Bighorn River; Bighorn near Bighorn (mouth); Soap, Rotten Grass, and lower Tullock creeks; Tongue River near Miles City

Table 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Physical factors-TSS (turbidity)[c] (continued)	Poor fishery (O)	Lower Pumpkin Creek; Yellowstone-Terry to Intake
	Poor fishery (F)	Beauvais, Sunday, and lower Rosebud creeks; little Powder River
	Poor fishery (C)	Lower Pryor Creek; Powder River; Yellowstone River near Sidney
	Very poor fishery (R)	Yellowstone-Terry to Intake
	Very poor fishery (O)	Beauvais and Sunday creeks; little Powder River; Yellowstone River near Sidney
	Very poor fishery (F)	Upper Powder River
	Very poor fishery (C)	Lower Pryor Creek; lower Powder River; Glendive Creek
Physical factors-Temperature[d]	B-D_1 streams (definite problem)	Lower Pryor Creek
	B-D_2 streams (possible problem)	Lower little Bighorn and upper Tongue rivers
	B-D_3 streams (possible problem)	Sunday and lower Mizpah creeks
Physical factors-Turbidity[e]	Turbidity effects (R)	Yellowstone-Big Timber to Laurel; small Yellowstone tributaries-Laurel to Custer
	Turbidity effects (O)	Yellowstone-Laurel to Miles City; Arrow and Fly creeks; upper little Bighorn River; Sage Creek; lower Sarpy and lower Armells creeks; upper Rosebud Creek; upper Tongue River (except the Tongue below dam); small Tongue tributaries; Hanging Woman and lower Pumpkin creeks
	Turbidity effects (F)	Lower little Bighorn, lower Bighorn, and lower Tongue rivers

Table 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Physical factors-Turbidity[e] (continued)	Turbidity effects (C)	Pryor Creek; Pass and Owl creeks (little Bighorn tributaries); Beauvais, Soap, Rotten Grass, and Tullock creeks; Sunday Creek; lower Rosebud Creek; Powder and little Powder rivers; lower Mizpah and tributaries; Yellowstone-Terry to Sidney; O'Fallon drainage; Glendive Creek
	B-D_3 streams (R)	Lower Tullock, Sarpy, and east fork of Armells creeks; lower Rosebud and Otter creeks; upper Powder River
	Critical levels (<3 mg/l) (R)	Lower Sarpy Creek; upper Powder River
Eutrophic potential[f]	Phosphorus (R,O)	Most of the streams in the Yellowstone Basin produced a few or occasional samples with phosphorus in excess of reference criteria and the EPA's reference levels.
	Phosphorus (F)	Yellowstone River near Laurel; Arrow and Sunday creeks; Yellowstone-Terry to Intake
	Phosphorus (C)	Yellowstone near Corwin Springs; Yellowstone-Huntley to Custer; Bighorn River near Hardin; Beauvais and Rotten Grass creeks; lower Rosebud Creek; upper Tongue River; Powder River; Yellowstone near Sidney
	Phosphorus (F) (EPA recommendation)	Yellowstone River near Huntley; Bighorn River near Hardin; Beauvais, Sunday, and lower Rosebud creeks; upper Tongue River
	Phosphorus (C) (EPA recommendation)	Yellowstone near Custer; Powder River; Yellowstone near Sidney
	Nitrogen (R,O)	Most of the streams in the Yellowstone Basin produced a few or occasional samples with nitrogen in excess of reference criteria and the EPA's reference levels.

TABLE 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Eutrophic potential[f] (continued)	Nitrogen (F)	Yellowstone River near Custer; Bighorn River near Hardin; Sunday Creek; Powder River; Yellowstone-Terry to Intake and near Sidney
	Nitrogen (C)	Arrow Creek
	Nitrogen (F,C) (EPA recommendation)	No streams in the Yellowstone Basin
	Phosphorus and nitrogen (N,R)	Most streams in the Yellowstone Basin were non-eutrophic
	Phosphorus and nitrogen (O)	Sunday Creek; Yellowstone-Terry to Intake
	Phosphorus and nitrogen (F)	Arrow Creek; Yellowstone near Custer; Bighorn near Hardin; Powder River; Yellowstone near Sidney
	Phosphorus and nitrogen (C)	No streams (possibly eutrophic)
	Phosphorus and nitrogen (F,C) (EPA recommendation)	No streams (high probability of eutrophy)
Toxic-Harmful substances and health hazards	Aluminum	Yellowstone, Bighorn, and Tongue Rivers; Otter and Beauvais creeks all had a few samples in excess of reference criteria, but this probably does not suggest a hazard. TR concentrations were generally high but dissolved levels were typically low.
	Silver	Only a few analyses were made; some samples were in excess of minimal risk levels, but did not indicate a hazard
	Arsenic	No apparent problems, even in the upper Yellowstone

Table 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Copper (R)	Yellowstone River above Livingston; upper Bighorn River; Beauvais Creek; upper Yellowstone
	Copper (R?)	Small Yellowstone tributaries between Laurel and Custer; Tullock and Sunday creeks; Mizpah drainage
	Iron (R)	Yellowstone above Custer[g], upper Bighorn River; lower Bighorn River[g]; west fork Armells Creek[g], lower Armells Creek[g]; Rosebud drainage; Tongue River near Miles City (except below dam to Brandenburg); small Tongue tributaries; Hanging Woman[g], Otter[g], and Pumpkin[g] creeks; Powder River[g]; Yellowstone near Sidney[g].
	Iron (R?)	Small Yellowstone tributaries below Laurel[g]; Sage Creek
	Iron (O)	Yellowstone River near Miles City[g]; Sarpy Creek[g]; upper Tongue River[g]
	Iron (O?)	Soap[g], Rotten Grass[g], and Tullock[g] creeks; Sunday Creek[g]; Mizpah[g] and O'Fallon[g] drainages
	Iron (C)	Beauvais Creek[g]; little Powder River[g]
	Total mercury (grab sample) (R)	Bighorn River; Yellowstone River near Myers; upper Tongue and lower Tongue River below Birney; Hanging Woman, Otter, and Pumpkin creeks
	Total mercury (grab sample) (R?)	Little Bighorn River and tributaries; Tongue River below the dam
	Total mercury (grab sample) (O)	Yellowstone above Huntley[h]; Beauvais Creek; small Yellowstone tributaries between the Bighorn and Powder rivers; lower Rosebud Creek[h]; small Tongue tributaries[h]; Yellowstone River-Terry to Intake; Yellowstone River near Sidney[h]

Table 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Total mercury (grab sample) (F)	Yellowstone-Forsyth to Miles City[h]; lower Sarpy Creek; lower Armells Creek[h]; Powder River[h]
	Total mercury (grab sample) (C)	Upper Sarpy[h] and Armells[h] creeks; little Powder River[h]
	Inadequate mercury data	Small Yellowstone tributaries; little Bighorn River and tributaries; upper Bighorn River and most tributaries; Sunday Creek; upper Rosebud Creek and tributaries; upper Tongue and below dam; Pumpkin Creek; Mizpah and O'Fallon drainages
	Manganese (distinct hazard)	No streams in the Yellowstone Basin
	Manganese (slight hazard) (F)	Yellowstone above Laurel; upper Bighorn River; Beauvais, Tullock, and Sarpy creeks; small Tongue tributaries; upper Powder and little Powder rivers; Yellowstone near Sidney
	Manganese (slight hazard) (R?)	Small Yellowstone tributaries between Laurel and Custer; Sunday Creek; Mizpah drainage
	Manganese (slight hazard) (O)	Armells Creek
	Selenium (R)	Yellowstone-Laurel to Billings; Beauvais Creek; upper Powder River
	Zinc (very slight hazard) (R)	Yellowstone River above Billings; Yellowstone River near Miles City; Armells Creek; Rosebud drainage; Yellowstone River near Sidney
	Zinc (very slight hazard) (R?)	Soap, Rotten Grass, and Tullock creeks; Sarpy and Pumpkin creeks
	Zinc (very slight hazard) (R,O)	Tongue River

Table 129 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Zinc (very slight hazard) (O)	Yellowstone-Myers to Forsyth; small Tongue tributaries; Otter Creek; Yellowstone River-Terry to Intake
	Zinc (very slight hazard) (F)	Beauvais Creek; Powder River
	Zinc (very slight hazard) (C)	Bighorn River
	Zinc (definite hazard) (R)	Small Yellowstone tributaries between the Bighorn and Powder rivers; little Powder River
	Fluoride (R)	Small Yellowstone tributaries between the Bighorn and Powder rivers; little Powder River
	Cyanide (R)	Yellowstone River-Laurel to Billings; upper Powder River
	Phenols	Probably not at levels high enough to affect the aquatic biota
	Ammonia (un-ionized)[i] (R)	Yellowstone-Livingston to Laurel; upper Bighorn River; Yellowstone River near Miles City; upper Powder River
	Ammonia (un-ionized)[i] (O)	Yellowstone-Laurel to Custer; east fork of Armells Creek
	Ammonia (unionized)[i] (C)	Upper Sarpy Creek

NOTE: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

Table 129 (continued)

[b]Based on TDS concentrations and SC levels.

[c]Generally based on median seasonal suspended sediment concentrations. Samples where high suspended sediment levels were frequently and consistently obtained probably indicate major overall degradation of the fishery; samples where high suspended sediment levels were only rarely or occasionally obtained indicate runoff events with lesser effects on the fishery.

[d]In general, temperature ranges and maximum temperatures of the streams in the Yellowstone Basin were in accord with the B-D designations assigned by the State of Montana.

[e]Retardation of primary production through reduced light penetration; generally based on a median turbidity of 25 JTU (from Klarich 1976).

[f]Arrow Creek, the Yellowstone River near Custer, the Bighorn River near Hardin, the Powder River, and the Yellowstone River near Sidney were the locations most likely to have eutrophic conditions, but none demonstrated a high probability of developing eutrophy.

[g]Potentially hazardous iron levels to aquatic life occurred.

[h]Median mercury exceeded the average criteria. Detection levels of numerous analyses were inadequate to fully assess the potential mercury problems in many cases.

[i]Based on a pH value of 8.0; ammonia data are not available on many streams.

TABLE 130. Summary of the potential for organic pollution in the Yellowstone River Basin of Montana.

Parameter Group	Restricting Parameters[a]	Affected Streams
Oxygen status	Low percentage DO saturation[b] (R)	Yellowstone-Myers to Sidney; lower Tongue River; Powder River (a few extremely low readings of less than 40 percent were obtained in conjunction with high TSS levels)
	Low percentage DO saturation[b] (O)	Armells and Rosebud creeks; small Tongue tributaries; Hanging Woman and Otter creeks
	Low percentage DO percentage[b] (F)	Sarpy and Mizpah creeks
	High BOD_5[c] (R)	Tullock, lower Sarpy, and lower Armells creeks; small Yellowstone tributaries between the Bighorn and Powder rivers; Sunday and Pumpkin creeks
	High BOD_5[c] (O)	Mizpah drainage and lower O'Fallon Creek
	High BOD_5[c] (F)	Upper Sarpy Creek; little Powder River
	High TOC[d] (R)	Yellowstone River above Livingston never had excessive TOC levels; Yellowstone-Livingston to Laurel; Yellowstone-Laurel to Billings never had excessive TOC levels; Yellowstone-Huntley to Custer; Bighorn River; Yellowstone-Myers to Miles City
	High TOC[d] (O)	Upper and middle Tongue River; Yellowstone-Terry to Sidney
	High TOC[d] (F)	Tongue River near Miles City
	High TOC[d] (F?)	Little Powder River
	High TOC[d] (C)	All Tongue tributaries; lower Powder River

Table 130 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Oxygen status (continued)	Very high TOC and COD levels (>40 mg/l in at least one sample)	Yellowstone River below Livingston; upper Sarpy Creek; small Tongue tributaries; lower Powder River

NOTES: Streams not listed for a water quality parameter were not affected by the restricting parameters; also, non-affecting parameters are omitted.

No COD data was available on Armells and Rosebud creeks and many other streams.

[a]Water quality parameters listed are those that rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]Based on Beauvais Creek data.

[c]A median value of 5 mg/l and a maximum level of 10 mg/l from Beauvais Creek were used as reference points, but even these values are not particularly notable.

[d]Values of 10 mg/l were used for TOC and 20 mg/l for COD, surface water average, for general reference. These levels were not exceptional. In general, the Yellowstone Basin does not appear to be influenced by much organic pollution, including the reach near Laurel-Billings. The only exception may be in upper Sarpy Creek.

TABLE 131. Summary of violations of state water quality standards in the Yellowstone River Basin of Montana.

Parameter Group	Restricting Parameters[a]	Affected Streams
Salinity and common ions	pH ($B\text{-}D_1$ stream) (R)	Yellowstone River above Laurel; lower Pryor Creek
	pH ($B\text{-}D_2$, $B\text{-}D_3$ streams (R)	Upper Sarpy and O'Fallon creeks; Glendive Creek
Physical factors-temperature[b]	$B\text{-}D_1$ streams (definite problem)	Lower Pryor Creek
	$B\text{-}D_2$ streams (possible problem)	Lower little Bighorn and upper Tongue rivers
	$B\text{-}D_3$ streams (possible problem)	Sunday and lower Mizpah creeks
Toxic-Harmful substances and health hazards	Fecal coliforms (grab sample) (R)	Yellowstone near Laurel; Owl and Pass creeks (little Bighorn tributaries); lower Armells Creek; small Yellowstone tributaries below Bighorn; all Tongue tributaries
	Fecal coliforms (grab sample) (R?)	Fly Creek; upper Rosebud Creek and tributaries (the lower Rosebud never had excessive levels)
	Fecal coliforms (grab sample) (O)	Yellowstone-Custer to Forsyth; Pryor Creek drainage; most Bighorn tributaries and the little Bighorn River; upper Sarpy Creek; upper Tongue River (the middle Tongue never had excessive levels); lower Tongue near Miles City; Powder and little Powder rivers; Yellowstone near Sidney; O'Fallon drainage
	Fecal coliforms (grab sample) (O?)	Arrow Creek

Table 131 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Toxic-Harmful substances (continued)	Fecal coliforms (grab sample) (F)	Yellowstone-Billings to Huntley; Yellowstone near Miles City; Sunday Creek; Mizpah drainage; Yellowstone-Terry to Intake
	Fecal coliforms (average) (R?)	Arrow and Fly creeks; Pass Creek; upper Rosebud Creek and tributaries (the lower Rosebud never had excessive levels)
	Fecal coliforms (average) (O)	Yellowstone River near Custer; Pryor Creek drainage; Yellowstone-Myers to Miles City; upper Tongue River (the remainder of the Tongue below the dam never had excessive levels); Powder River; Mizpah drainage
	Fecal coliforms (average) (O?)	Soap Creek (Bighorn tributary)
	Fecal Coliforms (average) (F)	Yellowstone River near Billings and from Terry to Intake; Sunday Creek
	Fecal coliforms (average) (C)	Yellowstone River near Huntley
	Radiochemistry	The small amounts of radiochemical data available on the Yellowstone Basin indicate that these constituents should cause no problems.
	Oil and grease (R)	Yellowstone-Livingston to Laurel (Yellowstone-Huntley to Custer never had excessive levels); upper Sarpy Creek

NOTES: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted.

In many cases, the R and O violations listed for fecal coliforms were associated primarily with runoff.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]In general, temperature ranges and maximum temperatures of the streams in the Yellowstone Basin were in accord with the B-D designations assigned by the State of Montana.

TABLE 132. Summary of aesthetic quality in the Yellowstone River Basin of Montana.

Parameter Group	Restricting Parameters[a]	Affected Streams
Physical factors	Color (slightly colored)[b] (R)	Yellowstone-Laurel to Billings; Bighorn River and Beauvais Creek; Yellowstone River near Miles City; Tongue River near Miles City; Yellowstone near Sidney
		No data is available on Yellowstone-Livingston to Laurel, Yellowstone-Custer to Forsyth, Tongue River above Miles City, Yellowstone-Terry to Intake
	Color (slightly colored)[b] (N)	Yellowstone-Corwin Springs to Livingston; Yellowstone-Billings to Custer
	Color (slightly colored)[b] (C)	Upper Powder River; no data is available on the lower Powder and little Powder r-vers
	Color (highly colored)[b] (O)	Upper Powder River
	Color (highly colored)[b] (C)	Upper Sarpy Creek; no data available on lower Sarpy
	Turbidity (TSS) (R)	Yellowstone-Laurel; little Bighorn tributaries; Bighorn-Yellowtail tributaries; upper Tongue River; Hanging Woman Creek; possibly Otter Creek
	Turbidity-TSS (O)	Yellowstone-Billings to Intake; Arrow Creek; little Bighorn River; lower Bighorn River; Bighorn tributaries (Soap, Rotten Grass, and Tullock creeks); Sarpy and Armells creeks; small Yellowstone tributaries below Bighorn; upper Rosebud Creek; small Tongue tributaries; Pumpkin Creek; little Powder River; Mizpah Creek; O'Fallon drainage

Table 132 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Physical factors (continued)	Turbidity-TSS (F)	Beauvais Creek; Sunday Creek; middle and lower Rosebud Creek; lower Tongue River (except below the dam); upper Powder River; lower Yellowstone River-Sidney
	Turbidity-TSS (C)	Pryor drainage; lower Powder River
Eutrophic potential[c]	Phosphorus (R,O)	Most of the streams in the Yellowstone Basin produced a few or occasional samples with phosphorus in excess of reference criteria and the EPA's reference levels.
	Phosphorus (F)	Yellowstone River near Laurel; Arrow and Sunday creeks; Yellowstone-Terry to Intake
	Phosphorus (C)	Yellowstone near Corwin Springs; Yellowstone-Huntley to Custer; Bighorn River near Hardin; Beauvais and Rotten Grass creeks; lower Rosebud Creek; upper Tongue River; Powder River; Yellowstone near Sidney
	Phosphorus (F) (EPA recommendation)	Yellowstone River near Huntley; Bighorn River near Hardin; Beauvais, Sunday, and lower Rosebud creeks; upper Tongue River
	Phosphorus (C) (EPA recommendation)	Yellowstone near Custer; Powder River; Yellowstone near Sidney
	Nitrogen (R,O)	Most of the streams in the Yellowstone Basin produced a few or occasional samples with nitrogen in excess of reference criteria and the EPA's reference levels.
	Nitrogen (F)	Yellowstone River near Custer; Bighorn River near Hardin; Sunday Creek; Powder River; Yellowstone-Terry to Intake and near Sidney
	Nitrogen (C)	Arrow Creek
	Nitrogen (F,C) (EPA recommendation)	No streams in the Yellowstone Basin

Table 132 (continued)

Parameter Group	Restricting Parameters[a]	Affected Streams
Eutrophic potential[c] (continued)	Phosphorus and nitrogen (N,R)	Most streams in the Yellowstone Basin were non-eutrophic
	Phosphorus and nitrogen (O)	Sunday Creek; Yellowstone-Terry to Intake
	Phosphorus and nitrogen (F)	Arrow Creek; Yellowstone near Custer; Bighorn near Hardin; Powder River; Yellowstone near Sidney
	Phosphorus and nitrogen (C)	No streams (possibly eutrophic)
	Phosphorus and nitrogen (F,C) (EPA recommendation)	No streams (high probability of eutrophy)
Toxic-Harmful substances and health hazards	Oil and grease (R)	Yellowstone-Livingston to Laurel; upper Sarpy Creek
	Oil and grease (N)	Yellowstone-Huntley to Custer
	Phenols	The small amount of data available on phenols indicate that this constituent is apparently not at adequate levels to taint fish flesh and degrade sports fisheries at present; however, this has been a problem in the Yellowstone River below Billings in past years
	MBAS[d] (detectable) (R)	Several locations on the Yellowstone River
	MBAS[d] (detectable) (R)	Upper Bighorn River (no data available on lower reach)
	MBAS[d] (detectable) (F)	Upper Powder River (no data available on lower reach)
	MBAS[d] (high levels)	No streams with available data

Table 132 (continued)

NOTE: Streams not listed were not affected by the restricting parameters. Also, non-affecting parameters are usually omitted.

[a]Restricting water quality parameters listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]Color of ten units was used as a reference point. Color data was not available for many streams, such as the Little Bighorn River; Armells, Rosebud, and Mizpah creeks; and most small streams.

[c]Arrow Creek, the Yellowstone River near Custer, the Bighorn River near Hardin, the Powder River, and the Yellowstone River near Sidney were the locations most likely to have eutrophic conditions, but none demonstrated a high probability of developing eutrophy.

[d]MBAS data indicate the occurrence of synthetic detergents. Concentrations higher than 0.5 mg/l indicate the potential development of unsightly foaming in flowing waters. However, this does not appear likely in the Yellowstone Basin, which had MBAS levels generally less than 0.05 mg/l, but data are lacking for most streams in the drainage.

TABLE 133. Summary of miscellaneous constituents in the Yellowstone River Basin of Montana.

Constituents[a]	Affected Streams
Pesticides-herbicides	Available data indicate that pesticides-herbicides probably do not cause water quality problems in the Yellowstone Basin. These constituents were detected in only a small percentage of the samples analyzed and in small concentrations.
Strontium	This constituent does not appear to be at levels high enough to cause radiochemical water quality problems in the Yellowstone drainage.
Silica	This constituent does not occur in concentrations high enough to degrade water quality in the Yellowstone Basin.
Fecal strep[b] (R)	Lower Bighorn, lower Tongue, and lower Powder rivers; lower Yellowstone River near Sidney
Fecal strep[b] (F)	Beauvais Creek

NOTE: Streams not listed were not affected by the constituents listed.

[a]Constituents listed are those which rarely (R), occasionally (O), frequently (F), consistently (C), or never (N) exceeded the associated reference criteria for a water use or feature.

[b]Fecal strep data are available on only a few streams in the Yellowstone drainage; the state's fecal coliform criteria for grab samples serves as the reference point. As indicated, fecal strep concentrations were not particularly high and did not suggest municipal pollution; FC:FS ratios generally indicate animal rather than human wastes entering the streams. FC:FS values were typically less than one.

The major exception was found in the lower segment of the Yellowstone River near Sidney, which was apparently affected by municipal inputs judging from its FC:FS ratio greater than two. Fecal strep data are not available on the Yellowstone River below Laurel-Billings, where municipal pollution is also apparently a problem.

Impacts of water withdrawals

PROJECTIONS OF FUTURE USE

In order to adequately and uniformly assess the potential effects of water withdrawals on the many aspects of the present study, it was necessary to make projections of specific levels of future withdrawals. The methodology by which this was done is explained in report No. 1 in this series, in which also the three projected levels of development, low, intermediate, and high, are explained in more detail. Summarized in appendix A, these three future levels of development were formulated for energy, irrigation, and municipal water use. Annual water depletions associated with the future levels of development were included in the projections. These projected depletions, and the types of development projected, provide a basis for determining the level of impact that would occur if these levels of development were carried through.

POTENTIAL WATER QUALITY EFFECTS BY SUBREGION

UPPER YELLOWSTONE SUBBASIN

Total Dissolved Solids

Fourteen years of records (1951-58, 1963-69) on the Yellowstone River at Billings were used to develop the regression equations given in table 134 which were the basis for the analyses. Three levels of development were projected for the Yellowstone River at Billings. In each, a negligible or zero salt input to the stream was assumed for one set of calculations under a 50th percentile median flow and a 90th percentile low flow. Calculations were also made with salt pickups of one-half ton per acre per year and one ton per acre per year under the conditions of each projection and with each of the two associated flow levels. This approach provided 18 separate analyses of the Yellowstone River at Billings as summarized in table 135 (low level of development), table 136 (intermediate level of development), and table 137 (high level of development).

Low Level of Development. Projected increases in TDS in the Yellowstone River at Billings under the low level of development generally would have negligible effects on irrigation; this is true regardless of the flow assumption and even when a maximum salt pickup of one ton per acre per year is assumed in the calculations. In fact, the inclusion of salt pickup by irrigation return flows had only a small effect on increasing the TDS levels of the river under the low level of development. As indicated in figure 5, major increases in TDS are projected to occur during the late summer and fall. With median flows, significant increases in TDS concentrations were obtained only in August and September (12.3 percent to 14.3 percent), and increases of less than 7 percent were obtained during the rest of the year. For 90th percentile low flows, increases were greater through most of the year, ranging from a low of less than 1 percent in March to highs approaching 25 percent during the fall (figure 6).

TABLE 134. Regression equations between TDS (in mg/l) and monthly discharge (Q) (in acre-feet) in the Yellowstone River at Billings, 1951-58 and 1963-69.

Month	Best Fit Equation	r^2	Significance
Jan	log TDS = 3.16424 - .12912 log Q	.073	a
Feb	log TDS = 3.54116 - .20614 log Q	.196	a
Mar	TDS = 1527.71 - 235.17461 log Q	.766	b
Apr	log TDS = 4.24384 - .34054 log Q	.645	b
May	TDS = 924.22705 - 131.16983 log Q	.606	b
June	log TDS = 2.57791 - .08230 log Q	.063	a
July	TDS = 935.46143 - 135.05623 log Q	.827	b
Aug	log TDS = 4.27605 - .35261 log Q	.850	b
Sept	TDS = 1622.26001 - 251.31508 log Q	.868	b
Oct	log TDS = 5.05812 - .48689 log Q	.834	b
Nov	TDS = 2255.61938 - 368.94141 log Q	.806	b
Dec	TDS = 2119.83569 - 346.26465 log Q	.510	b
All months	log TDS = 4.82194 - .44798 log Q	.934	b

[a]Not significant at 5 percent level.

[b]Significant at 1 percent level.

However, such increases under low-flow conditions would appear to be of insufficient magnitude to affect the use of the Yellowstone River at Billings for irrigational or municipal purposes.

Intermediate Level of Development. TDS increases under the intermediate level of development at 50th percentile values are projected to be very small over most of the year. Major effects are predicted to occur in August and September (increases of 16 percent to 19 percent over the historical). Concentration increases are greater through a large portion of the year under low-flow conditions. These range from less than 1 percent during the winter and spring to highs approaching 22 percent during the fall. However, TDS concentrations do not increase to a level that would preclude the use of Yellowstone River water for beneficial uses in the vicinity of Billings; this would be true under median flow and drought/low-flow conditions, even with a maximum salt pickup.

TABLE 135. TDS values in the Yellowstone River at Billings, assuming a low level of development without the Fish and Game reservation.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	259,964	264	245,036	273	273	274	178,376	317	163,456	332	334	335
Nov	219,651	285	219,666	285	286	286	188,047	310	188,062	311	311	312
Dec	178,447	301	178,411	302	302	303	133,321	345	133,290	346	347	347
Jan	152,997	312	153,036	313	313	314	100,573	330	100,470	331	331	332
Feb	159,627	294	159,451	295	295	295	120,732	312	120,568	312	312	313
March	210,571	276	210,452	276	277	277	143,958	315	143,850	315	316	316
April	245,835	256	241,904	258	258	258	171,383	289	167,308	292	293	293
May	755,249	153	697,674	158	159	159	398,290	190	340,719	200	200	201
June	1,617,805	117	1,545,894	117	118	118	1,137,038	120	1,065,127	121	122	122
July	906,166	131	804,278	138	139	139	481,261	168	379,376	183	184	185
Aug	322,491	216	230,954	243	245	247	211,401	250	119,876	307	310	314
Sept	247,691	267	184,038	300	301	302	172,160	306	108,507	358	360	362
Annual	5,276,494	182	4,870,794	187	188	188	3,436,540	211	3,030,609	220	221	221

[a]Salt pickup given in tons per acre per year.

TABLE 136. TDS values in the Yellowstone River at Billings, assuming an intermediate level of development without the Fish and Game reservation.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	259,964	264	244,956	274	275	277	178,376	317	163,380	334	336	339
Nov	219,651	285	219,982	286	287	288	188,047	310	188,379	312	313	314
Dec	178,447	301	178,661	302	303	304	133,321	345	133,545	346	348	349
Jan	152,997	312	153,219	313	314	315	100,573	330	100,663	331	332	334
Feb	159,627	294	159,567	295	295	296	120,732	312	120,690	310	313	314
March	210,571	276	210,636	277	277	278	143,958	315	144,040	316	317	318
April	245,835	256	241,574	258	259	260	171,383	289	166,985	293	294	295
May	755,249	153	691,032	159	160	161	398,290	190	334,079	202	203	205
June	1,617,805	117	1,537,069	118	118	119	1,137,038	120	1,056,308	122	123	123
July	906,166	131	787,143	140	141	142	481,261	168	362,245	187	189	191
Aug	322,491	216	217,809	249	253	257	211,401	250	106,737	319	327	335
Sept	247,691	267	178,382	303	306	309	172,160	306	102,850	364	368	373
Annual	5,276,494	182	4,820,030	189	189	191	3,436,540	211	2,979,901	222	223	225

[a]Salt pickup given in tons per acre per year.

TABLE 137. TDS values in the Yellowstone River near Billings, assuming a high level of development without the Fish and Game reservation.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	259,964	264	244,866	274	277	279	178,376	317	163,295	335	339	342
Nov	219,651	285	220,263	286	288	289	188,047	310	188,660	312	314	316
Dec	178,447	301	178,882	302	304	306	133,321	345	133,769	347	349	351
Jan	152,997	312	153,367	313	315	316	100,573	330	100,820	332	334	336
Feb	159,627	294	159,657	295	296	297	120,732	312	120,787	313	314	315
March	210,571	276	210,786	277	278	279	143,958	315	144,195	316	318	319
April	245,835	256	241,219	258	260	261	171,383	289	166,637	294	295	297
May	755,249	153	684,165	160	161	162	398,290	190	327,214	204	206	209
June	1,617,805	117	1,528,209	118	119	119	1,137,038	120	1,047,449	123	124	125
July	906,166	131	769,993	142	143	145	481,261	168	345,099	190	194	198
Aug	322,491	216	204,654	255	261	267	211,401	250	93,589	334	348	362
Sept	247,691	267	172,690	307	311	315	172,160	306	97,157	371	378	385
Annual	5,276,494	182	4,768,751	190	191	192	3,436,540	211	2,928,671	223	226	228

[a]Salt pickup given in tons per acre per year.

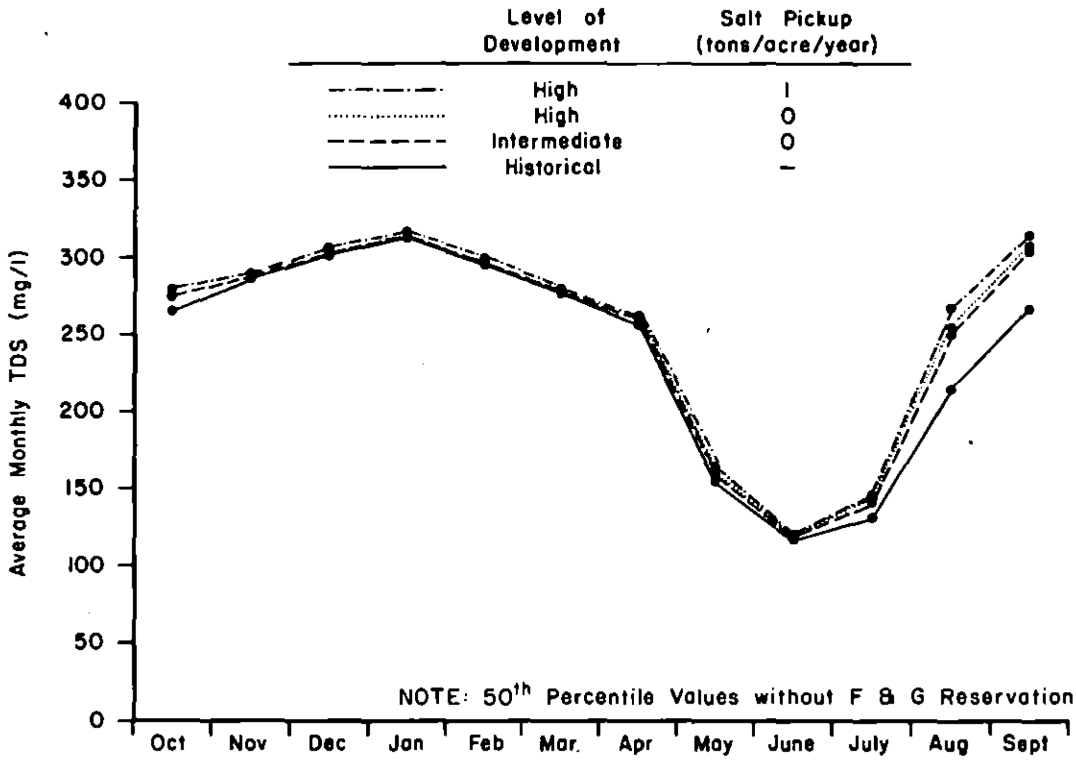

Figure 5. Average monthly TDS concentrations in the Yellowstone River at Billings at 50th percentile values.

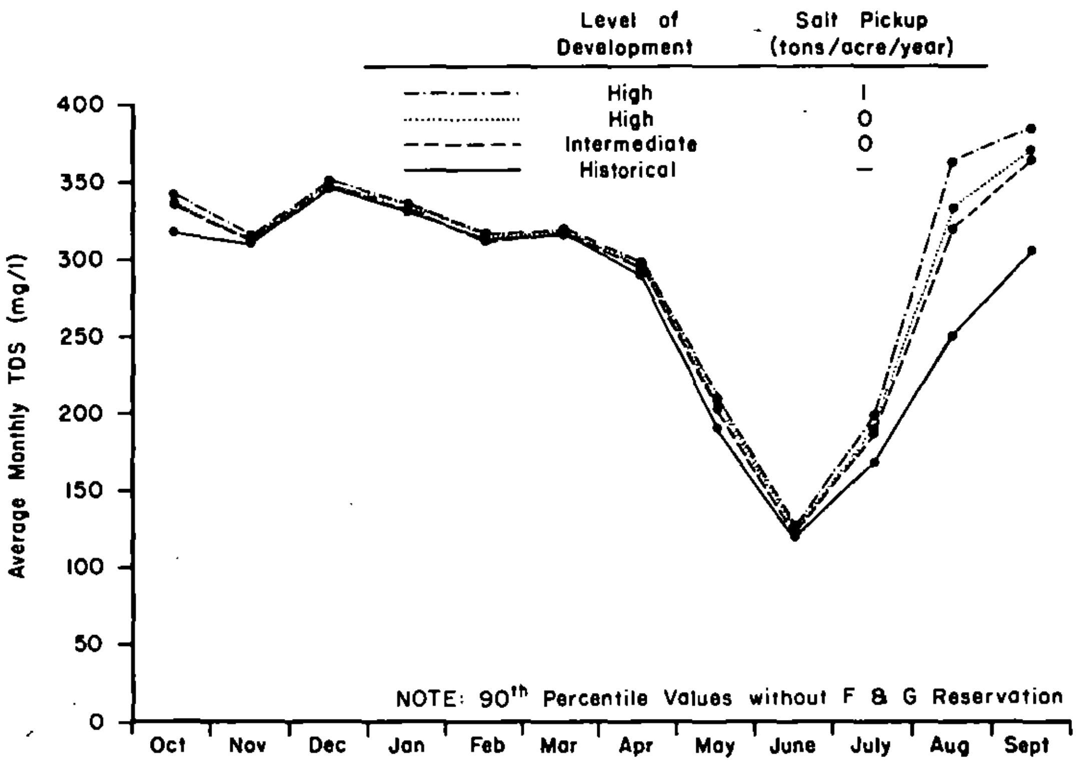

Figure 6. Average monthly TDS concentrations in the Yellowstone River at Billings at 90th percentile values.

High Level of Development. Effects of the high level of development in increasing mean monthly TDS concentrations in the Yellowstone River at Billings are illustrated in figure 5 for median flows and in figure 6 for 90th percentile low flows. The major increases in TDS under this level of development occur from July to October in both flow regimes; however, effects are more noticeable under drought conditions. As noted on other levels of development, the inclusion of a one ton per acre per year salt pickup does not greatly increase TDS levels through any of the months with the possible exception of August. Projected TDS concentrations in the Yellowstone River at Billings under this level of development are somewhat higher than those projected from the others, but not to a large degree. As a result, conditions defining the high level of development would not be expected to cause alterations in the TDS levels in the river in sufficient magnitude to affect its use.

Other Parameters

In general, other parameters should show only minor changes under any level of development. Possible exceptions might be evident during August and September of low-flow years. Nintieth percentile flows are reduced approximately 50 percent during these two months. Such a drastic reduction in flow could adversely affect the river's ability to assimilate waste from the Billings area and result in high water temperatures and reduced dissolved oxygen levels that would temporarily stress the aquatic ecosystem. Data were not available to quantify these effects.

Conclusion

Although both the intermediate and high levels of development would cause measurable increases in TDS and a general reduction in water quality, the Yellowstone River would still contain water of fairly high quality suitable for almost all beneficial uses.

BIGHORN SUBBASIN

Total Dissolved Solids

The usual inverse relationship between TDS and discharge (Q) has been obliterated because of storage and regulation by Yellowtail dam. Insufficient below-dam records were available to develop monthly relationships, and a single equation for all months failed to predict seasonal variations. Therefore, a two-stage method was used to obtain initial TDS concentrations:

1) average monthly TDS concentrations for the 1968-74 period were computed for the Bighorn River near St. Xavier (figure 7); and

2) thirty-nine months of concurrent water quality records (1966-69) at two stations--Bighorn River near St. Xavier and Bighorn River at Bighorn--were used to develop the following linear regression equation (11):

$$TDS_B = 57.1 + .93596\ TDS_{SX}\ (r^2 = .928)$$

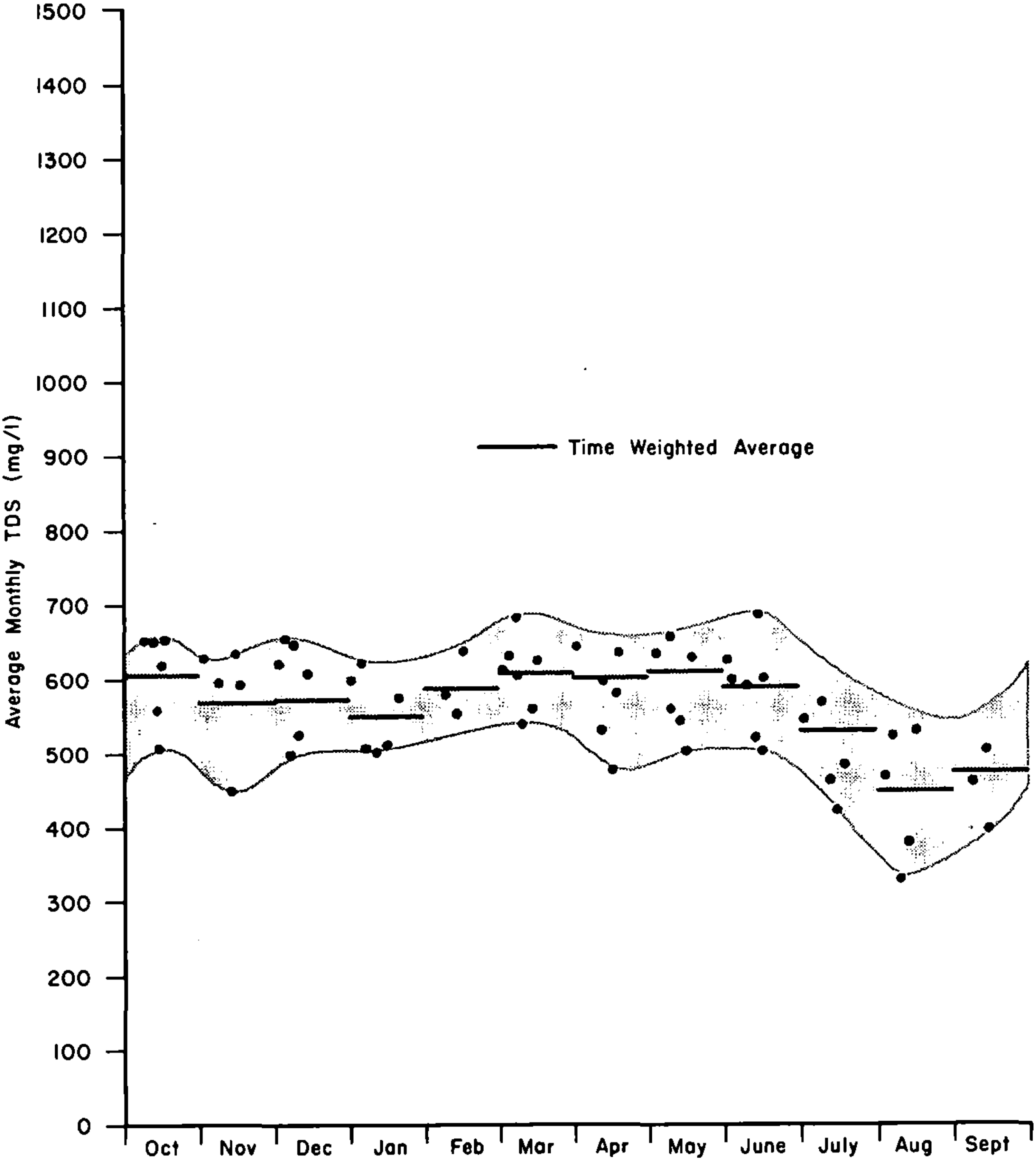

Figure 7. Average monthly TDS concentrations in the Bighorn River near St. Xavier, 1968-74.

where:

TDS_B is the average monthly TDS at Bighorn, and TDS_{SX} is the average monthly TDS near St. Xavier.

Equation (11) was used with the average monthly TDS concentrations near St. Xavier from figure 7 to compute average monthly TDS values for the Bighorn River near Bighorn; this became the basis for $LTDS_T$ of figure 2 and equation (2) (equations 1 through 10 are presented in "Impacts of Water Withdrawals" in the Methods section of this report).

Results for the Bighorn Subbasin are presented in tables 138 and 139 and figures 8 and 9, and summarized below for the intermediate and high levels of development . A low level of development was not formally simulated because the effects on flow and TDS would have been insignificant.

Intermediate Level of Development. The annual average TDS concentration increased 1.5 percent for the 50th percentile flow and 2.2 percent for the 90th percentile flow with 0 salt pickup, and 1.9 percent 3.1 percent for 1 ton per acre per year salt pickup. Most of the increase occurred in July and August. At the 90th percentile flow level, for example, TDS concentrations in August increased from 475 mg/l (natural) to 526 mg/l and 557 mg/l for 0 and 1 ton per acre per year salt pickup.

High Level of Development. Annual TDS concentrations were less than 2 percent higher than comparable values under the intermediate level of development. Again, July and August accounted for most of the increase. August increases ranged from 5.3 percent for 50th percentile flows with no salt pickup to 32 percent for 90th percentile flows with one ton per acre per year salt pickup. Salinity levels near the mouth of the Bighorn River would increase somewhat in normal years. (Assuming 0 salt pickup, 50 percentile values in August would increase from 475 mg/l to 575 mg/l.) A series of dry years, accompanied by the higher TDS concentrations, could adversely affect cropland irrigated with the water. In general, however, irrigators should experience no major new problems under either level of development.

Other Parameters

The increase in TDS will be accompanied by increases in hardness and SO_4 (sulfate) concentration, all of which will render the water less desirable for domestic purposes. Fiftieth percentile flow SO_4 values for August, will increase from 216 mg/l to 288 mg/l under the high level of development with 1 ton per acre per year salt pickup (based on the equation $SO_4 = -54.0 + .56781\ TDS$ ($r^2 = .978$). Nintieth percentile flow values will exceed 300 mg/l for the same month and level of development. The recommended limits for drinking water are 250 mg/l for SO_4 and 500 mg/l for TDS. These limits are presently exceeded during much of the year, and they would be exceeded even more under the intermediate and high levels of development.

Although no limits have been established for hardness, current Bighorn River water is considered hard, averaging more than 300 mg;l as $CaCO_3$. Hardness will

TABLE 138. TDS values in the Bighorn River, assuming an intermediate level of development without the Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	197,267	622	194,045	626		629	131,491	622	140,169	627		631
Nov	183,408	588	184,077	591		593	108,807	588	142,153	590		591
Dec	170,710	592	164,977	594		595	115,815	592	109,022	595		597
Jan	144,461	573	143,349	575		576	102,107	573	100,767	576		577
Feb	144,973	607	144,398	609		610	109,160	607	107,600	609		610
March	199,787	627	211,631	628		629	116,122	627	157,238	629		630
April	182,515	621	204,188	623		624	123,442	621	119,215	624		626
May	280,501	628	259,527	632		634	103,152	628	135,198	635		640
June	464,795	609	566,793	612		613	165,561	609	137,846	618		625
July	312,406	552	261,441	559		563	58,461	552	30,130	609		647
Aug	143,048	475	81,338	500		512	78,132	475	36,351	526		557
Sept	172,343	502	155,622	508		512	98,694	502	91,851	512		519
Annual	2,596,214	588	2,571,386	597		599	1,310,944	590	1,307,540	603		608

[a]Salt pickup given in tons per acre per year.

TABLE 139. TDS values in the Bighorn River at Bighorn, assuming a high level of development without the Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	197,267	622	188,241	628		632	131,491	622	134,252	628		631
Nov	183,408	588	180,204	592		594	108,807	588	138,223	593		596
Dec	170,710	592	160,974	595		597	115,815	592	104,977	597		601
Jan	144,461	573	139,343	576		578	102,107	573	96,807	577		580
Feb	144,973	607	140,336	609		611	109,160	607	107,737	610		612
March	199,787	627	207,573	629		630	116,122	627	153,146	630		632
April	182,515	621	198,322	623		625	123,442	621	113,168	625		629
May	280,501	628	234,007	634		639	103,152	628	109,680	642		651
June	464,795	609	534,673	613		615	165,561	609	105,791	628		640
July	312,406	552	204,851	565		573	58,461	552	30,000	640		697
Aug	143,048	475	35,368	555		603	78,132	475	30,000	569		626
Sept	172,343	502	131,494	513		521	98,694	502	57,261	528		545
Annual	2,596,215	588	2,355,386	603		607	1,310,944	590	1,181,042	610		618

[a]Salt pickup given in tons per acre per year.

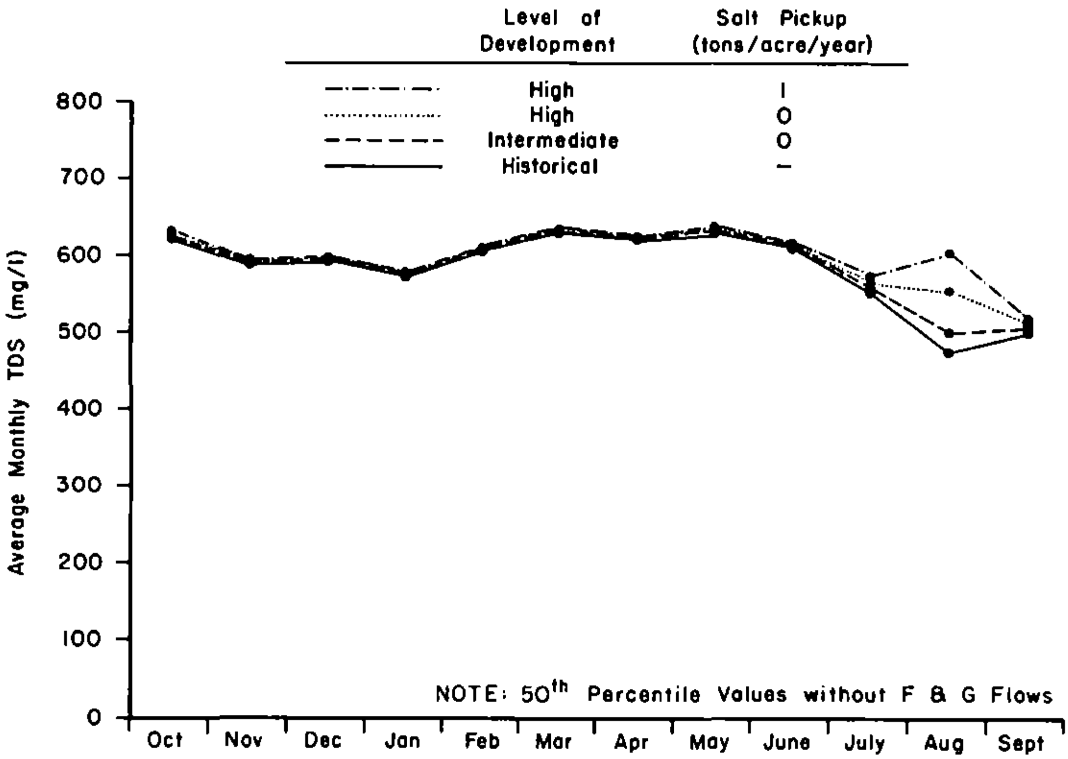

Figure 8. Average monthly TDS in the Bighorn River near Bighorn at 50th percentile values.

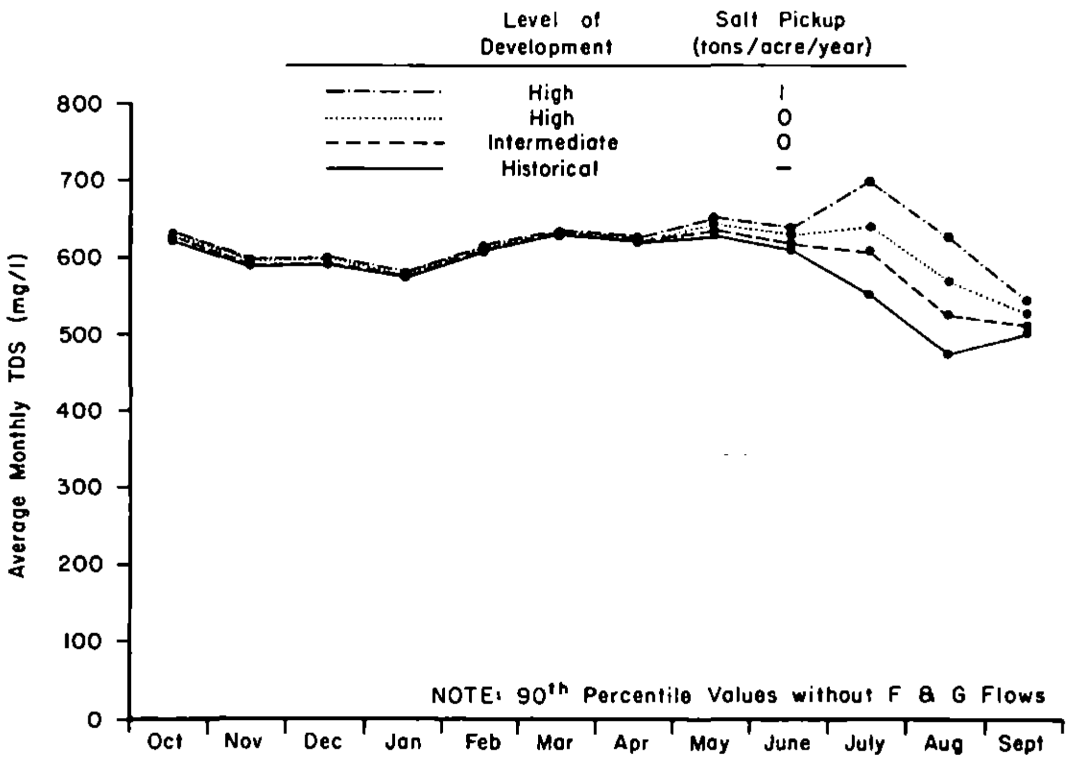

Figure 9. Average monthly TDS concentrations in the Bighorn River near Bighorn at 90th percentile values.

increase linearly with TDS. Therefore, problems associated with hard water--the necessity for using more soap in cleaning and laundering, the formation of scales in pipes, and the need to soften water before using it for certain purposes--will increase proportionately. Projected increases in hardness are so slight that consumers, principally residents of Hardin who draw their water supply from the Bighorn River, would hardly notice the change.

Major reductions in flow (50 percent or more) projected under both levels of development for July, August, and September, could have adverse impacts on other water quality parameters such as dissolved oxygen and temperature; this, in turn, could produce deleterious effects on the aquatic ecosystem. Discharges of 30,000 af (488 cfs) during July and August are less than historical extreme low flows both before and after the completion of Yellowtail dam. Therefore, it would be beneficial to maintain higher flows, of about 1000 cfs, in the river during all months. This flow would enhance water quality and improve the aquatic environment.

Summary

The intermediate level of development would produce only minor changes in water quality. Degradation of water quality under the high level of development would be somewhat more severe, especially in dry years. Bighorn River water is naturally high in total dissolved solids, including sulfate, and is hard. Values of all three of these parameters will increase, and thus render the water less desirable for beneficial uses. Furthermore, the low flows projected for July and August could result in detrimental changes in dissolved oxygen and water temperatures, with concomitant injury to the aquatic ecosystem.

MID-YELLOWSTONE SUBBASIN

Total Dissolved Solids

Only six years (1969-74) of TDS records were available on the Yellowstone River near Miles City, not enough to derive monthly relationships between TDS and Q. A significant relationship was obtained using data for all months, but it failed to accurately reflect the monthly variation in TDS. Consequently, monthly values of TDS at Miles City were obtained from regression equations between: (a) TDS and Q at Sidney, (b) TDS at Miles City and TDS at Sidney, and (c) Q at Sidney and Q at Miles City. Basically, the computational procedure was as follows:

1) Monthly values of Q were determined from hydrologic simulations.

2) The regression equation between Q at Sidney and Q at Miles City was used to obtain Q at Sidney corresponding to Q from step 1. The equation (figure 10) is:

   (12) $Q_{SD} = -1.388 + 1.126\ Q_{MC}$

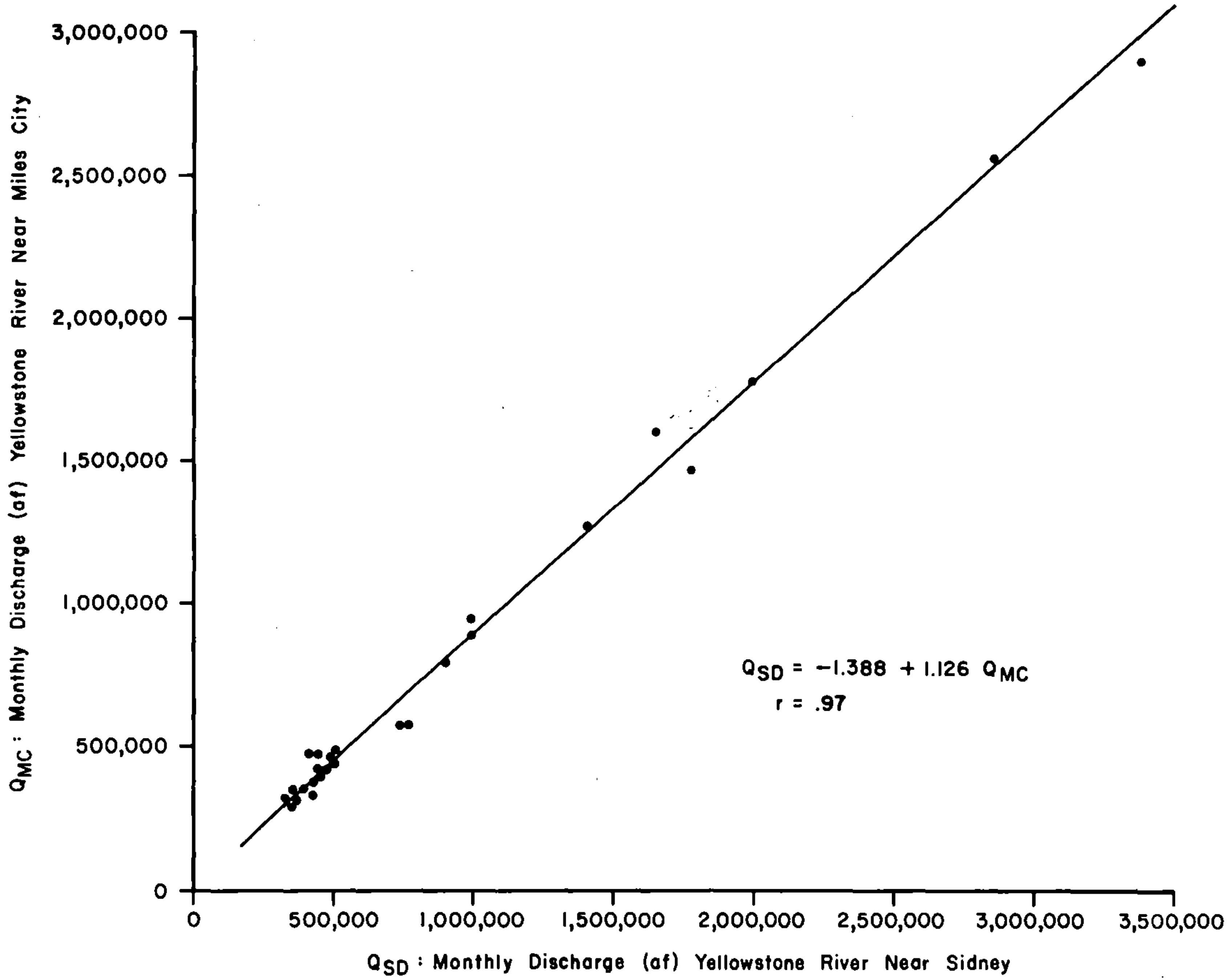

Figure 10. Discharge relationship between the Yellowstone River near Miles City and the Yellowstone River near Sidney.

where: Q_{SD} = discharge at Sidney, 1000 af

Q_{MC} = discharge at Miles City, 1000 af

3) Q_{SD} from step 2 and the appropriate monthly TDS-Q relationship for the Yellowstone River near Sidney (table 153) were used to obtain TDS for Sidney.

4) The regression equation between TDS at Miles City and TDS at Sidney (figure 11) was used to obtain TDS at Miles City corresponding to Q from step 1.

The procedure described is somewhat circuitous, but it more accurately reflects monthly variations in TDS than the use of a single relationship for all months. Results are presented in tables 140-142 and in figures 12 and 13, and are discussed below.

Low Level of Development. Diversions and return flows under this level of development would produce minor changes in TDS concentrations. Annual values would increase 3.0 percent (3.2 percent with a salt pickup of 1 ton per acre per year) with 50th percentile flows, and 3.7 percent (4.2 percent with salt pickup of 1 ton per acre per year) with 90th percentile flows. Significant increases occur only during July to September, when TDS values average 9.6 percent (10.1 percent with salt pickup of 1 ton per acre per year) higher at 50th percentile flows and 10.9 percent (11.7 percent with salt pickup of 1 ton per acre per year) higher at 90th percentile flows. August increases are approximately 15 percent at 50th percentile flows and 20 percent at 90th percentile flows. Projected increases in TDS would not be sufficient to affect use of the water for common beneficial uses. September values, for example, would be 507 mg/l at 50th percentile flows and 565 mg/l at 90th percentile flows.

Intermediate Level of Development. Annual average TDS values would be 4.0 percent (4.8 percent with salt pickup) higher than for natural concentrations at 50th percentile flows, and 5.1 percent (6.8 percent with salt pickup) higher at 90th percentile flows. Most of the increase would occur during the July-to-October period. Monthly TDS increases would be generally less than 10 percent except during August, when increases would be 21 percent (24 percent with salt pickup) under 50th percentile flows, and 33 percent (37 percent with salt pickup) under 90th percentile flows. Also, during July there would be an increase of 15 percent (17 percent with salt pickup) under 90th percentile flows. Projected TDS concentrations should pose little or no additional threat to current beneficial uses. Only August and September concentrations would be significantly higher than naturally occurring values: 50th percentile values would increase from 389 mg/l to 472 mg/l during August, and from 473 mg/l to 518 mg/l during September; 90th percentile values would increase from 459 mg/l to 610 mg/l during August, and from 595 mg/l to 583 mg/l during September.

High Level of Development. Average annual TDS increases would be less than 10 percent. Average annual values are misleading, however, because of the weighting effect of June, which produces the largest flow (26 to 28 percent of annual volume) and the lowest TDS concentrations of any month. Some months would show substantially higher increases that would render the water less

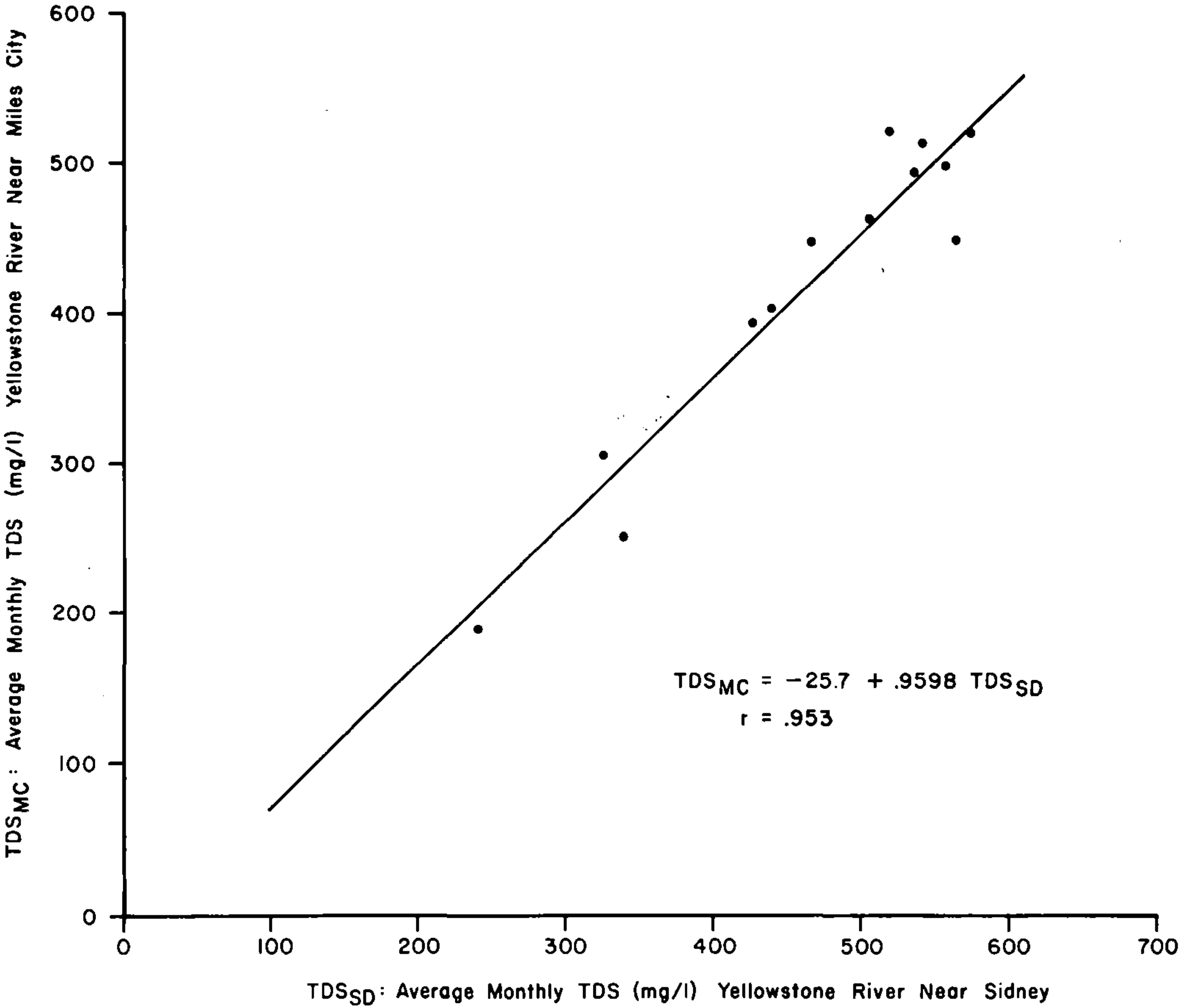

Figure 11. TDS relationship between the Yellowstone River near Miles City and the Yellowstone River near Sidney.

TABLE 140. TDS values in the mid-Yellowstone River, assuming a low level of development with no reservation or Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	484,960	477	462,205	488		489	340,670	560	323,536	573		574
Nov	414,095	517	409,310	518		520	322,048	578	333,575	568		570
Dec	348,555	572	337,255	577		580	221,141	657	217,102	657		661
Jan	301,526	590	296,842	589		594	199,194	672	194,918	667		676
Feb	301,438	542	302,286	544		542	230,446	580	225,893	578		584
March	471,873	493	488,389	486		488	298,629	568	294,533	568		572
April	477,479	545	465,915	547		549	334,211	582	326,058	583		586
May	1,079,204	304	988,032	322		323	523,115	412	439,194	430		431
June	2,234,590	251	2,129,436	247		249	1,280,809	214	1,175,717	213		213
July	1,240,724	255	1,080,117	272		273	547,511	290	436,485	315		317
Aug	458,038	389	305,904	447		449	275,029	459	170,649	553		559
Sept	428,158	473	342,057	507		510	252,952	545	218,790	565		568
Annual	8,240,640	372	7,607,748	383		384	4,825,755	428	4,348,450	444		446

[a]Salt pickup given in tons per acre per year.

TABLE 141. TDS values in the mid-Yellowstone River, assuming an intermediate level of development with no reservation or Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	484,960	477	459,151	493		497	340,670	560	320,492	579		585
Nov	414,095	517	406,677	521		526	322,048	578	330,930	570		577
Dec	348,555	572	334,446	579		585	221,141	657	214,307	659		669
Jan	301,526	590	293,910	589		599	199,194	672	191,983	669		685
Feb	301,438	542	299,204	537		546	230,446	580	222,809	577		589
March	471,873	493	485,442	488		491	298,629	568	291,594	570		576
April	477,479	545	462,291	549		553	334,211	582	322,432	586		591
May	1,079,204	304	975,673	326		329	523,115	412	426,837	439		444
June	2,234,590	251	2,114,183	249		251	1,280,809	214	1,160,467	216		218
July	1,240,724	255	1,053,213	278		280	547,511	290	409,575	332		339
Aug	458,038	389	284,700	472		483	275,029	459	149,464	610		630
Sept	428,158	473	331,134	518		524	252,952	545	199,867	583		593
Annual	8,240,640	372	7,500,023	387		390	4,825,755	428	4,240,757	450		457

[a]Salt pickup given in tons per acre per year.

TABLE 142. TDS values in the mid-Yellowstone River, assuming a high level of development with no reservation or Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	484,960	477	448,648	500		506	340,670	560	310,188	589		598
Nov	414,095	517	398,081	525		533	322,048	578	322,045	576		585
Dec	348,555	572	325,382	582		592	221,141	657	205,456	662		678
Jan	301,526	590	284,947	591		605	199,194	672	182,934	672		693
Feb	301,438	542	290,037	537		551	230,446	580	213,586	577		595
March	471,873	493	476,136	489		495	298,629	568	282,481	573		581
April	477,479	545	451,155	552		557	334,211	582	311,278	590		598
May	1,079,204	304	935,515	335		339	523,115	412	386,800	452		461
June	2,234,590	251	2,064,900	249		251	1,280,809	214	1,111,223	216		221
July	1,240,724	255	968,080	286		291	547,511	290	352,967	351		365
Aug	458,038	389	215,827	527		548	275,029	459	92,445	762		808
Sept	428,158	473	291,202	539		549	252,952	545	137,652	629		648
Annual	8,240,640	372	7,149,910	392		398	4,825,755	428	3,909,055	458		469

[a]Salt pickup given in tons per acre per year.

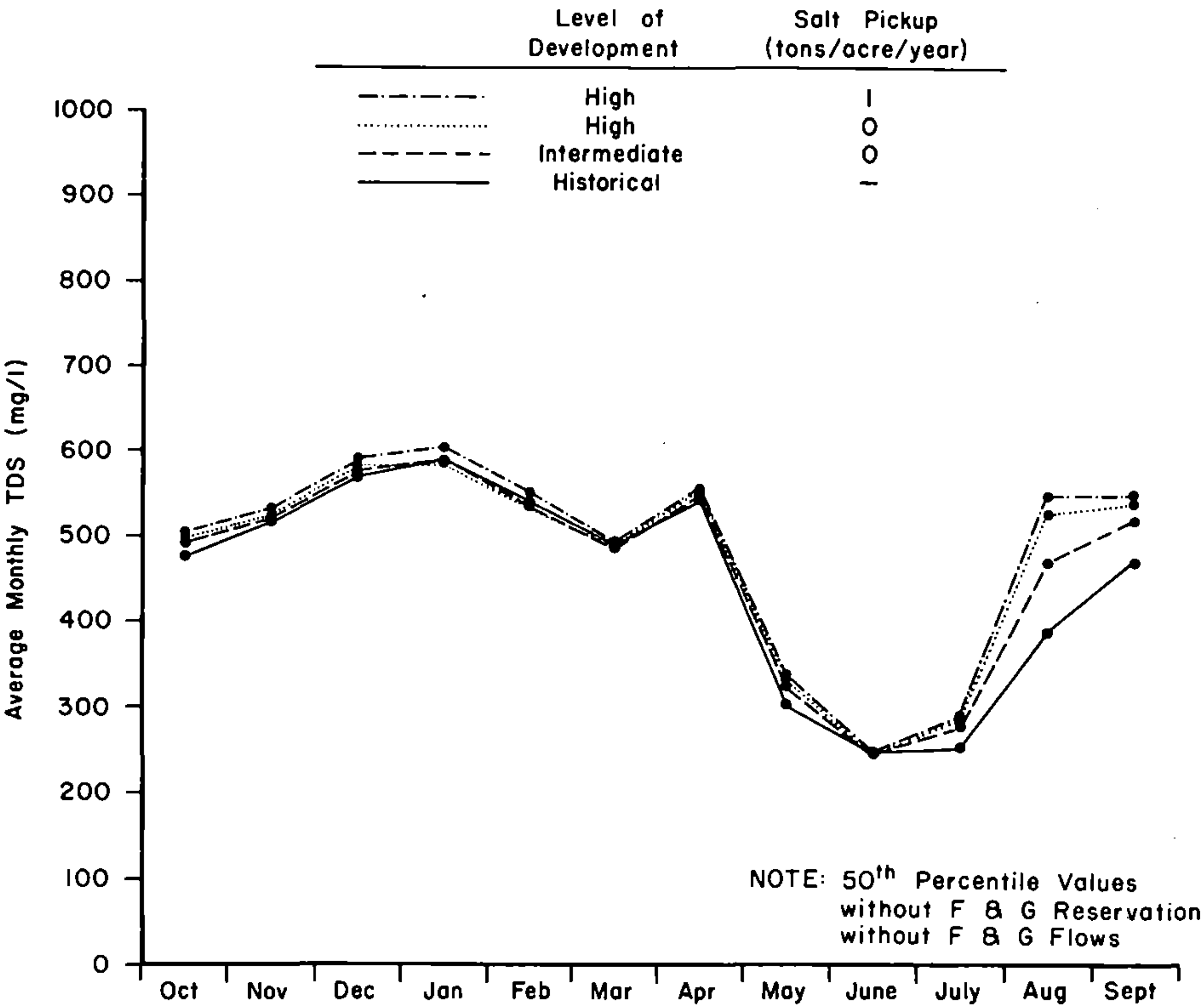

Figure 12. Comparison of historical and simulated TDS concentrations in the Yellowstone River near Miles City at 50th percentile values.

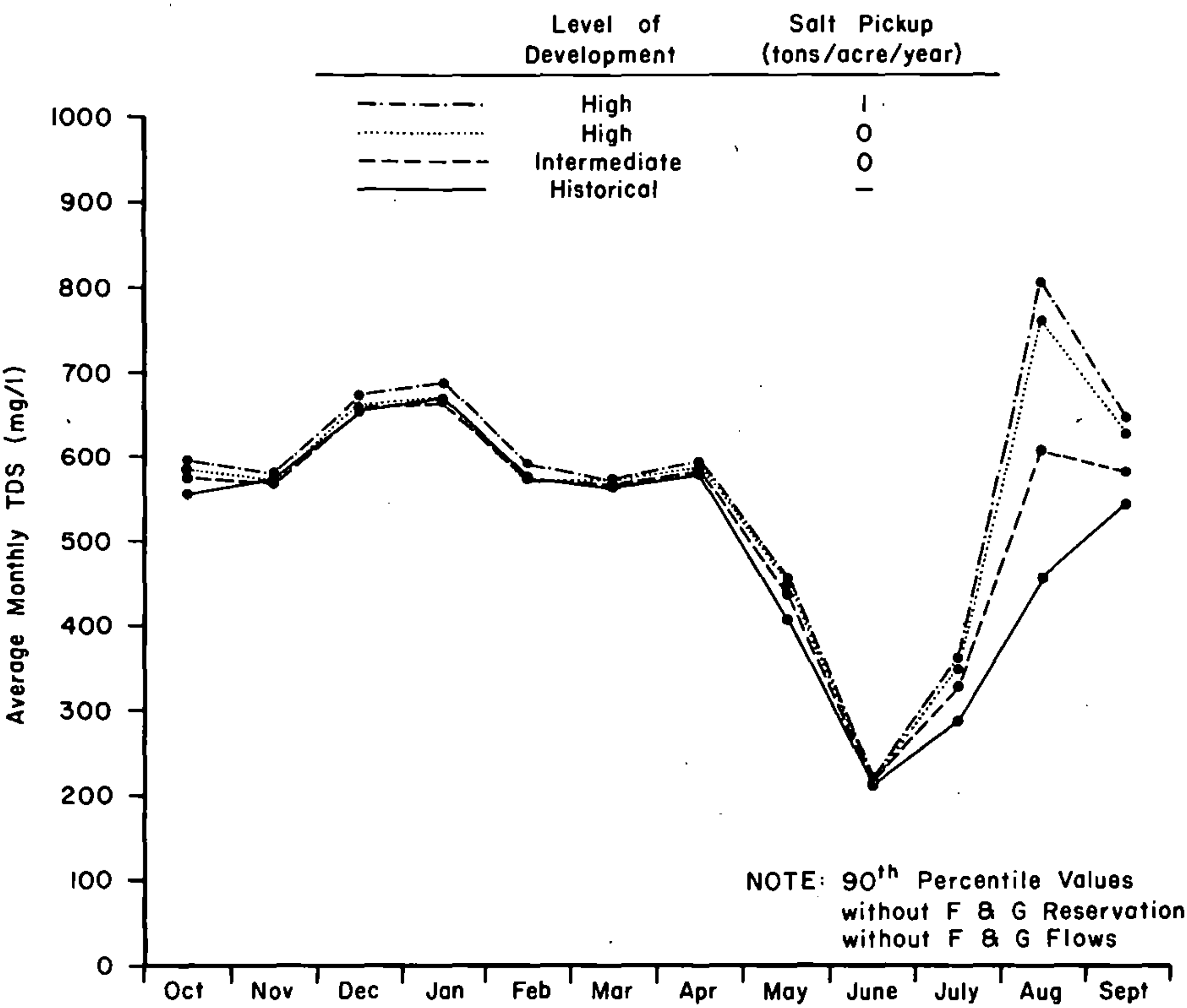

Figure 13. Comparison of historical and simulated TDS concentrations in the Yellowstone River near Miles City at 90th percentile values.

desirable for beneficial uses, especially during August, September, and October of dry years. At 50th percentile flows, August and September concentrations would be 36 percent (41 percent with salt pickup of 1 ton per acre per year), and 14 percent (16 percent with salt pickup of 1 ton per acre per year) higher than existing levels. Corresponding 90th percentile values would be 66 percent (76 percent) and 15 percent (19 percent) higher. Resulting concentrations would shift the water from a medium to a high salinity hazard (Richards 1954) during August, September, and October under both 50th percentile flows and 90th percentile flows. TDS concentrations would exceed 500 mg/l eight months of the year at 50th percentile flows--three more than under current conditions. TDS concentrations would exceed 500 mg/l nine months of the year at 90th percentile flows--one more than under current conditions, and 600 mg/l four months of the year--two more than under current conditions. As shown in figures 12 and 13 the high level of development would degrade water quality significantly more than the intermediate level of development during the July-October period, particularly during low-flow years. Irrigators, municipalities, and industry would experience higher costs and more management problems associated with the use of more saline water.

Other Parameters

Reduction in flow and increases in TDS concentrations would result in the degradation of other water quality parameters. Common dissolved constituents are approximately linear functions of TDS and would show proportionate increases. Sulfate, for example, would increase from 194 mg/l to 273 mg/l as TDS increases from 450 mg/l to 600 mg/l ($SO_4 = -42.18 + .5256$ TDS; $r = .995$). The Montana standard for sulfate in the Yellowstone River is 250 mg/l. The SAR would increase slightly (SAR = 0.4687 + .00264 TDS; $r = .950$), from about 1.66 to 2.05 as TDS increases from 450 mg/l to 600 mg/l, but the water would still have a low sodium hazard (Richards 1954). Each hundred-unit increase in TDS would increase the hardness of the water by approximately 40 mg/l. Since the water is already hard (200 mg/l as $CaCO_3$ at a TDS of 380 mg/l), further increases would be undesirable.

Nutrients levels may rise because of increased use of fertilizers on new irrigation lands and because of the concentrating effect of reduced streamflows. Water temperatures would increase slightly but probably less than 1°C. Diurnal variations in temperature and dissolved oxygen would increase slightly.

Summary

The low level of development would produce a slight reduction in water quality. Degradation would be somewhat more severe under the intermediate level, but major beneficial users would probably experience few long-term adverse impacts. The high level of development, however, would bring significant deleterious effects on water quality, particularly during low-flow years. Water quality would not degrade to the point that the water would be rendered unsuitable for beneficial uses, but it would require more costly treatment or more careful management.

TONGUE SUBBASIN

Total Dissolved Solids

Nineteen years of monthly records (1951-1969) on the Tongue River near Miles City were used to derive the regression equations between TDS and Q listed in table 143. All monthly equations are significant at the 1 percent level. The equations represent historical conditions with the existing Tongue River Reservoir at 68,000 af capacity in place. The intermediate and high levels of development project a 320,000-af reservoir at the same site, and the low level assumes a 112-af reservoir. Enlargement of the Tongue River Reservoir would modify the conditions upon which the regression equations were based. The extent of the modifications cannot be accurately predicted. Therefore, first the equations in table 143 were used unaltered for all levels of development according to the methodology illustrated in figure 2 (in the Methods section of this report). To check the results, TDS values at Miles City were recomputed based on water quality and discharge records for the Tongue River at the state border, assuming complete mixing in the reservoir according to equations (8), (9), and (10) (in "Impacts of Water Withdrawals" under the Methods section), and following the logic of figure 2. Results of the first simulations are presented in tables 144-147 and in figures 14 and 15, and are summarized briefly below. Note that in most instances, monthly increases in TDS concentrations are much more severe than those indicated by annual values, which reflect the diluting effect of the spring runoff.

Low Level of Development. Annual changes in TDS concentrations showed a 1 percent decrease (53 percent increase with a salt pickup of 1 ton per acre per year) at 50th percentile flows and a 16 percent (28 percent with a salt pickup of 1 ton per acre per year) increase at 90th percentile low flows. Increases from July through November would be substantial, averaging 48 percent (87 percent with salt pickup of 1 ton per acre per year) higher at 50th percentile flows and 79 percent (149 percent with salt pickup) higher at 90th percentile flows. Actual concentrations would average 746 mg/l (944 mg/l with salt pickup) at 50th percentile flows, compared with 502 mg/l under current conditions. August concentrations would increase by factors of 2.4 (3.9 with salt pickup) and 2.0 (3.0 with salt pickup) at 50th percentile and 90th percentile flows, or from 509 mg/l to 1238 mg/l (1973 mg/l with salt pickup) and from 765 mg/l to 1565 mg/l (2300 mg/l with salt pickup).

Intermediate Level of Development. Annual increases in TDS concentrations would be 20 percent (39 percent with salt pickup of 1 ton per acre per year) at 50th percentile values, and 39 percent (78 percent with salt pickup) at 90th percentile values. Values in July and August at 50th percentile flows would increase by factors of 2.4 (3.9 with salt pickup) to 3.1 (5.1 with salt pickup). TDS concentrations at 50th percentile flows would exceed 600 mg/l 10 months of the year; TDS concentrations at 90th percentile flows would exceed 679 mg/l every month of the year. Concentrations in July and August would exceed 1149 mg/l (1884 mg/l with salt pickup) at 50th percentile flows. TDS concentrations would exceed 1277 mg/l (2012 mg/l with salt pickup) from June through October at 90th percentile flows, making the water undesirable for most beneficial uses.

TABLE 143. Regression equation between TDS concentrations and monthly discharge (Q) in the Tongue River near Miles City, 1951-1969.

Month	Best Fit Equation	r^2	Significance
Jan	log TDS = 2.968046 - .00001178 Q	.373	a
Feb	log TDS = 2.8869196 - .0000093196 Q	.718	a
Mar	TDS = 1445.71 - 217.25081 log Q	.539	a
Apr	TDS = 1524.68 - 217.70712 log Q	.867	a
May	TDS = 1348.75 - 191.64864 log Q	.546	a
June	TDS = 1221.21 - 189.03383 log Q	.750	a
July	TDS = 1513.50 - 260.79199 log Q	.815	a
Aug	TDS = 1686.28 - 301.87476 log Q	.819	a
Sept	log TDS = 3.51775 - .20078 log Q	.869	a
Oct	TDS = 1647.14 - 265.4541 log Q	.787	a
Nov	log TDS = 3.69492 - .21753 log Q	.627	a
Dec	TDS = 2375.20 - 408.74805 log Q	.420	a
All months	TDS = 1672.10 - 267.88599 log Q	.583	a

NOTE: TDS concentrations represent average monthly figures in mg/l; Q figures are in acre-feet.

[a]Significant at 1 percent level.

High Level of Development Without Fish and Game Flows. Because of the large storage capacity and the elimination of flows for instream purposes, flows and concentrations would be fairly uniform throughout the year, consisting essentially of irrigation return flow except during the June 50th percentile values when excess water must be released. Annual TDS concentrations would be 41 percent (88 percent with salt pickup of 1 ton per acre per year) and 60 percent (128 percent with salt pickup) higher than historical values, and would average about 1180 mg/l (1900 mg/l with salt pickup) and 1280 mg/l (2000 mg/l with salt pickup) during most months at 50th percentile and 90th percentile flows, respectively.

TABLE 144. TDS values in the Tongue River, assuming a low level of development with 100 percent of the Northern Great Plains Resources Program's Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	14,569	540	6,585	682	715	748	2,152	762	1,562	1,062	1,285	1,338
Nov	17,490	590	6,365	753	774	795	5,533	760	4,943	825	852	879
Dec	12,356	703	8,390	775	787	800	6,332	820	5,667	860	879	898
Jan	10,266	700	8,320	740	750	759	8,114	740	7,379	766	777	788
Feb	11,882	596	8,245	646	653	659	6,385	670	5,834	681	690	700
March	28,278	480	23,812	499	502	505	13,524	548	12,260	570	578	583
April	24,569	570	23,129	581	586	590	8,923	665	11,375	653	662	672
May	43,154	459	44,807	465	472	478	12,479	563	15,337	584	603	622
June	82,096	291	103,865	279	283	286	13,564	440	4,479	746	831	915
July	25,204	368	13,994	442	471	499	3,135	604	1,315	1,565	1,933	2,300
Aug	7,746	509	1,315	1,238	1,606	1,973	1,107	765	1,315	1,565	1,933	2,300
Sept	11,541	501	6,730	614	654	693	1,190	800	730	1,457	1,825	2,192
Annual	289,151	454	255,557	448	458	468	82,438	623	72,196	722	761	796

[a]Salt pickup given in tons per acre per year.

TABLE 145. TDS values in the Tongue River, assuming an intermediate level of development with 60 percent of the Northern Great Plains Resources Program's Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	14,569	540	4,770	767		947	2,152	762	1,170	1,277		2,012
Nov	17,490	590	4,335	800		925	5,533	760	2,338	955		1,186
Dec	12,356	703	5,445	816		895	6,332	820	2,862	886		1,036
Jan	10,266	700	5,300	775		836	8,114	740	4,624	800		870
Feb	11,882	596	5,150	674		715	6,385	670	2,745	719		796
March	28,278	480	7,640	605		647	13,524	548	7,640	610		652
April	24,569	570	8,860	669		717	8,923	665	5,133	736		819
May	43,154	459	17,205	566		634	12,479	563	9,237	679		807
June	82,096	291	57,310	344		370	13,564	440	2,045	1,371		2,107
July	25,204	368	2,630	1,149		1,884	3,135	604	2,630	1,371		2,106
Aug	7,746	509	2,630	1,236		1,971	1,107	765	2,630	1,371		2,106
Sept	11,541	501	4,182	776		1,033	1,190	800	1,460	1,372		2,107
Annual	289,151	454	125,457	547		633	82,438	623	44,514	869		1,110

[a]Salt pickup given in tons per acre per year.

TABLE 146. TDS values in the Tongue River, assuming a high level of development without the Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	14,569	540	1,755	1,178	1,545	1,913	2,152	762	1,755	1,282	1,650	2,018
Nov	17,490	590	1,097	1,177	1,545	1,913	5,533	760	1,097	1,282	1,650	2,017
Dec	12,356	703	878	1,177	1,545	1,912	6,332	820	878	1,282	1,649	2,017
Jan	10,266	700	658	1,178	1,545	1,913	8,114	740	658	1,283	1,650	2,018
Feb	11,882	596	439	1,177	1,545	1,912	6,385	670	439	1,282	1,649	2,017
March	28,278	480	658	1,172	1,540	1,908	13,524	548	658	1,283	1,650	2,018
April	24,569	570	878	1,136	1,504	1,872	8,923	665	878	1,282	1,649	2,017
May	43,154	459	2,413	1,137	1,505	1,872	12,479	563	2,413	1,282	1,650	2,018
June	82,096	291	45,968	379	404	429	13,564	440	3,072	1,281	1,650	2,017
July	25,204	368	3,949	1,178	1,545	1,913	3,135	604	3,949	1,282	1,650	2,018
Aug	7,746	509	3,949	1,178	1,545	1,913	1,107	765	3,949	1,282	1,650	2,018
Sept	11,541	501	2,194	1,177	1,545	1,913	1,190	800	2,194	1,282	1,650	2,017
Annual	289,151	454	64,836	609	734	857	82,438	623	21,940	1,282	1,650	2,018

[a]Salt pickup given in tons per acre per year.

TABLE 147. TDS values in the Tongue River, assuming a high level of development with Fish and Game flows.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q	TDS	Q	0	½	1	Q	TDS	Q	0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	14,569	540	2,655	1,003	1,246	1,489	2,152	762	2,655	1,077	1,313	1,556
Nov	17,490	590	1,997	998	1,200	1,402	5,533	760	1,997	1,054	1,256	1,458
Dec	12,356	703	1,778	1,018	1,200	1,381	6,332	820	1,778	1,069	1,250	1,432
Jan	10,266	700	1,558	967	1,122	1,277	8,114	740	1,558	1,010	1,165	1,320
Feb	11,882	596	1,339	852	972	1,093	6,385	670	1,339	885	1,006	1,126
March	28,278	480	3,358	722	794	866	13,524	548	3,358	743	815	887
April	24,569	570	3,578	793	883	973	8,923	665	3,578	828	918	1,008
May	43,154	459	5,113	827	1,000	1,174	12,479	563	5,113	895	1,069	1,242
June	82,096	291	40,320	394	422	450	13,564	440	3,972	1,091	1,376	1,660
July	25,204	368	4,849	1,032	1,331	1,631	3,135	604	4,849	1,115	1,414	1,714
Aug	7,746	509	4,849	1,035	1,335	1,632	1,107	765	4,849	1,118	1,417	1,717
Sept	11,541	501	3,094	985	1,245	1,506	1,190	800	3,094	1,056	1,317	1,578
Annual	289,151	454	74,488	638	747	855	82,438	623	38,140	998	1,210	1,421

[a]Salt pickup given in tons per acre per year.

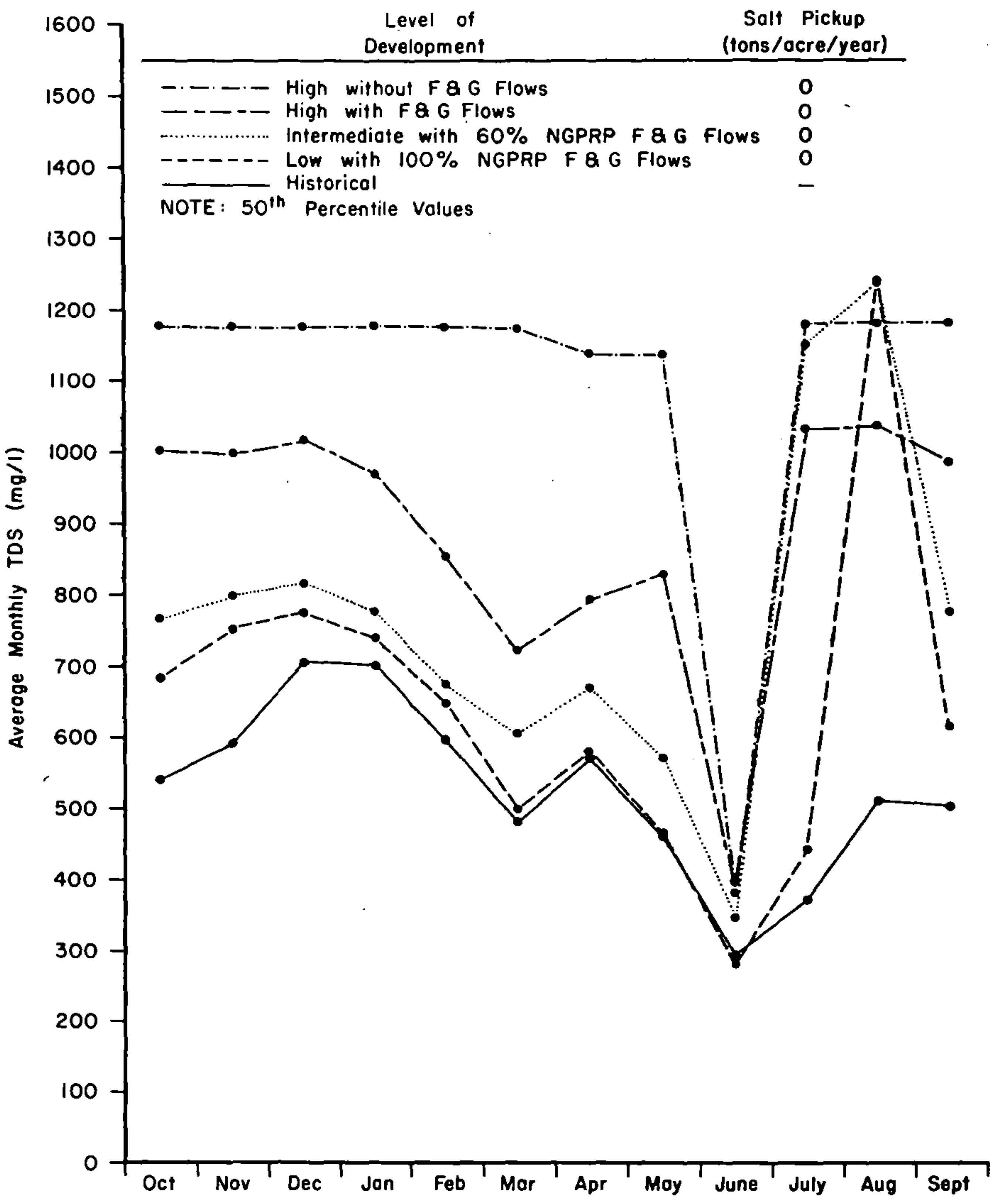

Figure 14. Comparison of historical and simulated TDS concentrations in the Tongue River near Miles City at 50th percentile values.

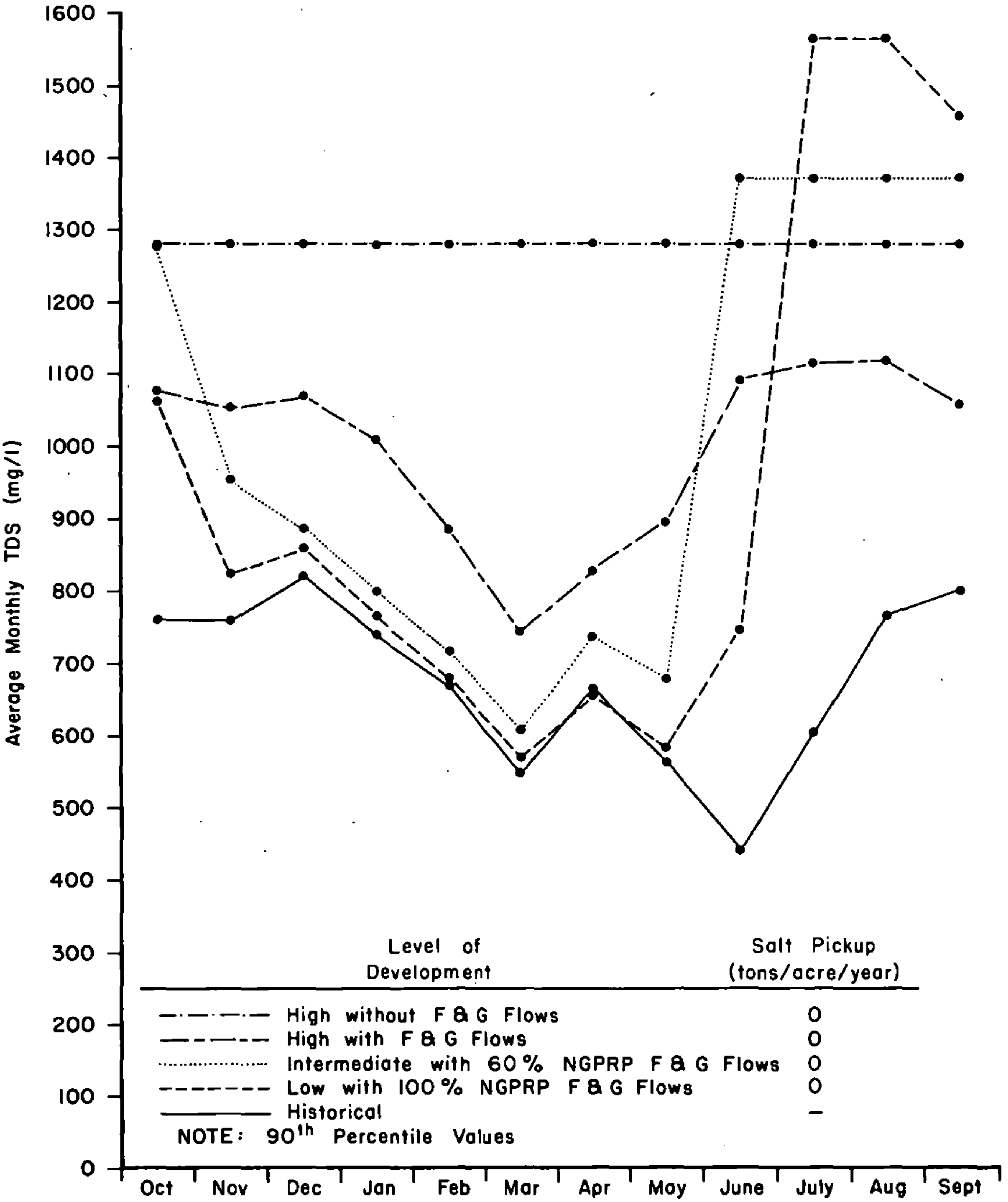

Figure 15. Comparison of historical and simulated TDS concentrations in the Tongue River near Miles City at 90th percentile values.

High Level of Development with Fish and Game Flows. The higher flows at this level of development would alleviate somewhat the impacts projected under the high level of development without the fish and game flows, but TDS concentrations would still increase substantially over present values. Monthly TDS values would average over 1000 mg/l (1500 mg/l with salt pickup of 1 ton per acre per year) from July through December at 50th percentile flows, and about 10 percent less than 90th percentile values. Overall, average annual concentrations would increase 60 percent (128 percent with salt pickup) at 50th percentile flows, and 41 percent (88 percent with salt pickup) at 90th percentile flows. July and August concentrations would be somewhat less than under the intermediate level of development, but 11 out of 12 months would show TDS values exceeding 722 mg/l (866 mg/l with salt pickup) during 50 percent of the years.

Check on Simulated TDS Concentrations. Because of the proposed enlargement of the Tongue River Reservoir, the equations listed in table 143, which were the basis for simulating future TDS values, may not be valid in the future. Therefore, regression equations developed from five years (1966-1970) of records on the Tongue River at the state border near Decker and equations (8), (9), and (10), which describe TDS changes in the reservoir, were used to check results. The applicable equations are given in table 148.

TABLE 148. Regression equation between TDS concentrations and monthly discharge (Q) in the Tongue River at the state border near Decker, 1966-1970.

Months	Best Fit Equation	r^2	Significance
Mar-Apr	$\log TDS = 2.85147 - .00455\ Q$	.45	a
May-July	$\log TDS = 3.0107 - .32961 \log Q$	.84	b
Aug-Feb	$\log TDS = 3.10784 - .35604 \log Q$	.76	b

NOTE: TDS concentrations represent average monthly figures in mg/l; Q represents monthly discharge in thousands of acre-feet.

[a]Significant at 5 percent level.

[b]Significant at 1 percent level.

In essence, CO_1 from equation (10) is used to obtain $LTDS_T$ of equation (2). TDS values obtained from using the state border records, method B, theoretically should be less than values obtained using records at Miles City, method A, because method A reflects the natural increase in TDS between the dam and Miles City. In general, this expectation was realized. Figures 16-21 compare simulated TDS values from both methods for the various levels of development. Comparisons lead to the following comments:

1) There was good agreement between the methods at the 90th percentile flows.

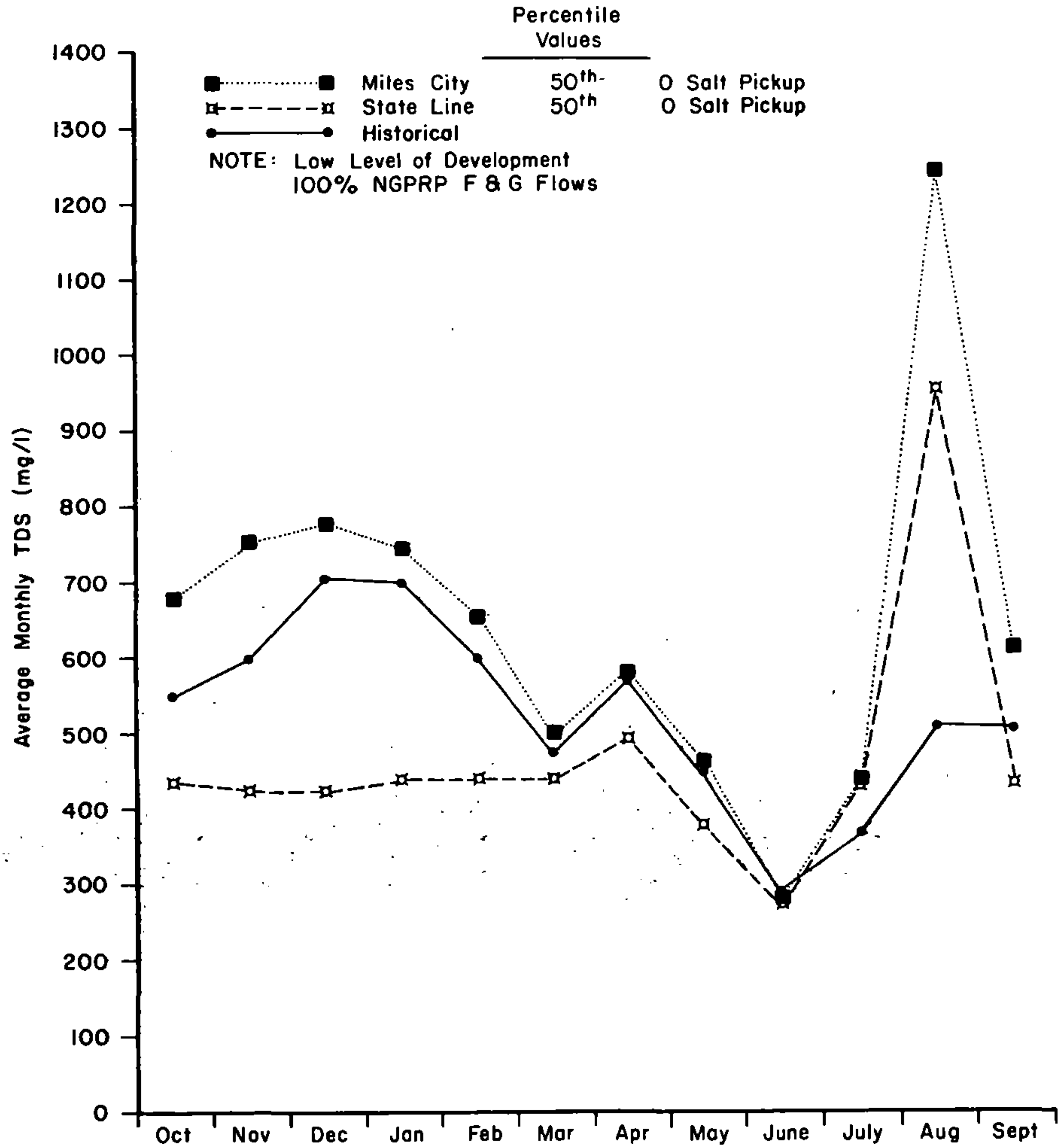

Figure 16. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the low level of development at 50th percentile values.

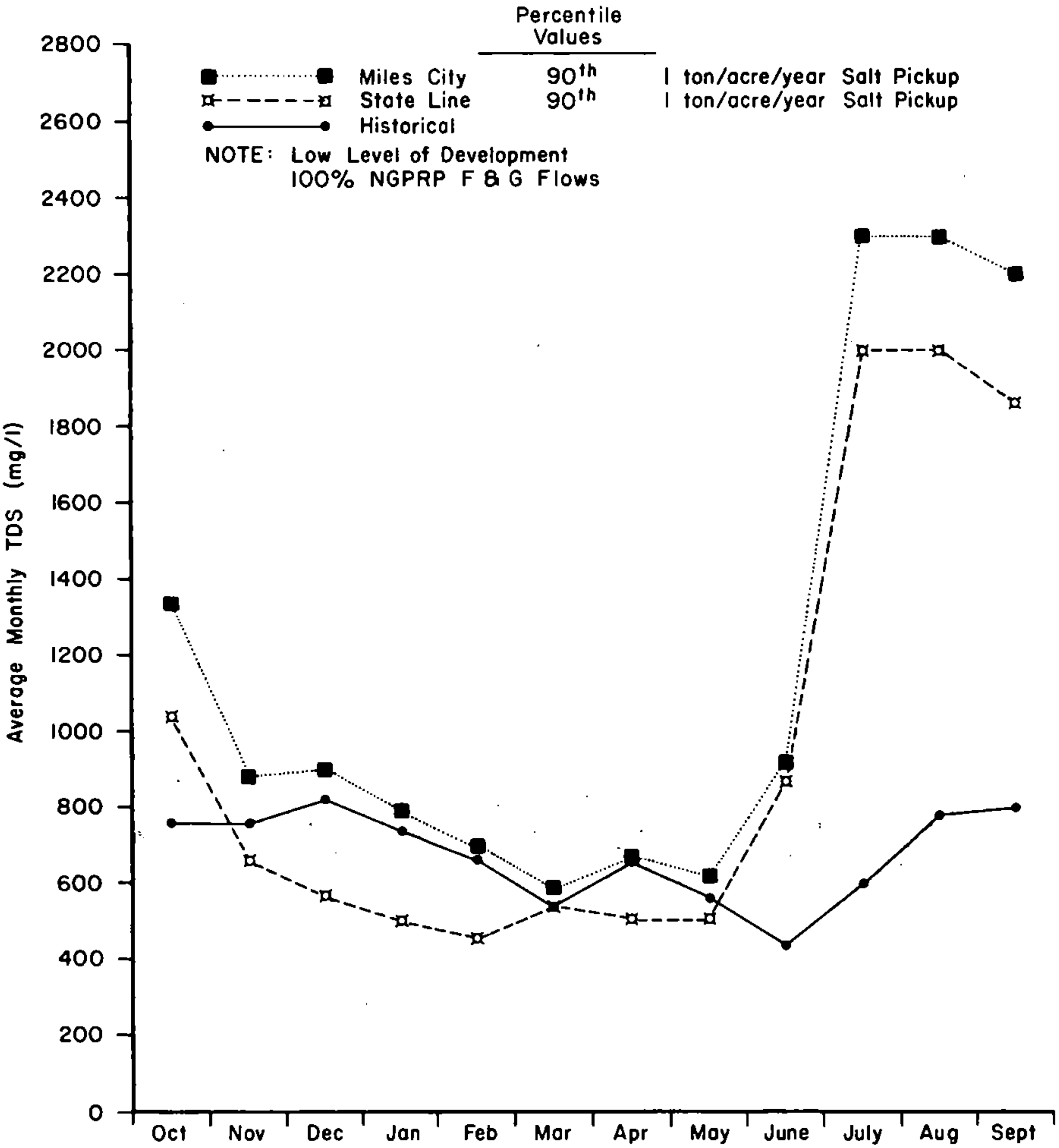

Figure 17. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the low level of development at 90th percentile values.

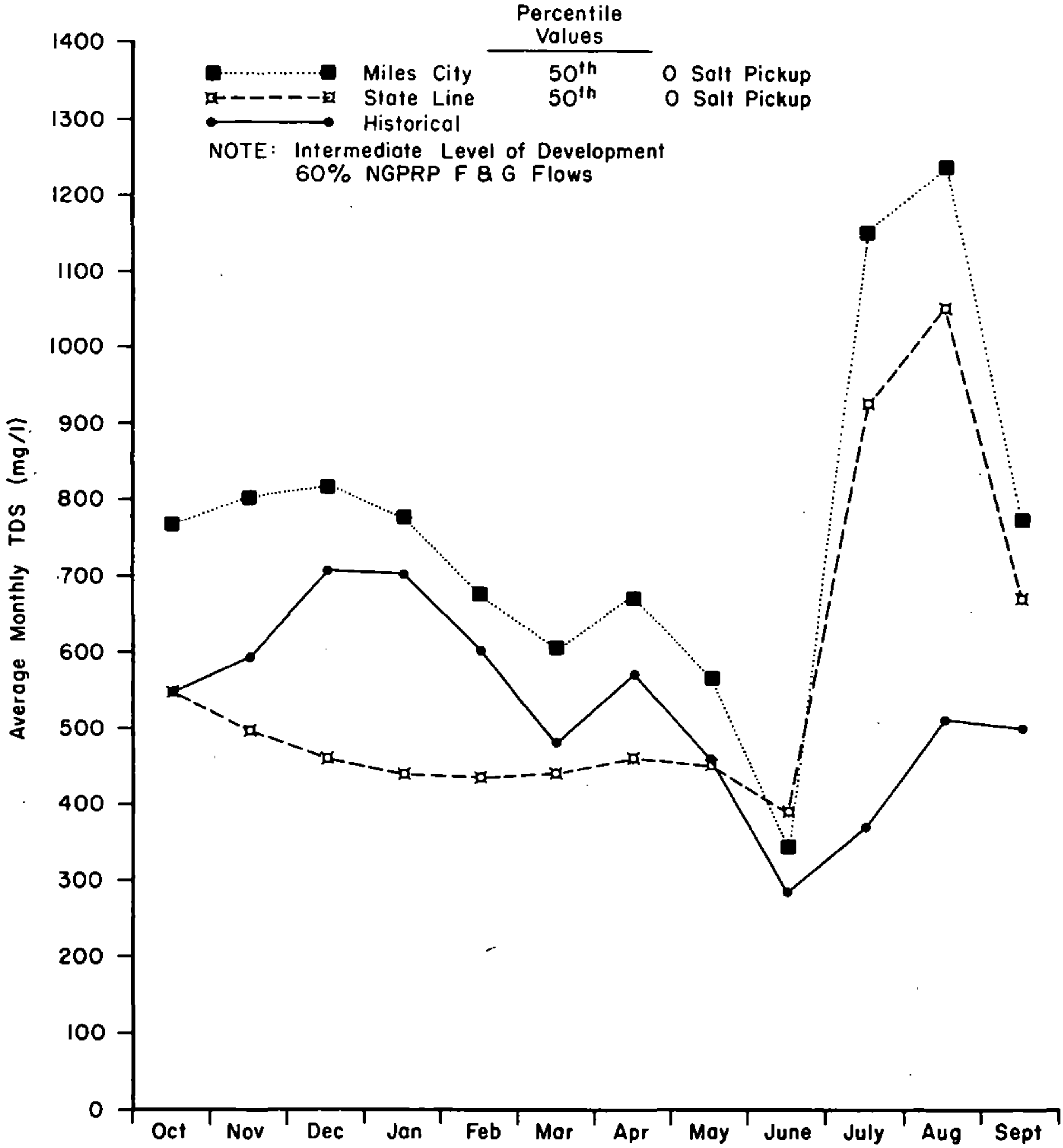

Figure 18. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the intermediate level of development at 50th percentile values.

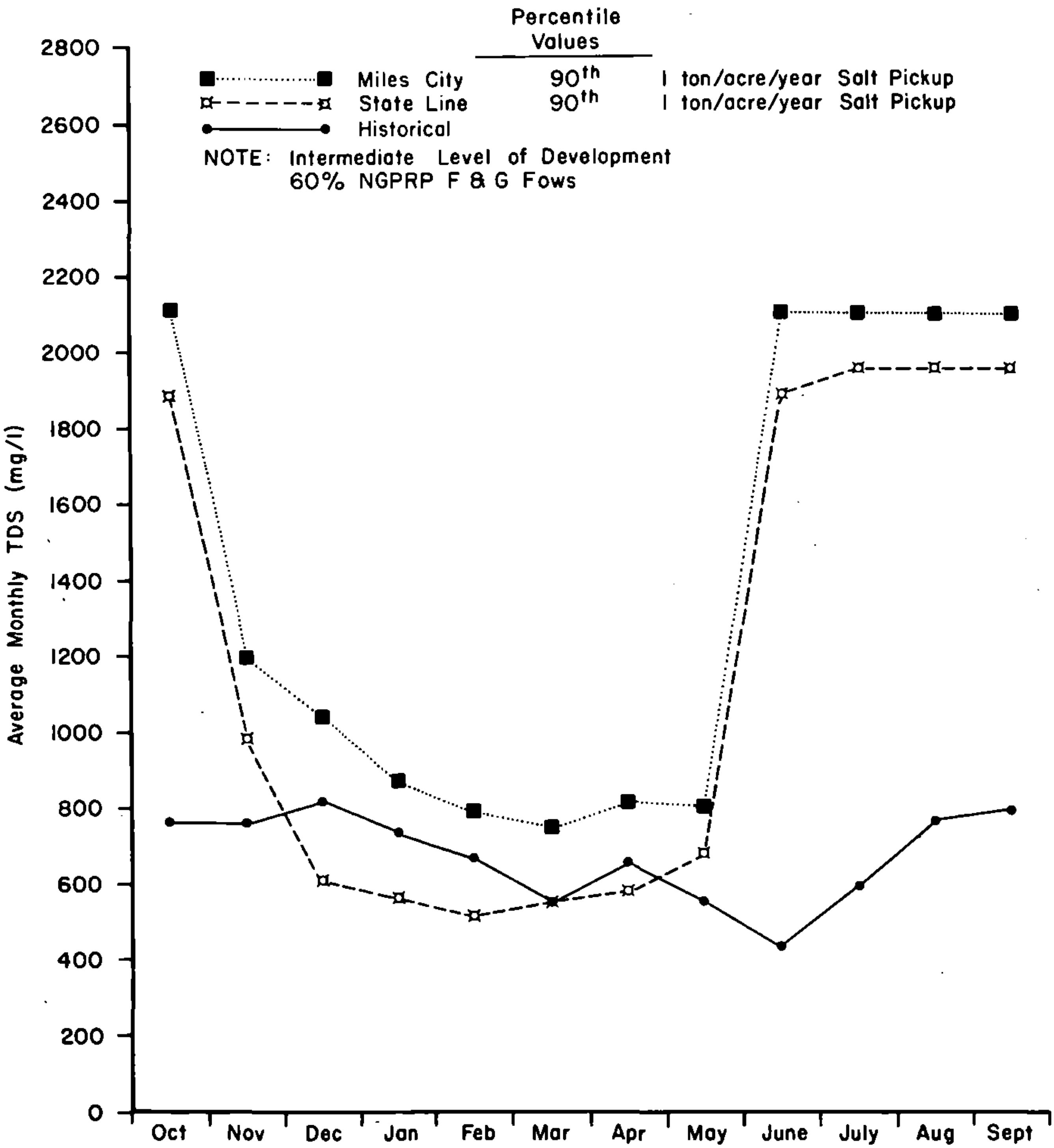

Figure 19. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the intermediate level of development at 90th percentile values.

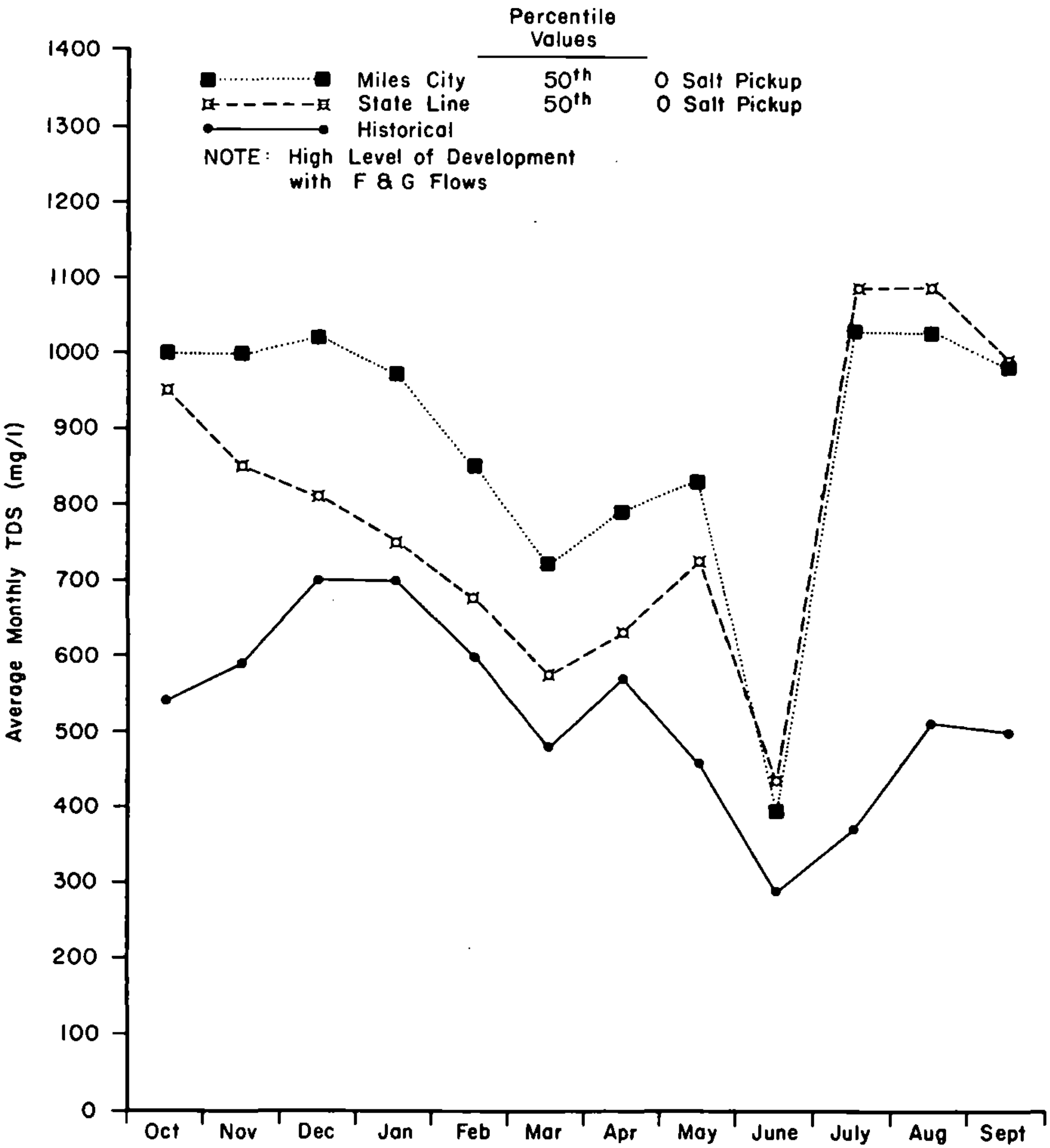

Figure 20. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the high level of development at 50th percentile values.

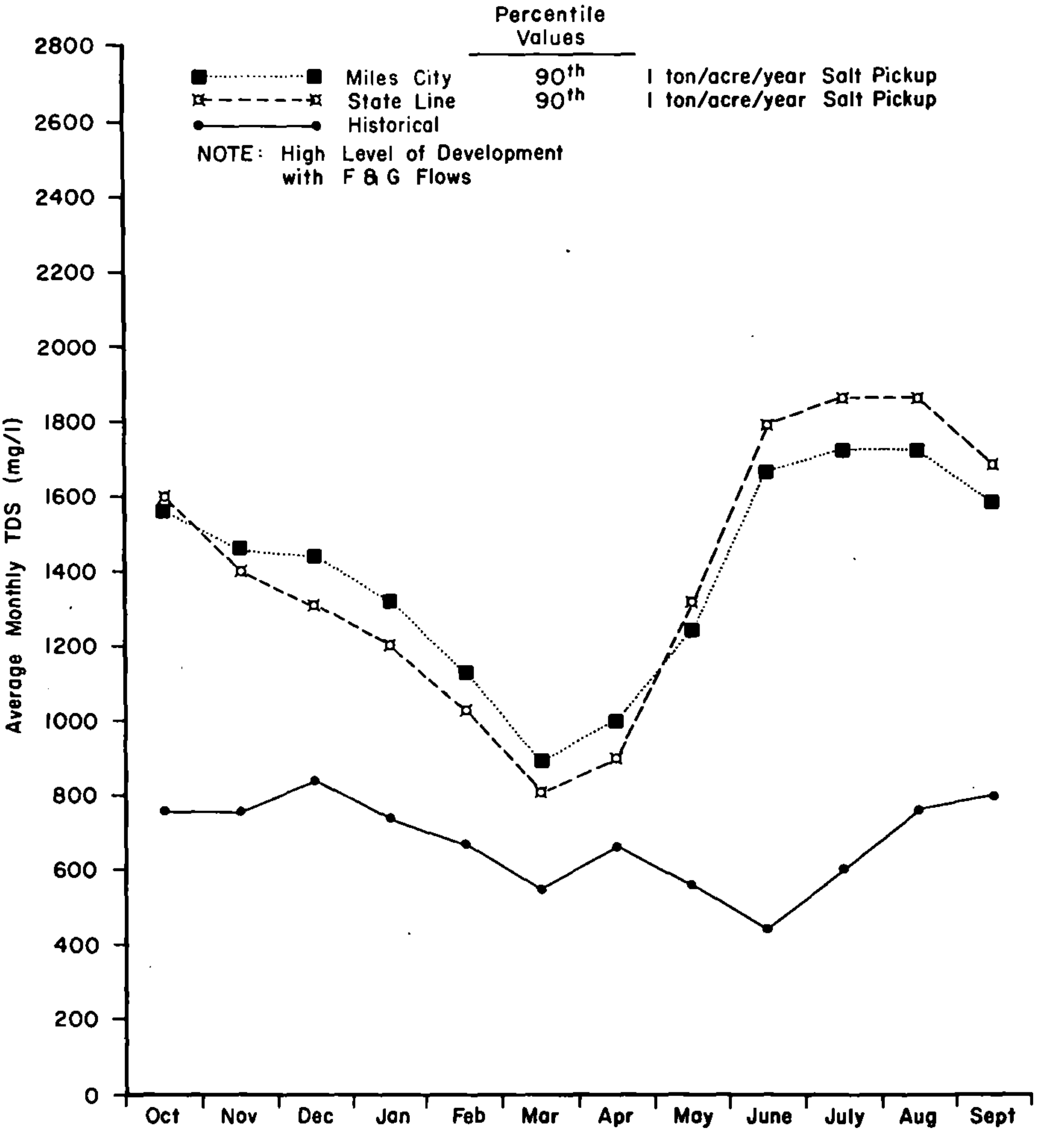

Figure 21. Comparison of TDS concentrations in the Tongue River at Miles City computed from records at Miles City and the state border, assuming complete mixing in the reservoir, and using the high level of development at 90th percentile values.

2) Fiftieth percentile values were consistently lower from method B. Except during the summer, method B produced TDS concentrations lower than historical values; this is not impossible considering the lessening effect of the reservoir, but it is probably unrealistic considering the deterioration in quality between the dam and Miles City.

3) The general conclusions are the same under either method. Further development of the Tongue River would cause significant increases in TDS concentrations at Miles City, especially during the summer and fall.

Other Parameters

Major reductions in flow, accompanied by substantial increases in TDS, would produce significant deterioration of overall water quality. Dissolved constituents generally increase linearly with TDS concentrations. Sodium is naturally low and should not become a problem; the SAR would increase from 1.38 when TDS is 450 to 2.6 when TDS is 1200 (SAR = .573 + .00169 TDS; r = .708). Sulfate, on the other hand, is fairly high now--182 mg/l at a TDS of 450 (SO_4 = -41.4 + .496 TDS; r = .985). It would reach 256 mg/l for TDS concentrations of 600 mg/l and 554 mg/l for TDS concentrations of 1200 mg/l. Hardness also would increase substantially from its already high levels of 250-400 mg/l. Nutrients may increase because of the irrigation of new land and the concomitant increase in irrigation return flow. Water temperatures would be higher because of reduced streamflows, but the magnitude of these increases is difficult to predict. The waste assimilation capacity would be reduced, perhaps accompanied by a reduction in dissolved oxygen. TSS concentration tends to decrease as discharge is reduced. Moreover, the larger Tongue River Reservoir should remove more sediment from the water than the existing structure. However, these effects may be offset at least partially by the increased production of sediment from expanded mining and agricultural operations.

Summary

All levels of development analyzed for the Tongue River subbasin would produce significant reductions in water quality at Miles City, primarily because of the combination of substantially reduced streamflows and increased salt loads from irrigation return flows. TDS, sulfate, and hardness would increase above the already high levels. Sodium would probably increase but not enough to cause a problem. The aquatic environment would be severely stressed by the low late summer flows which would be higher in dissolved minerals and nutrients, possibly lower in dissolved oxygen, and subject to higher temperatures and increased diurnal variation in both temperature and dissolved oxygen.

POWDER RIVER SUBBASIN

Total Dissolved Solids

The Powder River is characterized by large variations in flow and water quality. Historically, discharge at Locate, near the mouth, has varied from 0 to 31,000 cfs., with flows less than 30 cfs. and greater than 5000 cfs. common. The Powder River carries an extremely high sediment load and annually contributes several million tons of sediment to the Yellowstone River (an average of 6 million tons per year for 1951-1953 and 1974). In addition, the water carries a high and variable load of TDS concentrations. Because of the wide variation in discharge and quality, and the paucity of water quality records (1951-1963 is available on the Powder River near Locate), the regression equations between TDS and discharge in table 149 generally are not as reliable as similar equations for the other subbasins. The listed equations, however, were used to obtain estimates of historical TDS values.

The projected construction of a large dam on the Powder River at Moorhead required that equations (8), (9), and (10), which describe water quality changes in a reservoir, be employed. Analysis of concurrent records for the February 1951 to September 1953 period (the only period with records at Moorhead) revealed no statistically significant difference between average monthly TDS values of the Powder River near Locate and the Powder River at Moorhead. Consequently, equations between TDS and Q for the Powder River near Locate (table 149) were used to calculate TDS of reservoir inflow, CI_1 of equation (9).

Because of the excessive sediment carried by the Powder River, the proposed dam at Moorhead was assumed to provide 875,000 af of inactive storage capacity in which to store incoming sediment. Theoretically, at the end of the economic life of the reservoir, this space would be filled with sediment, leaving only 275,000 af of a total storage capacity of 1,150,000 af for use (USBR 1969). Because water quality calculations are based on complete mixing of incoming flow with reservoir contents, VR_0, the storage in the reservoir, could become an important parameter of equation (8). Therefore, water quality was simulated separately using both the initial 1,150,000 af and the final 275,000 af storage capacities. Results, illustrated in figures 22 and 23, indicate that TDS is relatively insensitive to the storage capacity. Consequently, the discussion that follows considers only the case of 1,150,000 af active storage, which would be more indicative of the early life of the structure.

Only two levels of development, labeled low and high, were considered for the Powder Subbasin. Results are presented in tables 150 and 151 and in figures 24 and 25, and are briefly summarized below.

Low Level of Development. A large dam at Moorhead would lessen the natural variation in TDS immediately below the dam, as indicated in figure 22, and produce a nearly constant concentration of approximately 1100 mg/l. Subsequent use of reservoir releases for irrigation, however, would significantly increase TDS concentrations at the mouth of the Powder River. Annual concentrations would increase 18 percent (25 percent with salt pickup of 1 ton per acre per year) and 97 percent (129 percent with salt pickup) at the 50th percentile and 90th percentile flows, respectively, from 1137 mg/l to 1339 mg/l (1423 mg/l

TABLE 149. Regression equations between TDS and monthly discharge (Q) in the Powder River near Locate, 1951-1963.

Month	Best Fit Equation	r^2	Significance
Jan	TDS = 2009.9 - .04002 Q	.154	a
Feb	TDS = 3965.75 - 663.84961 log Q	.745	b
Mar	log TDS = 3.14148 - .0000027288 Q	.863	b
Apr	TDS = 1603.99 - .00769 Q	.764	b
May	TDS = 2952.2 - 408.35 log Q	.179	a
June	log TDS = 3.50657 - .10253 log Q	.256	a
July	TDS = 4378.26 - 707.0542 log Q	.579	b
Aug	TDS = 2171.01 - 136.38783 log Q	.067	a
Sept	log TDS = 3.35371 - 0.06055 log Q	.170	a
Oct	TDS = 3479.57 - 521.59961 log Q	.517	b
Nov	log TDS = 3.37988 - .00002 Q	.856	b
Dec	log TDS = 3.40523 - .00002 Q	.759	b
All months	TDS = 3348.9 - 469.92334	.457	b

NOTE: TDS represents average monthly figures in mg/l; Q represents monthly discharge in acre-feet.

[a]Not significant at 4 percent level.

[b]Significant at 1 percent level.

with salt pickup) and from 1390 mg/l to 2739 mg/l (3188 mg/l with salt pickup). Monthly increases would be more dramatic. July through January values would increase by factors ranging from 1.69 (2.07 with salt pickup) to 2.46 (3.05 with salt pickup) at 50th percentile flows, or from an average 7-month concentration of 1552 mg/l to 3221 mg/l (3956 mg/l with salt pickup). February through June increases would be comparatively modest at 50th percentile flows, but at 90th percentile flows, all months would show high TDS waters; over ten months of the year (June-March) TDS concentrations would exceed 3400 mg/l (4100 mg/l with salt pickup). During many months (even in average years), the Powder River at its mouth would consist almost entirely of irrigation return flow and would have TDS concentrations exceeding 3000 mg/l. Obviously such water would not be suitable for most beneficial uses.

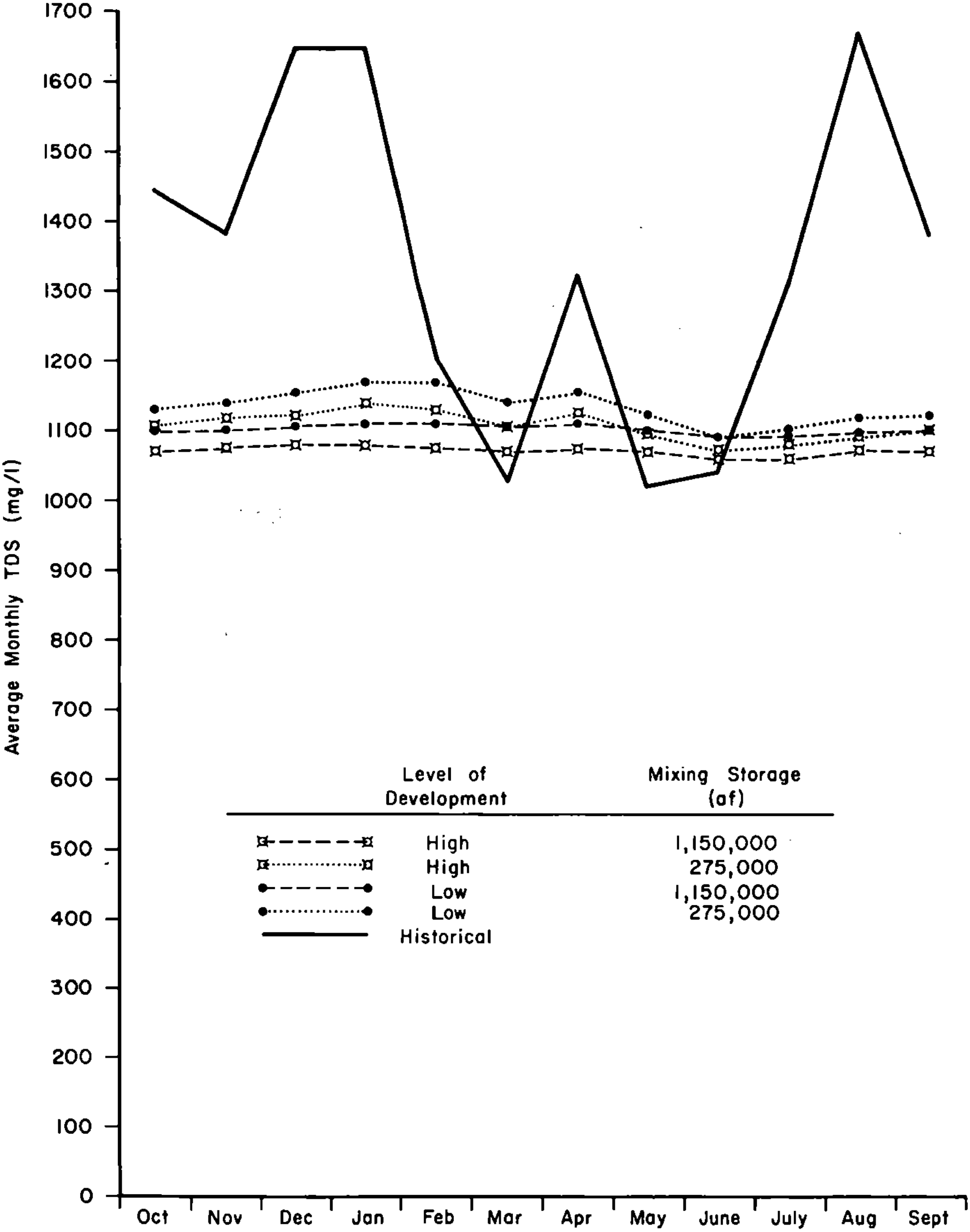

Figure 22. Effects of reservoir storage on TDS concentrations in the Powder River near Moorhead.

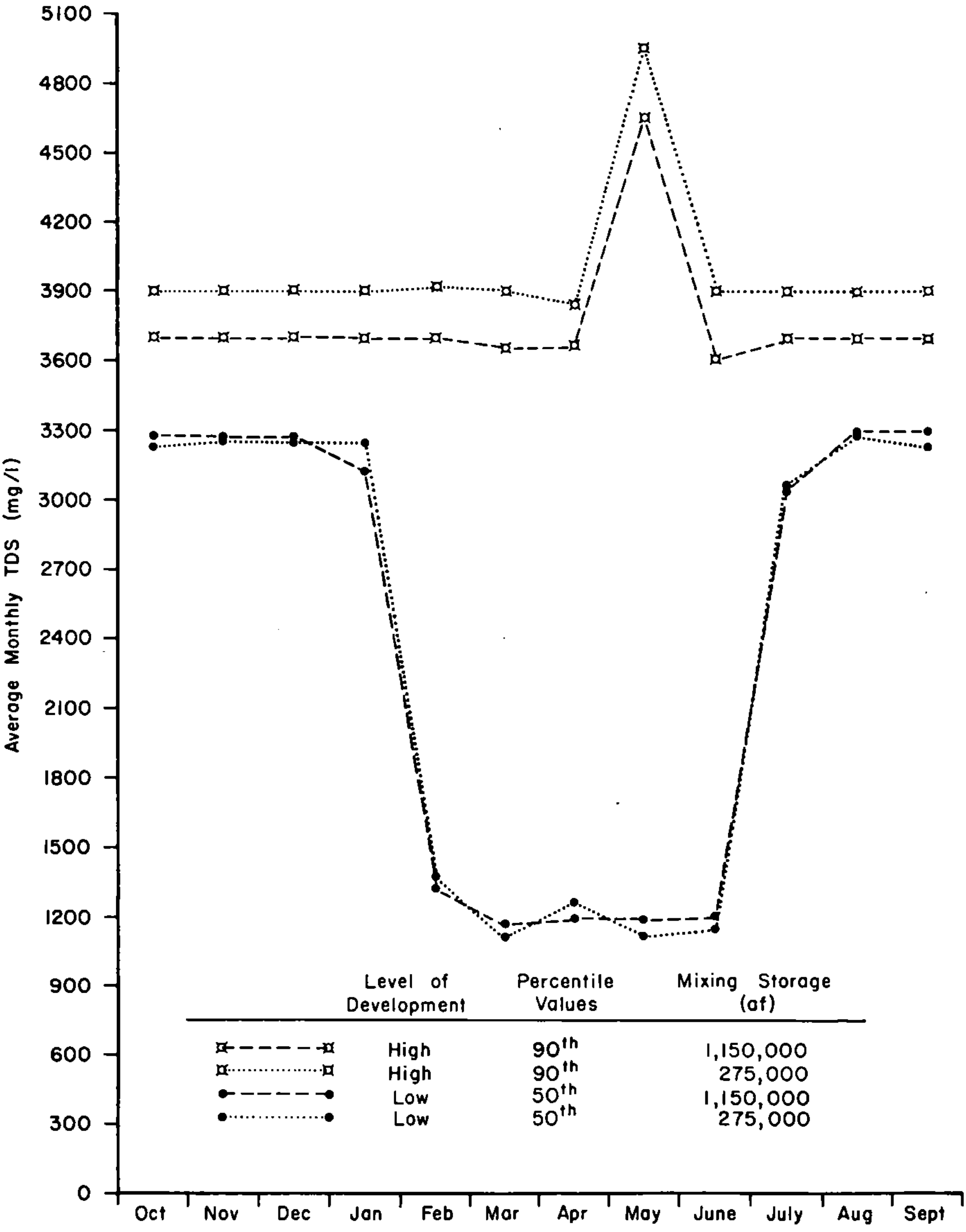

Figure 23. Effects of active storage level on average monthly TDS concentrations in the Powder River near Locate.

TABLE 150. TDS values in the Powder River, assuming a low level of development with 1,150,000 af storage.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	TDS at Salt pickup[a] of: 0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	7,192	1,468	2,000	3,267		4,003	553	2,049	2,000	3,511		4,246
Nov	10,351	1,475	1,250	3,267		4,002	3,688	2,017	1,250	3,511		4,246
Dec	7,069	1,929	1,000	3,267		4,002	3,750	2,196	1,000	3,511		4,246
Jan	6,393	1,754	750	3,121		3,856	1,967	1,931	750	3,511		4,246
Feb	11,160	1,279	3,312	1,320		1,431	3,565	1,608	500	3,511		4,246
March	53,543	989	34,922	1,163		1,178	17,889	1,238	750	3,472		4,208
April	34,266	1,340	30,600	1,192		1,216	20,643	1,445	2,315	2,059		2,376
May	63,747	990	51,484	1,189		1,200	26,065	1,149	14,066	1,704		1,743
June	100,360	986	91,303	1,204		1,256	10,946	1,237	3,500	3,439		4,174
July	27,601	1,238	4,500	3,041		3,776	2,889	1,931	4,500	3,511		4,246
Aug	9,221	1,637	4,500	3,292		4,027	861	1,771	4,500	3,511		4,246
Sept	4,164	1,363	2,500	3,292		4,027	535	1,544	2,500	3,511		4,246
Annual	335,067	1,137	228,121	1,339		1,423	93,331	1,390	37,631	2,739		3,188

[a]Salt pickup given in tons per acre per year.

TABLE 151. TDS values in the Powder River at Locate, assuming a high level of development with 1,150,000 af storage.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	7,192	1,468	3,000	3,504		4,320	553	2,049	3,000	3,699		4,515
Nov	10,351	1,475	1,880	3,467		4,281	3,688	2,017	1,880	3,692		4,506
Dec	7,069	1,929	1,500	3,476		4,290	3,750	2,196	1,500	3,702		4,516
Jan	6,393	1,754	1,130	3,460		4,274	1,967	1,931	1,130	3,685		4,499
Feb	11,160	1,279	750	3,462		4,276	3,565	1,608	750	3,702		4,515
March	53,543	989	3,054	1,953		2,254	17,889	1,238	1,130	3,644		4,457
April	34,266	1,340	22,028	1,312		1,367	20,643	1,445	1,500	3,660		4,474
May	63,747	990	33,507	1,464		1,492	26,065	1,149	4,040	4,639		4,867
June	100,360	986	66,765	1,200		1,265	10,946	1,237	5,260	3,604		4,419
July	27,601	1,238	6,760	3,433		4,249	2,889	1,931	6,760	3,694		4,510
Aug	9,221	1,637	6,760	3,499		4,315	861	1,771	6,760	3,694		4,510
Sept	4,164	1,363	3,760	3,498		4,312	535	1,544	3,760	3,693		4,506
Annual	335,067	1,137	150,894	1,675		1,862	93,331	1,390	37,470	3,781		4,532

[a] Salt pickup given in tons per acre per year.

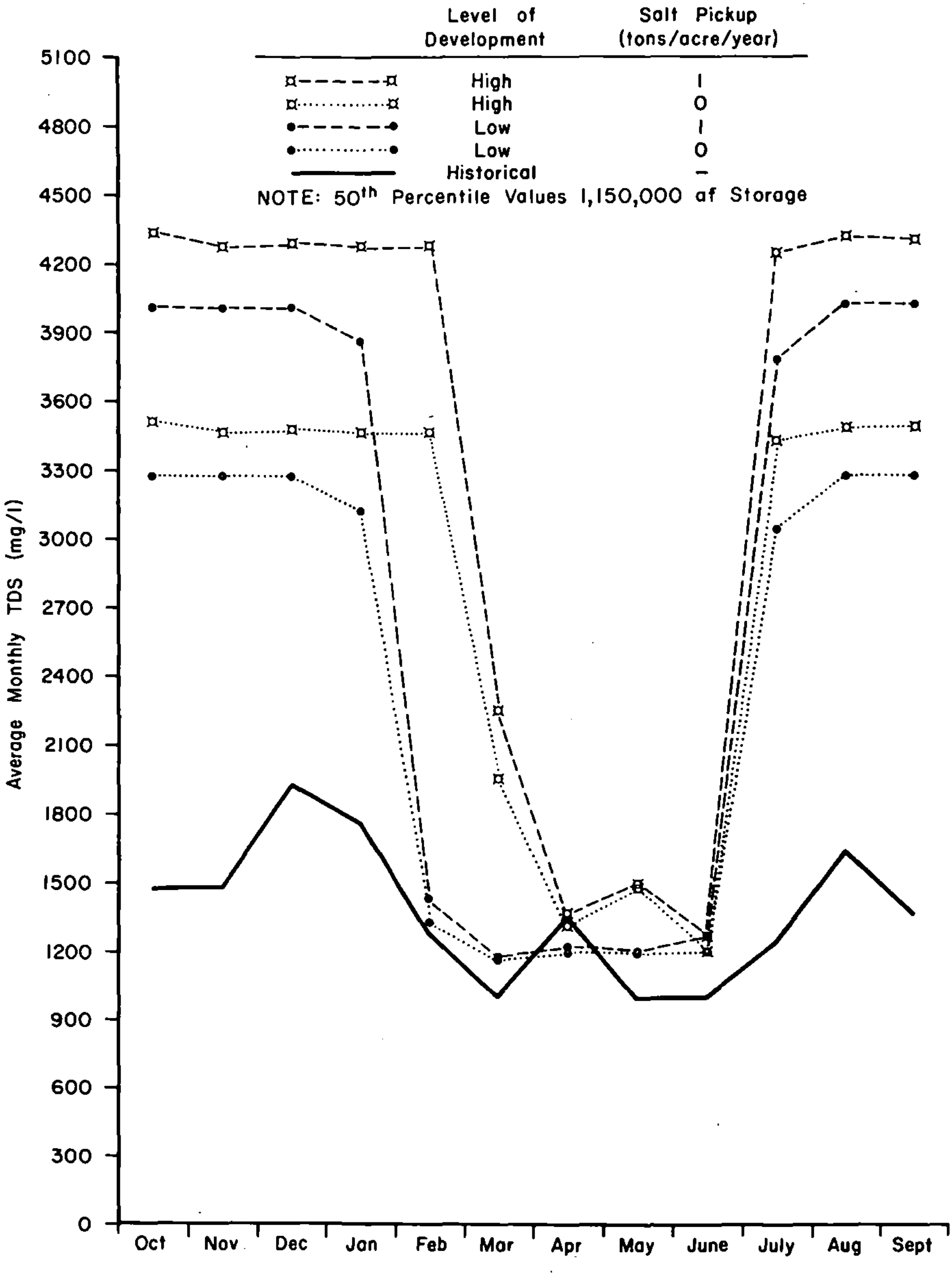

Figure 24. Average monthly TDS concentrations in the Powder River near Locate at 50th percentile values with 1,150,000 af storage.

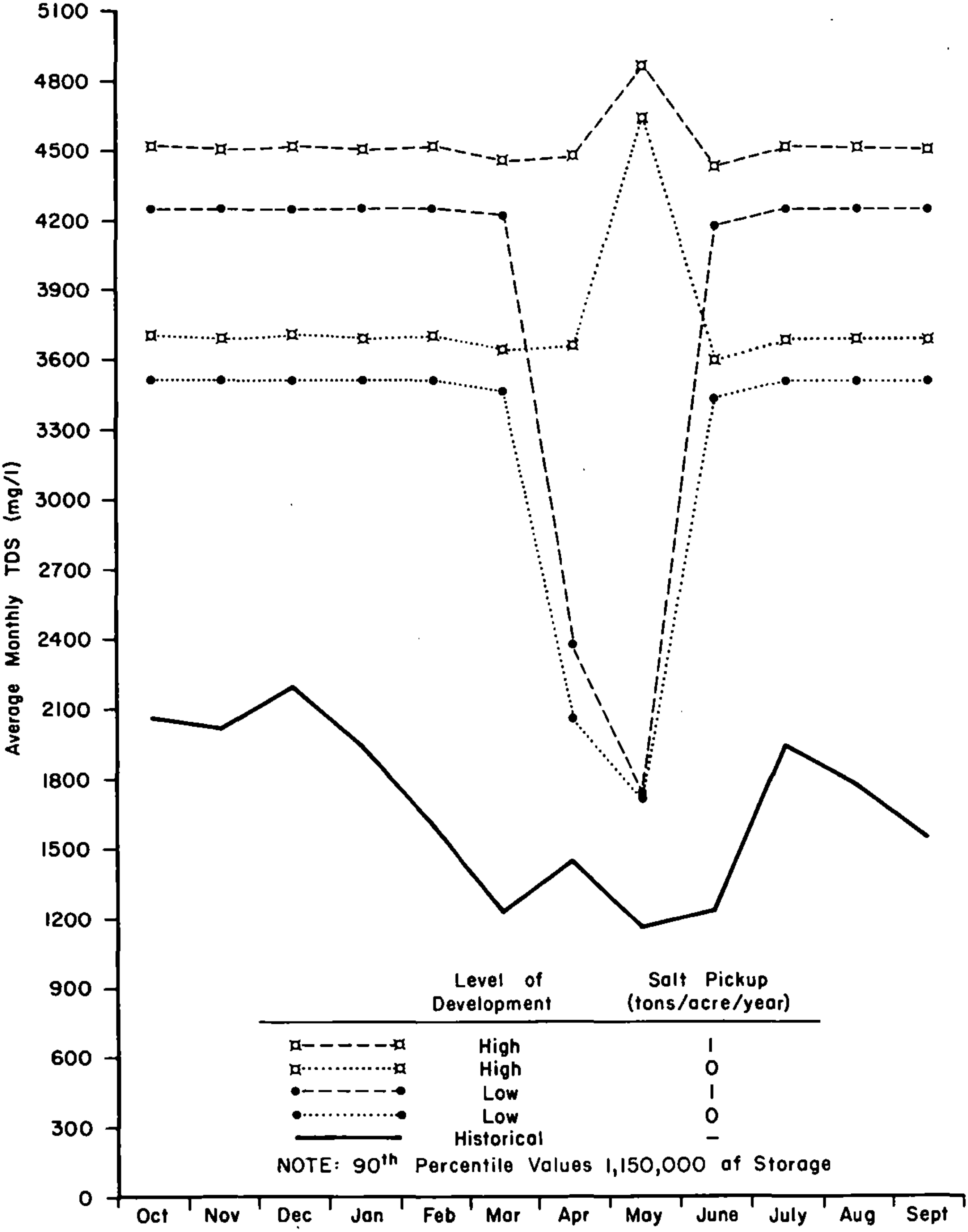

Figure 25. Average monthly TDS concentrations in the Powder River at Locate at 90th percentile values with 1,150,000 af storage.

High Level of Development. Annual TDS concentrations would increase 47 percent (64 percent with salt pickup of 1 ton per acre per year) and 172 percent (226 percent with salt pickup) at 50th percentile and 90th percentile flows, respectively. Concentrations would be about doubled--to 3600 mg/l (4500 mg/l with salt pickup) or more--for all months under 90th percentile flows. At 50th percentile flows, TDS concentrations would average about 3500 mg/l (4300 mg/l with salt pickup) from July through February, or approximately 2.3 (2.8) times natural levels; factor increases would be 1.97 (2.27 with salt pickup) for March, 0.98 (1.02 with salt pickup) for April, 1.48 (1.51 with salt pickup) for May, and 1.22 (1.28 with salt pickup) for June. Flows at the mouth of the Powder River would consist essentially of irrigation return flows which would be unsuitable for most beneficial uses. Depending upon the location of new irrigated land, soil properties, and the type of irrigation system used, the water may become unsuitable for irrigation before it reaches the mouth of the river. In fact, water released from the dam would be classified as high salinity water and could not be used on soils with restricted drainage; according to Richards (1954), ". . . even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected." Obviously, before any land in the Powder River Valley is brought under irrigation, a thorough investigation should be undertaken to determine the compatibility of crop, soil, and water.

Other Parameters

Powder River water is characterized by high TSS as well as high TDS concentrations. Dissolved constituents consist primarily of sodium and sulfate ions, with lesser, but significant, concentrations of calcium, bicarbonate, and chloride. SAR values sometimes exceed 5 or 6, but generally range from 3-4. Construction of a large reservoir would tend to stabilize the concentrations of all dissolved minerals and the value of SAR (assuming no significant dissolution or precipitation of minerals within the reservoir). Moreover, incoming sediment would be trapped behind the dam. Based on historical records, and assuming complete mixing within the reservoir, releases from the dam should have approximately the concentrations listed in table 152.

TABLE 152. Concentrations of dissolved minerals and SAR value that would be released from a reservoir constructed on the Powder River, based upon historical records.

	Concentrations
TDS	1125 mg/l
Na	159 mg/l
SO_4	572 mg/l
HCO_3	209 mg/l
Hardness	486 mg/l
SAR	3.13

Such water would be undesirable for most beneficial uses. It would be suitable for irrigation only for salt resistant crops on well-drained soils. The high levels of TDS, SO_4, and hardness preclude its use for domestic purposes unless no better source is available.

The significant increases in TDS that would result from using reservoir releases for irrigation would be accompanied by corresponding increases in the dissolved constituents. The mix of ions may be altered somewhat, depending upon chemical properties of the soils irrigated. The net result, in any case, would be further contamination. By the time it enters the Yellowstone, Powder River water would contain excessive concentrations of several minerals, and would be unuseable for almost all beneficial purposes.

Containment of flood waters, with their enormous sediment loads, behind the dam would reduce the sediment concentration in water released from the reservoir. The Powder River channel is highly erodible, and it is likely that considerable scouring would occur below the dam. For a given discharge, the river may eventually carry as much sediment after construction of the dam as it did before. Because the dam would store floodwaters and release a more uniform flow downstream, however, the total annual sediment load discharged into the Yellowstone River should be reduced by construction of the dam.

In an average year, under both levels of development, discharges would be reduced 10 percent to 85 percent during the July-to-September period. The result could be an increase in water temperature, a decrease in dissolved oxygen, and an increase in the diurnal variation of both. At 90th percentile flows, on the other hand, discharges would be higher than under natural conditions. Therefore, water temperatures and dissolved oxygen levels may increase. The key factor would be the effect of the large reservoir on water quality below the dam. The quality of releases would depend on many factors, including the nature of chemical and physical changes that may occur during storage, biological activity in the reservoir, and the depth at which water is withdrawn--factors that are difficult to quantify before construction and operation of the prototype.

Summary

Powder River water naturally contains relatively high concentrations of both TDS and TSS. Construction of a large dam at Moorhead would reduce the sediment load in the river below the dam and tend to stabilize the concentration of TDS at approximately 1100 mg/l, which would classify the water as having a high salinity hazard. Subsequent use of such water for irrigation would increase TDS concentrations by factors of 2 to 3 before the water would reach the Yellowstone River.

The low flows (which would often consist essentially of irrigation return flows) and high TDS levels would be accompanied by higher SAR values and increased hardness, plus higher concentrations of all dissolved minerals. Many of these parameters, such as sodium, sulfate, and hardness, are already excessive (the sulfate standard is 250 mg/l, and water is hard at 100 mg/l; typical concentrations in the Powder River are 400-700 mg/l sulfates and 300-600 mg/l hardness). Moreover, dissolved oxygen levels may be depressed and water temperatures elevated under either level of development, thereby greatly

stressing the aquatic environment. Obviously, any proposed developments on the Powder River should be carefully and thoroughly scrutinized to determine their economic feasibility and environmental desirability.

LOWER YELLOWSTONE SUBBASIN

Total Dissolved Solids

Nineteen years of records (1951-1969) on the Yellowstone River near Sidney were used to develop the regression equations between TDS and discharge given in table 153. Three levels of development were analyzed, each for an assumed salt pickup of 0 and 1 ton per acre per year. Results are presented in tables 154, 155, and 156, and are illustrated graphically in figures 26 and 27. Each level of development is discussed below.

Low Level of Development. Realization of the low level of development would cause a moderate increase in TDS concentrations in the Yellowstone River at Sidney. Average annual increases in TDS would be from 422 to 434 mg/l (445 mg/l with salt pickup of 1 ton per acre per year) at 50th percentile flows and from 486 to 515 mg/l (524 mg/l with salt pickup) at 90th percentile flows. Individual monthly increases generally would be less than 15 percent. Notable exceptions would be July and August at 90th percentile flows, when increases would be 20 percent (23 percent with salt pickup) and 31 percent (38 percent with salt pickup), respectively. The August concentration would increase from 542 to 709 mg/l (748 mg/l with salt pickup).

Intermediate Level of Development. Average annual increases in TDS would range from 9.5 percent at 50th percentile flows with 0 salt pickup to 15.2 percent at 90th percentile flows with 1 ton per acre per year salt pickup. At 50th percentile values, only March, August, and September would show major increases in salinity: 24 percent (26 percent with salt pickup of 1 ton per acre per year), 28 percent (47 percent with salt pickup), and 18 percent (21 percent with salt pickup). Increases would be more severe at 90th percentile flows. Percentage increases from July through October would be 37 (45 with salt pickup), 68 (83 with salt pickup), 17 (27 with salt pickup), and 10 (13 with salt pickup). Actual concentrations would average 691 mg/l (701 mg/l with salt pickup) from August through October at 90th percentile flow levels.

High Level of Development. If the development assumed by this projection were to occur, the lower Yellowstone Subbasin would show a major increase in TDS concentrations, especially during July, August, and September. Annual concentrations would increase from 422 to 459 mg/l (477 mg/l with salt pickup of 1 ton per acre per year) at 50th percentile flows and from 486 to 541 mg/l (586 mg/l with salt pickup) at 90th percentile flows. July, August, and September concentrations, however, would increase by 24 percent (36 percent with salt pickup), 41 percent (52 percent with salt pickup), and 24 percent (29 percent with salt pickup) at 50th percentile flows; and by 38 percent (60 percent with salt pickup), 108 percent (168 percent with salt pickup), and 30 percent (55 percent with salt pickup) at 90th percentile flows. August through October concentrations would average 637 mg/l (670 mg/l with salt pickup) at 50th percentile flows and 881 mg/l (1052 mg/l with salt pickup) at 90th percentile flows. Thus, even in average flow years, river water would have a high salinity hazard (Richards 1954) after July and during April.

TABLE 153. Regression equations between TDS and monthly discharge in the Yellowstone River near Sidney, 1951-1969.

Month	Best Fit Equation	r^2	Significance
Jan	log TDS = 4.45663 - .2983 log Q	.655	a
Feb	TDS = 2469.44 - 339.72412 log Q	.580	a
Mar	TDS = 2785.62 - 392.1665 log Q	.571	a
Apr	log TDS = 2.864506 - .0000001684 Q	.634	a
May	TDS = 561.71 - 0.00017959 Q	.494	a
June	TDS = 198.98 + 0.00003539 Q	.247	b
July	TDS = 917.41 - 101.69664 log Q	.250	b
Aug	TDS = 2303.31 - 327.66333 log Q	.602	a
Sept	log TDS = 2.85842 - .0000002973 Q	.543	a
Oct	TDS = 3745.50 - 561.71338 log Q	.722	a
Nov	TDS = 3852.08 - 579.99414 log Q	.629	a
Dec	TDS = 863.67 - .00061612 Q	.446	a
All months	TDS = 2827.38 - 403.47119 log Q	.685	a

NOTE: TDS represents average monthly concentrations in mg/l; Q represents monthly discharge in acre-feet.

[a]Significant at 1 percent level.

[b]Significant at 5 percent level.

Other Parameters

Significant reductions in flow and major increases in TDS would result in concomitant degradation of water quality as measured by various parameters. Unfortunately, techniques are not currently available to determine the magnitude of changes in most parameters. Most dissolved constituents vary fairly linearly with TDS concentrations. The plot for sulfate (SO_4) is shown on figure 28. A 20 percent increase in TDS, from 500 mg/l to 600 mg/l, would increase SO_4 from

TABLE 154. TDS values in the lower Yellowstone River near Sidney, assuming a low level of development.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1	Q	TDS	Q	TDS at Salt pickup[a] of: 0	½	1
	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)	(af)	(mg/l)	(af)	(mg/l)	(mg/l)	(mg/l)
Oct	489,571	549	453,165	580		585	338,778	639	305,608	680		690
Nov	441,416	578	441,005	580		587	340,461	644	340,600	647		657
Dec	360,109	642	350,824	642		651	243,249	714	234,670	718		732
Jan	327,344	648	316,982	650		662	200,095	750	201,851	743		760
Feb	340,096	590	338,537	587		597	256,410	632	249,182	630		643
March	635,385	510	612,714	514		518	343,573	615	304,539	633		641
April	547,605	592	538,938	582		586	345,280	640	388,858	621		627
May	1,139,647	357	1,037,764	349		391	569,424	459	480,471	496		501
June	2,321,298	281	2,217,202	283		285	1,217,402	242	1,123,425	250		254
July	1,244,331	298	1,085,901	336		342	532,541	335	393,007	403		412
Aug	446,355	452	353,761	516		537	237,778	542	138,179	709		748
Sept	431,778	537	326,062	599		609	218,388	622	174,059	685		704
Annual	8,724,936	422	8,072,855	435		445	4,843,379	486	4,335,349	515		524

[a]Salt pickup given in tons per acre per year.

TABLE 155. TDS values in the lower Yellowstone River near Sidney, assuming an intermediate level of development.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	489,571	549	450,778	598		610	338,778	639	305,093	705		722
Nov	441,416	578	422,969	597		614	340,461	644	337,869	654		674
Dec	360,109	642	339,545	655		677	243,249	714	231,366	718		751
Jan	327,344	648	310,589	648		677	200,095	750	198,777	735		780
Feb	340,096	590	329,219	584		610	256,410	632	246,089	623		656
March	635,385	510	592,839	633		643	343,573	615	294,179	647		666
April	547,605	592	513,823	602		611	345,280	640	363,422	647		661
May	1,139,647	357	1,001,548	403		407	569,424	459	440,103	532		543
June	2,321,298	281	2,155,473	287		291	1,217,402	242	1,101,047	265		273
July	1,244,331	298	1,049,411	356		364	532,541	335	358,134	459		486
Aug	446,355	452	325,254	579		663	237,778	542	109,601	910		994
Sept	431,778	537	309,139	634		651	218,388	622	160,003	725		790
Annual	8,724,936	422	7,800,587	462		475	4,843,379	486	4,145,683	539		560

[a]Salt pickup given in tons per acre per year.

TABLE 156. TDS values in the lower Yellowstone River near Sidney, assuming a high level of development.

	50th Percentile Values						90th Percentile Values					
	Historical		Simulated				Historical		Simulated			
				TDS at Salt pickup[a] of:						TDS at Salt pickup[a] of:		
	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)	Q (af)	TDS (mg/l)	Q (af)	0 (mg/l)	½ (mg/l)	1 (mg/l)
Oct	489,571	549	437,762	610		627	338,778	639	294,921	706		745
Nov	441,416	578	410,592	605		626	340,461	644	325,594	663		689
Dec	360,109	642	325,177	663		691	243,249	714	217,052	723		771
Jan	327,344	648	295,093	656		691	200,095	750	183,233	748		805
Feb	340,096	590	313,099	589		620	256,410	632	232,731	629		669
March	635,385	510	574,039	523		535	343,573	615	279,314	651		679
April	547,605	592	496,380	606		619	345,280	640	346,372	649		673
May	1,139,647	357	953,657	399		406	569,424	459	387,996	529		576
June	2,321,298	281	2,091,091	288		292	1,217,402	242	1,051,323	261		283
July	1,244,331	298	961,489	368		405	532,541	335	324,521	463		537
Aug	446,355	452	279,027	638		688	237,778	542	76,264	1,127		1,450
Sept	431,778	537	266,401	663		694	218,388	622	98,503	809		961
Annual	8,724,936	422	7,403,807	459		477	4,843,379	486	3,817,824	541		586

[a]Salt pickup given in tons per acre per year.

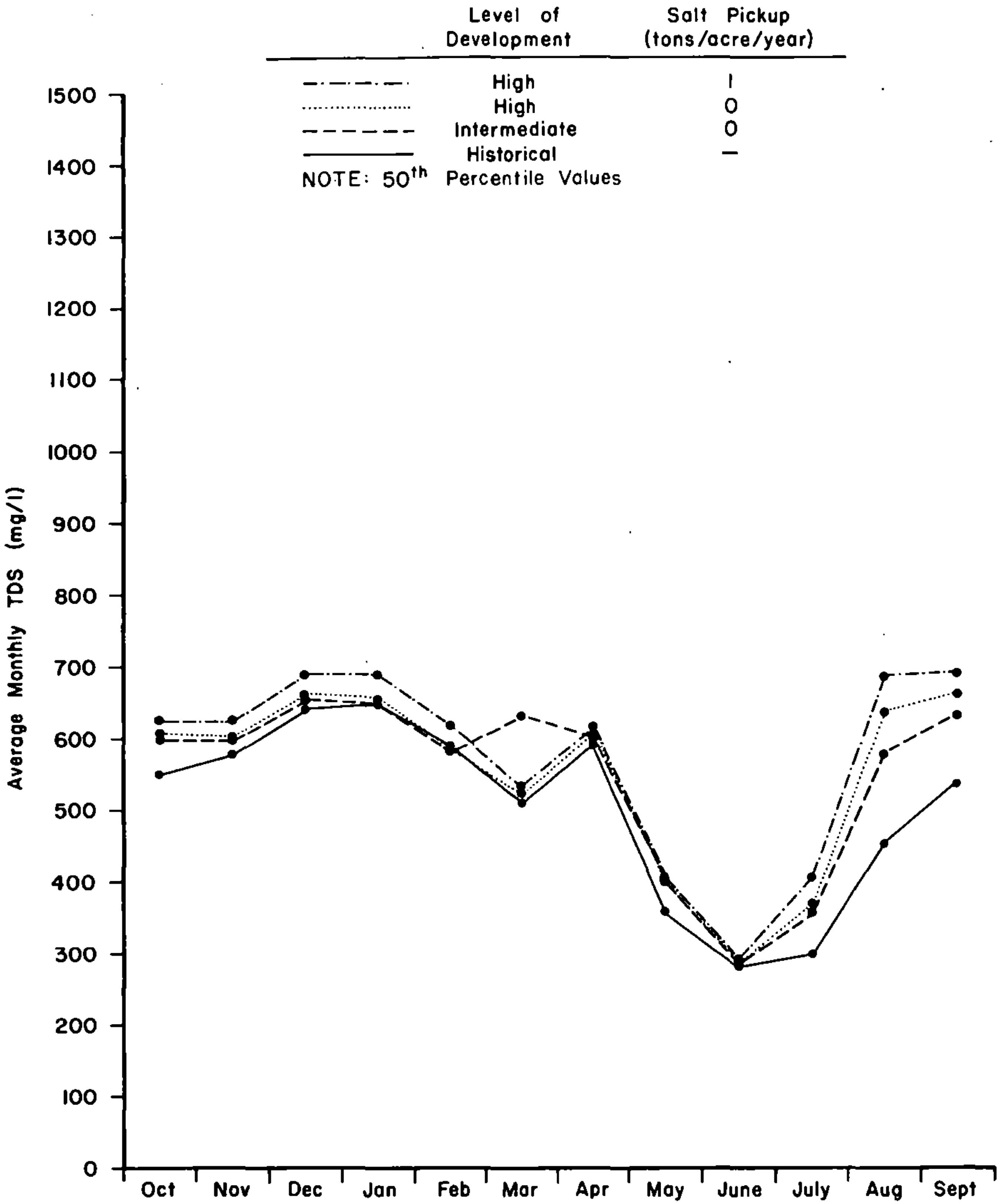

Figure 26. Comparison of historical and simulated TDS concentrations in the Yellowstone River near Sidney at 50th percentile flow values.

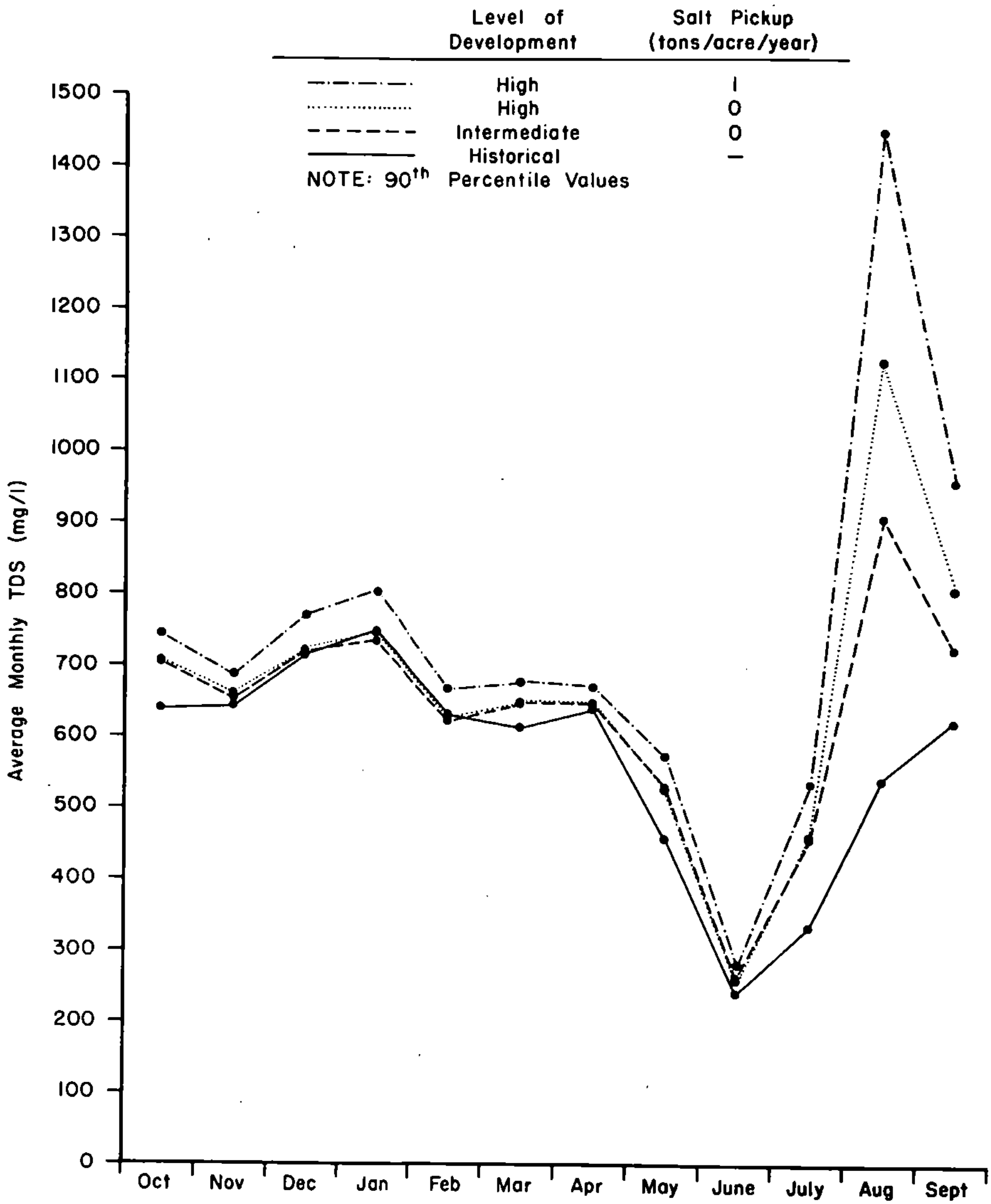

Figure 27. Comparison of historical and simulated TDS concentrations in the Yellowstone River near Sidney at 90th percentile flow values.

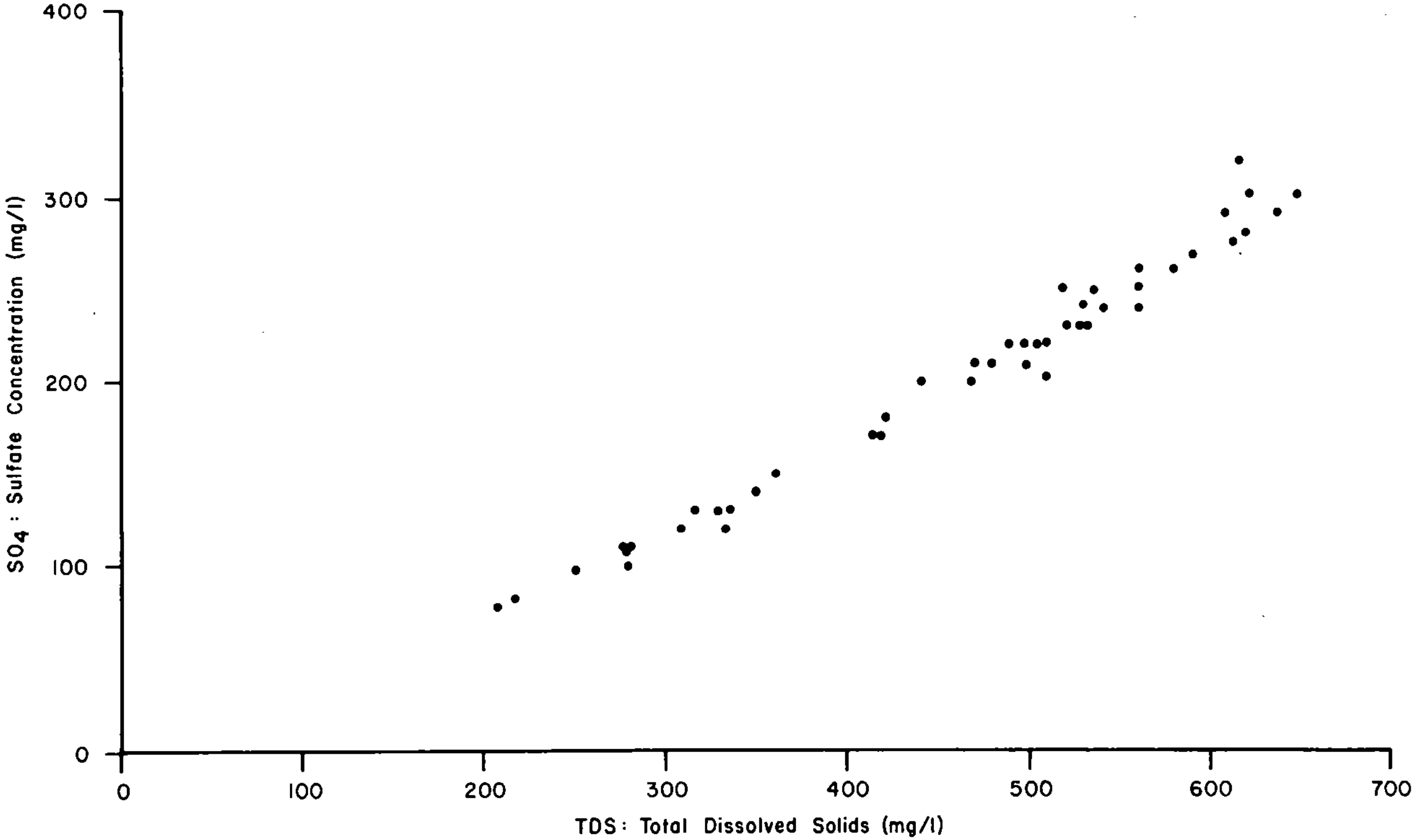

Figure 28. Comparison of SO_4 and TDS concentrations in the Yellowstone River near Sidney.

215 mg/l to 275 mg/l (approximately). The SO_4 water quality standard of 250 mg/l is exceeded in five months of the year under historical (considered natural by Montana law) conditions during a 50th percentile flow year. This frequency of standard violation would increase to seven months per year under the low level of development and to eight months under the intermediate and high levels of development.

Hardness would increase in proportion to higher TDS levels. In the Yellowstone River near Sidney, a 100 mg/l increase in TDS increases hardness by approximately 45 units. An increase in TDS from 500 to 600 mg/l would therefore result in a hardness of 290 mg/l. Although no legal standards have been adopted for hardness, anything over 100 mg/l becomes increasingly inconvenient for domestic use and some industrial applications.

Nutrient concentrations may increase because of fertilizer applications to new irrigation lands and because less water would be in the stream for dilution. Water temperatures would be somewhat higher because of reduced streamflows, but probably not more than ½°C. The river's waste assimilation capacity would be diminished. Dissolved oxygen levels may be reduced and diurnal variations would increase, primarily in late summer of low-flow years (Knudson and Swanson 1976).

Summary

The low level of development would have minor impacts on the overall water quality of the Yellowstone River near Sidney--only August and September of dry years would show significant increases in TDS. The high level of development, however, would cause a major reduction in water quality, especially during July, August, September, and October. During this four-month period, 50th percentile level discharges would be reduced more than 25 percent (38 percent during August and September) and 90th percentile level discharges would be reduced more than 40 percent (65 percent during August and September). Flow reductions of such magnitude would be accompanied by major increases in salinity, especially during the latter part of the irrigation season. Furthermore, nutrient levels probably would increase; water temperature and its diurnal range may increase, and dissolved oxygen and suspended sediment concentrations may decrease.

The net effect would be a deterioration of water quality and the aquatic environment. The water would be suitable for most beneficial uses most of the time. Municipal and industrial users may sustain higher treatment costs (although a reduction in TSS, if it were to occur, could reduce treatment costs) or more inconvenience (scaling, for example). Irrigators may encounter more salinity and drainage problems, reduced yields, or the necessity of more controlled management of their irrigation practices. The aquatic environment would suffer stresses because of the reductions in flow and degradation of water quality.

SENSITIVITY ANALYSES

INTRODUCTION

The methodology described in previous sections should not be considered infallible, but rather a "first generation" attempt to evaluate the flow of water and salt through the Yellowstone River Basin. There are several areas in which improvement could be made. Unfortunately, most such improvements are dependent upon data which have not been collected and field studies that have not been performed. Hence, there is an element of the unknown in several of the assumptions used. One unknown, total salt pickup by irrigation return flows, was acknowledged in the model through the use of two levels of salt pickup in most subbasins; that is, zero and one ton per acre per year. The actual salt pickup probably varies over a wide range of values throughout the basin. Also unknown is the distribution of return flows and the concentration of salts in return flow, both of which probably show considerably spatial and temporal variation.

DISTRIBUTION OF SALT RETURN

In the model irrigation return flows both salt and water were distributed according to the monthly percentages discussed previously in the explanation of table 20. In effect, irrigation return flow was assumed to have the same TDS concentration each month of the year. To test the sensitivity of the model a different distribution of salts was used, based on the following assumptions:

1) Return flow (water) is distributed according to the original assumption; i.e., beginning in April, each month's percentage of the total annual return flow is as follows: 4, 11, 14, 18, 18, 10, 8, 5, 4, 3, 2, 3.

2) Fifty percent of salt is returned during the October-to-March period, when flow is essentially all subsurface.

3) Fifty percent of salt is returned during the April-to-September period.

4) The resulting percentages of salt returned each month are as follows, beginning with April: 2.7, 7.3, 9.3, 12.0, 12.0, 6.7, 16.0, 10.0, 8.0, 6.0, 4.0, 6.0. This is the "adjusted" salt distribution.

The above distribution reflects the concept that subsurface return flow which predominates during the nonirrigation season, is higher in dissolved solids than surface return flow, which is assumed to dominate during the irrigation season. Comparisons were made of simulated stream TDS values in both the Tongue River and lower Yellowstone subbasins. Results are discussed below.

Tongue River Subbasin

The Tongue River was selected for analysis because the original simulations indicated that TDS would be increased substantially by further development. Use of the adjusted salt return distribution did not alter the basic conclusion. Figures 29 and 30 indicate that, as expected, the adjusted distribution simply

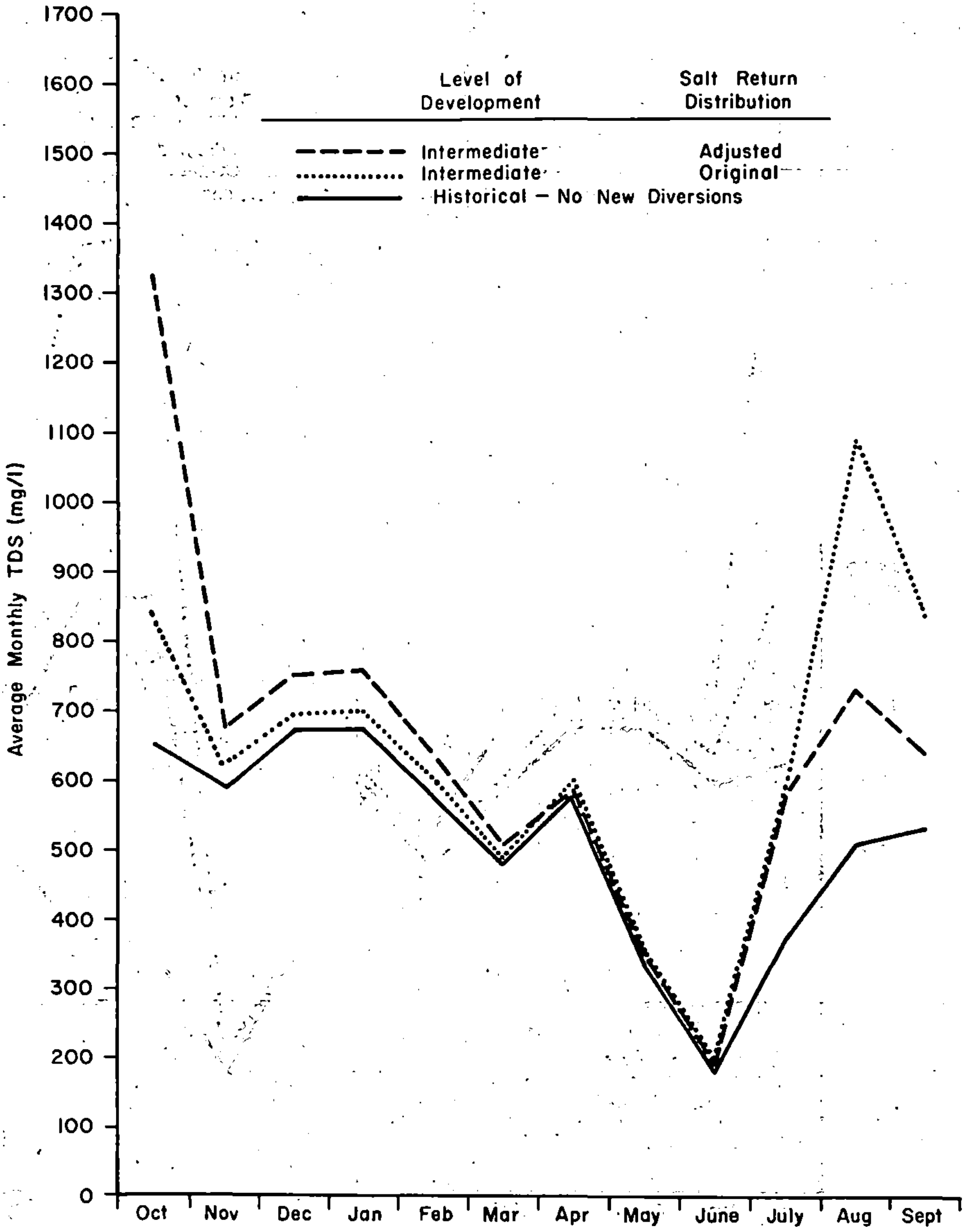

Figure 29. Effect on TDS concentrations of changing the monthly distribution of salt return from irrigation in the Tongue River near Miles City, using the intermediate level of development.

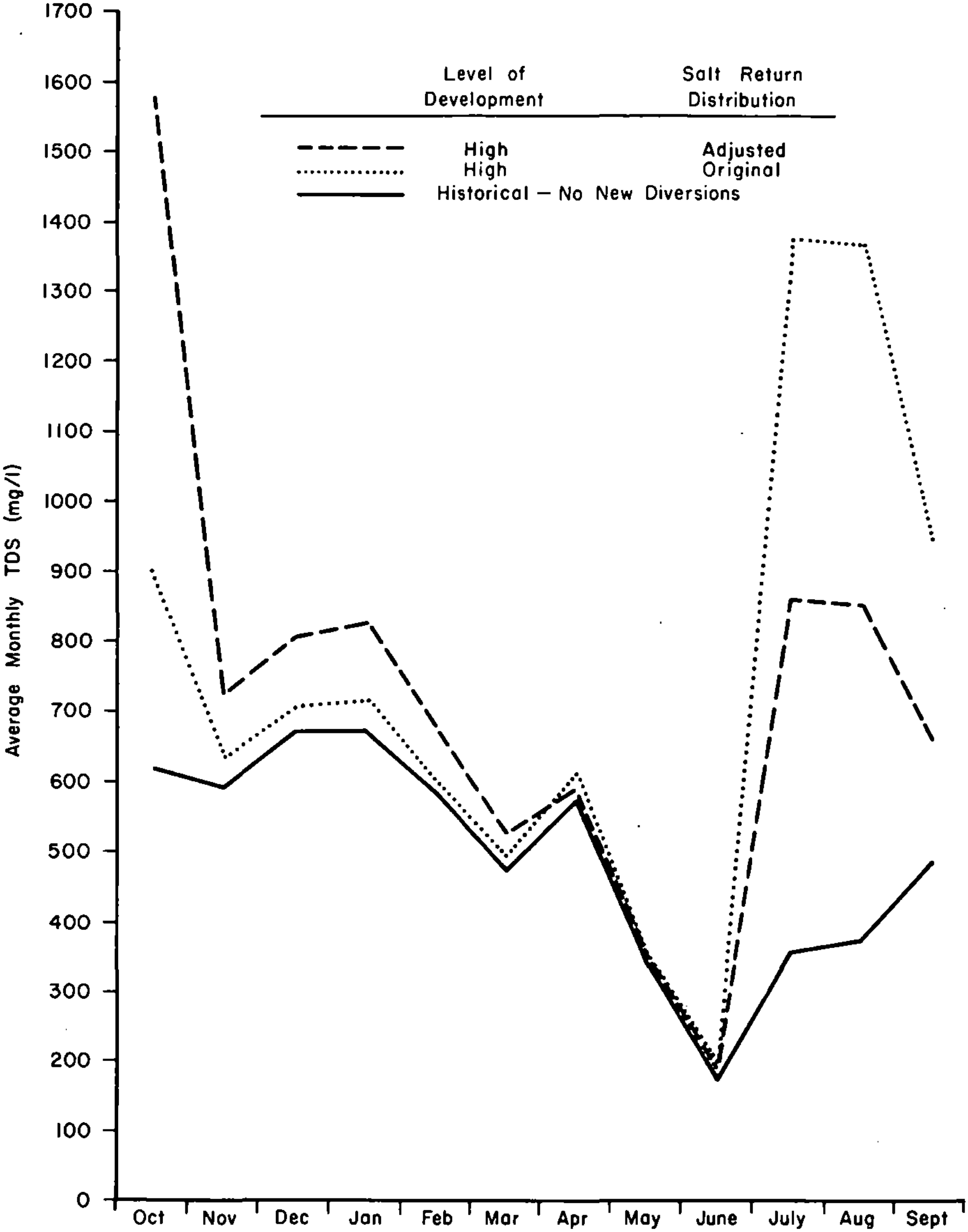

Figure 30. Effects on TDS concentrations of changing the monthly distribution of salt return from irrigation in the Tongue River near Miles City, using the high level of development.

shifts the highest simulated TDS values from July and August to October. Such a shift, if it occurred in practice, would lessen the impacts of increased salinity on irrigation because stream TDS would be less during the late irrigation season. Concentrations would still be significantly higher than under natural conditions. Moreover, the maximum concentrations would increase, though in October instead of August.

Lower Yellowstone Subbasin

The same change in stream salinity was evident in the lower Yellowstone Subbasin as in the Tongue--TDS levels would be reduced in late summer and increased during the fall and winter (figures 31 and 32). A shift of this nature could be beneficial to irrigators. It must be emphasized, however, that the adjusted salt return distribution probably underestimates the salt load returning to the stream in late summer. Water temperature data from the Lower Yellowstone Project, for example, indicate that substantial subsurface return flows may re-enter the river during the July-August period. During May, June, and the first half of July, temperatures in the main canal drain were higher than temperatures of the diverted water; from about July 15 until September 15 the reverse was true--the drainage water was lower in temperature than the diverted water (figure 33). A logical explanation is that during the early part of the irrigation season, drainage water consisted primarily of <u>surface</u> irrigation retirn flows which had increased in temperature during the irrigation cycle; after mid-July the drainage canal recovered significant inputs of <u>subsurface</u> irrigation return flows which tend to be cooler than surface flows. Hence, drainage water containing subsurface return flows would be cooler than diverted river water. Subsurface return flows from irrigation also are generally higher in salinity than surface returns. Thus it is conceivable that June, July, and September flows would have higher salt loads than originally assumed. The conclusion remains the same: additional irrigation development of the magnitude envisioned under the intermediate and high levels of development, would increase TDS concentrations significantly and to the detriment of current irrigators.

SALT PICKUP

The analyses for each subbasin included two levels of salt pickup, zero and one ton per acre per year. Generally, the graphs of TDS for each subbasin contained a plot of the high level of development values for both levels of salt pickup. In some instances, the intermediate level of development with one ton per acre per year salt pickup would have a more severe impact than the high level of development with zero salt pickup. In the lower Yellowstone, for example, the average TDS would be 459 mg/l for the high level of development with zero salt pickup, but 475 mg/l for the intermediate level of development with one ton per acre per year salt pickup. Thus, the leaching of salts by irrigation return flows can have significant impacts on stream salinity. Figures 34 and 35 illustrate the importance of salt pickup on the Tongue River and the lower Yellowstone. Obviously, as irrigation return flows comprise a larger portion of total streamflow, the rate of salt accretion assumes more importance.

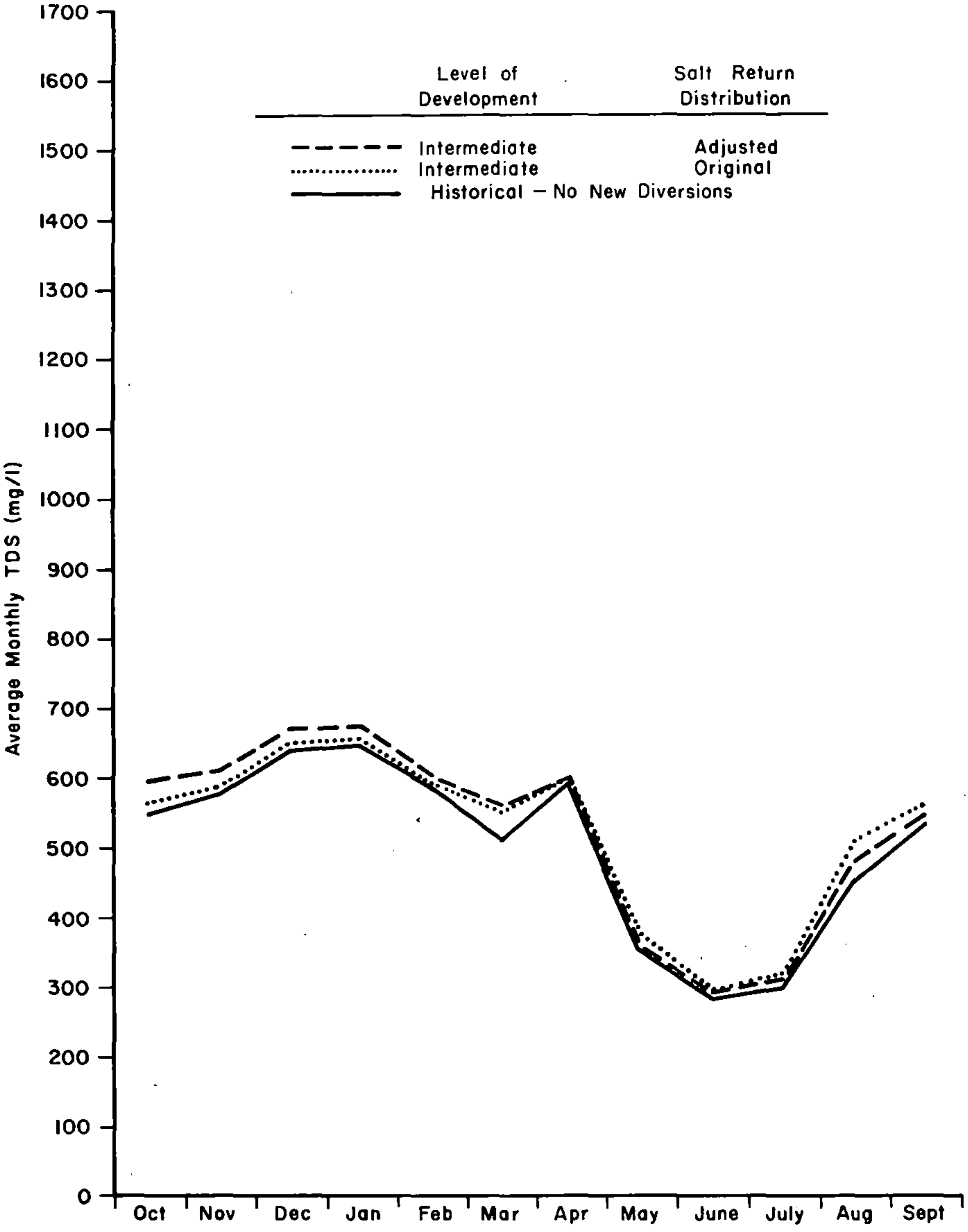

Figure 31. Effects on TDS levels of adjusting the monthly distribution of salt return from irrigation in the Yellowstone River near Sidney, using the intermediate level of development.

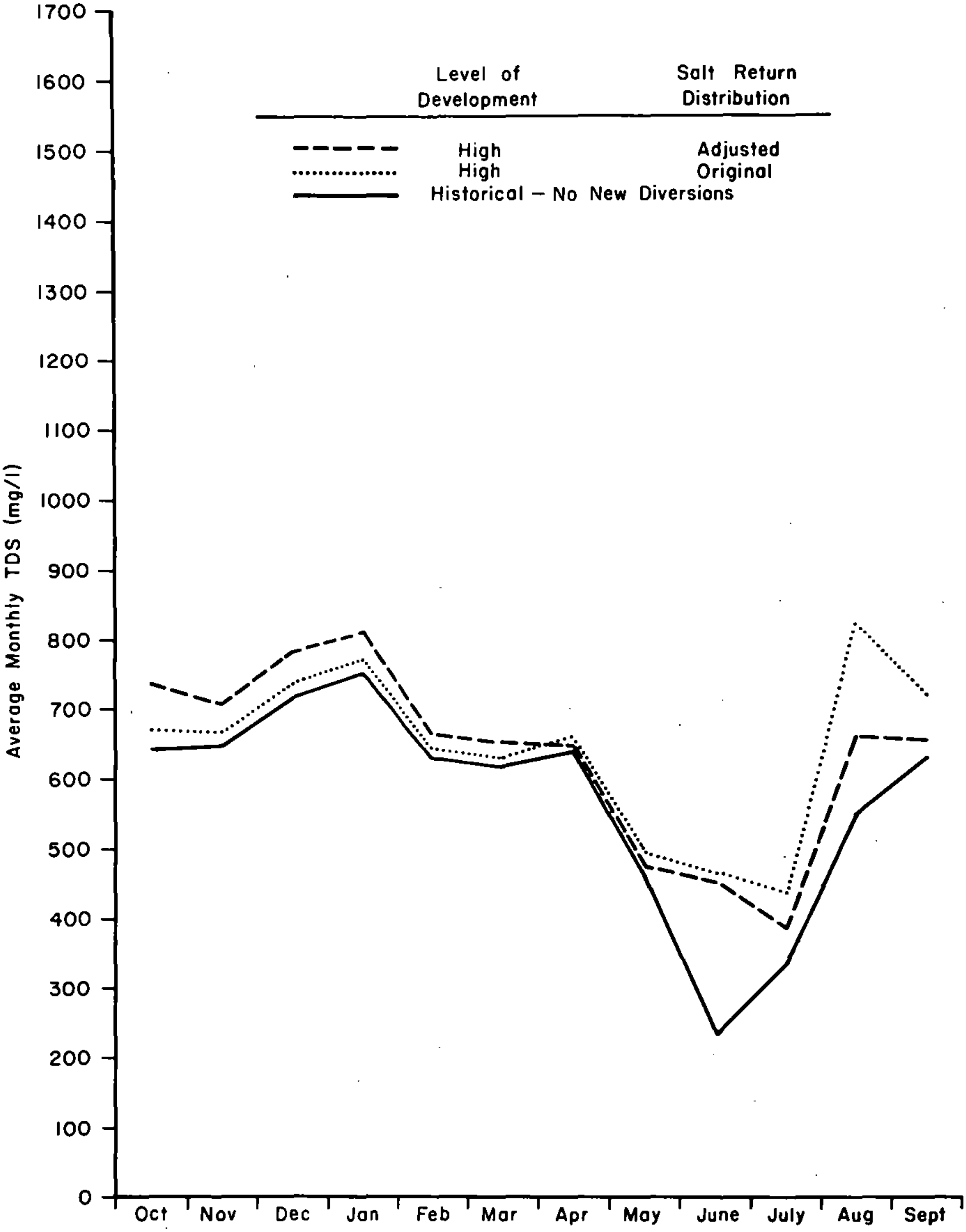

Figure 32. Effects on TDS levels of adjusting the monthly distribution of salt return from irrigation in the Yellowstone River near Sidney, using the high level of development.

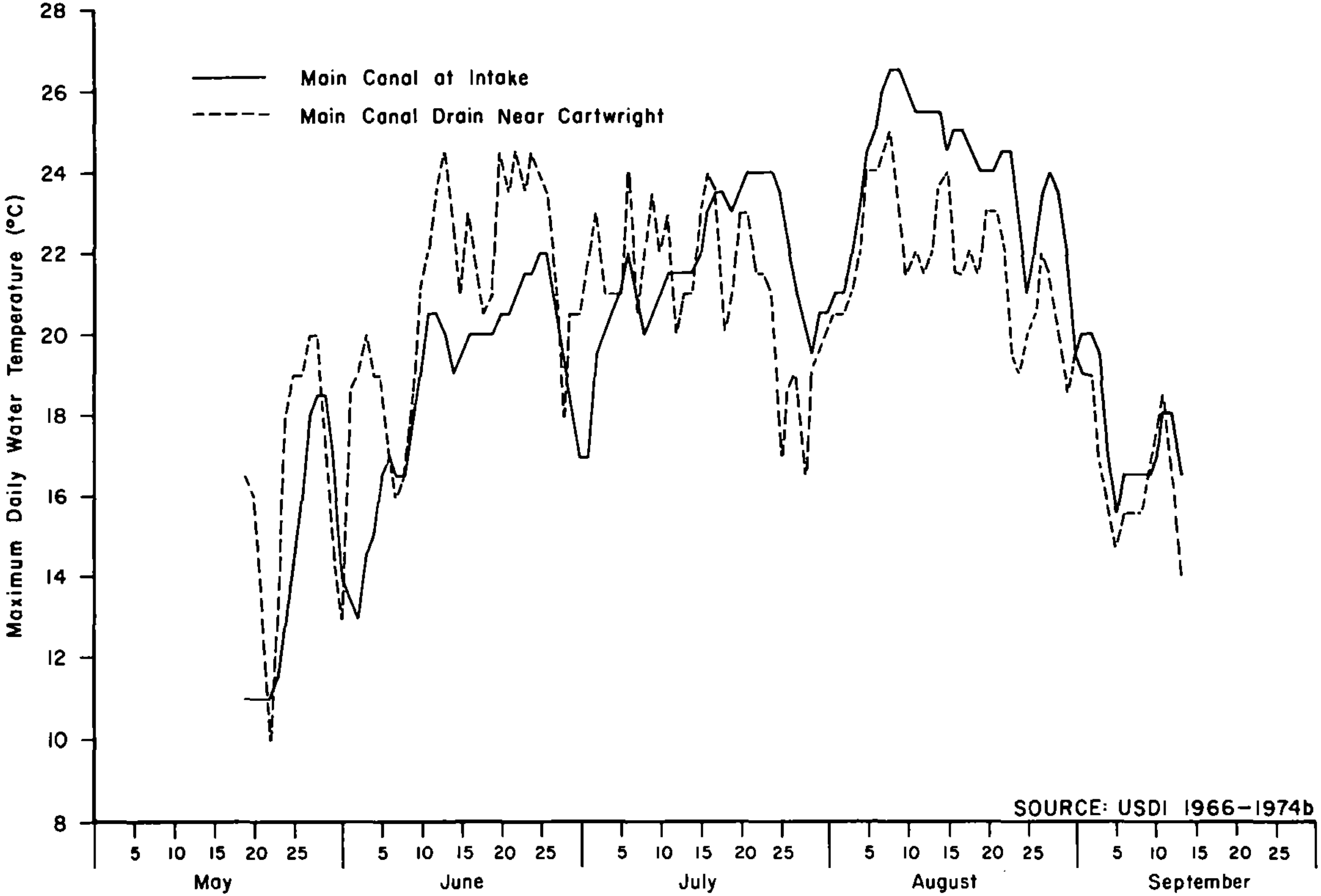

Figure 33. Water temperatures observed on the Lower Yellowstone Project, 1971.

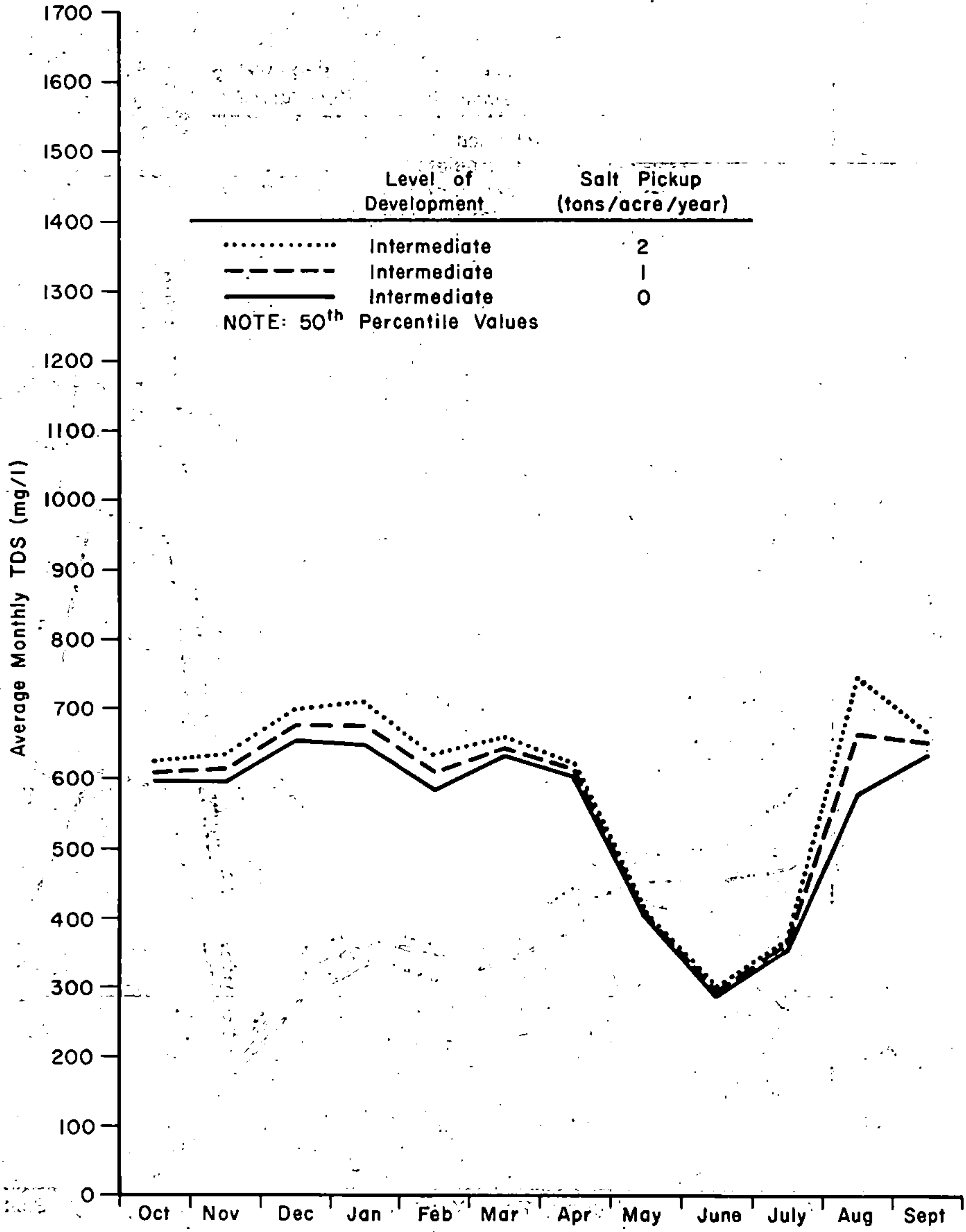

Figure 34. Effects of salt pickup rate on TDS concentrations in the Yellowstone River near Sidney, using the intermediate level of development at 50th percentile flows.

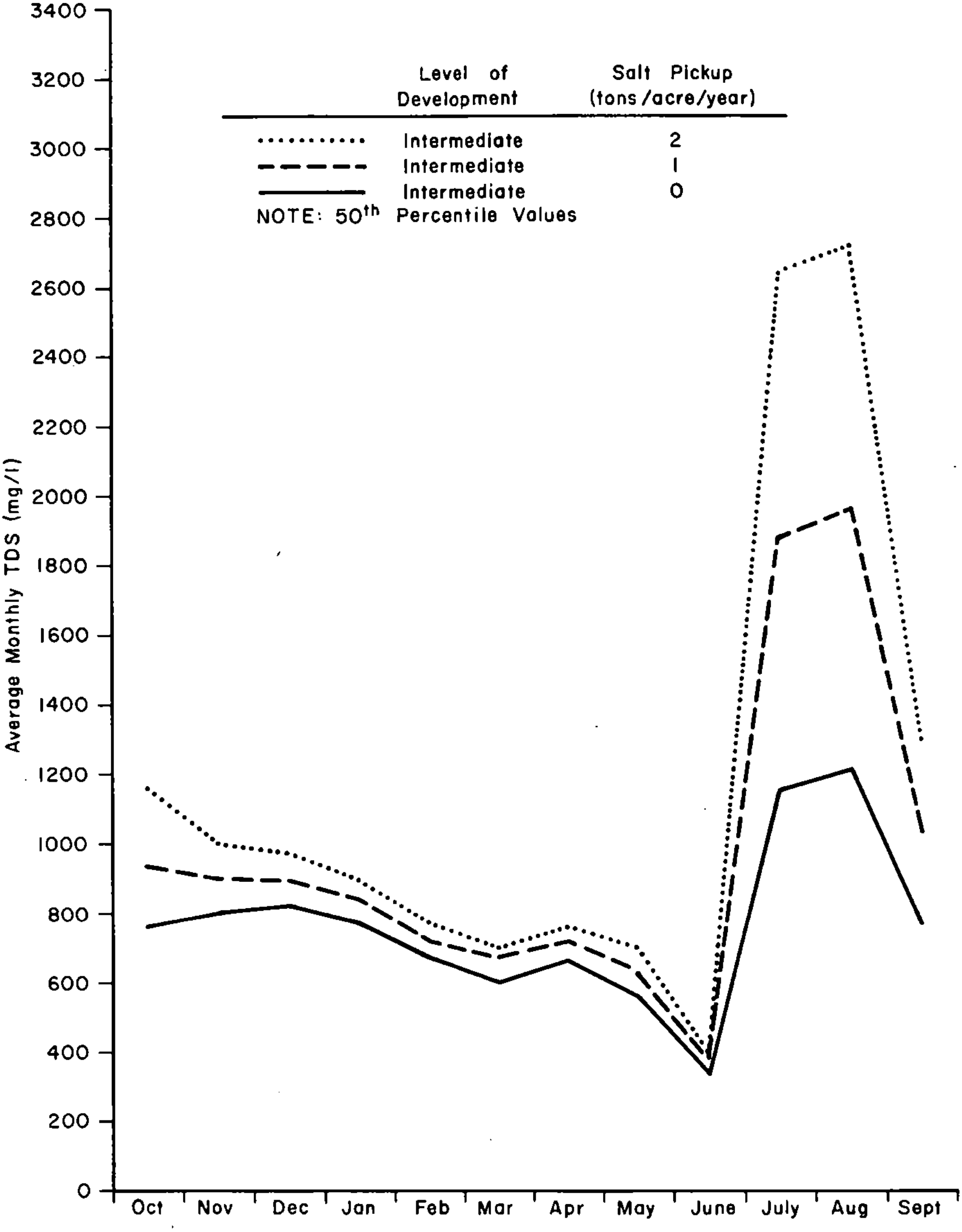

Figure 35. Effects of salt pickup rate on TDS concentrations in the Tongue River near Miles City, using the intermediate level of development at 50th percentile flows.

EXOGENOUS INFLUENCES

According to the assumptions of this study, the three dominant beneficial uses for which water will be diverted from streams in the basin over the next several years will be for irrigation, energy conversions, and municipal use. Consequently, water quality would be influenced primarily by these uses. There are other land and water uses, however, with the potential to diminish water quality, particularly in smaller streams or short reaches of larger streams.

DRYLAND FARMING

In eastern Montana, large tracts of rangeland are being converted to dryland farming, principally for the production of wheat. Geissler (1976) quotes an agricultural official's estimate that 50,000 new acres were turned over to wheat farming in 1975 and 1976. Some of this land is very fragile, and increased erosion by both wind and water is likely. The EPA (1973) reports that average erosion rates are 15 to 20 times higher from cropland than from rangeland. Through increased erosion, cropland may also contribute sediment, salts, nutrients, pesticides, organic loads, and bacteria. Consequently, increased dryland farming may adversely affect the water quality of streams in the Yellowstone River Basin.

SALINE SEEP

Saline seep is a process in which surface water infiltrates the soil profile, encounters a saline layer from which salts are dissolved, and emerges downslope. This saline seep may pond below the point of emergence, killing the vegetation and leaving a deposit of white salt when the water evaporates, or it may enter a watercourse and increase stream salinity. Kaiser et al. (1975) estimate that more than 25,000 acres in the Yellowstone River Basin of Montana are affected by saline seep. Dryland farming aggravates this condition; unless different farming methods are adopted, saline seep is likely to become a greater problem. Saline seep also can be caused by brines from oil and gas drilling operations, and possibly by leaching from coal spoil banks--both activities are prevalent in eastern Montana.

SILVICULTURE

About 11.5 percent of the Yellowstone River's watershed in Montana is comprised of forests. For physical and economic reasons, only a limited amount of timber harvesting from these forests occurs at present, and production is unlikely to increase dramatically in the future. Selective harvesting, however, has the potential to significantly degrade local water quality. Some of the major sources of pollution from forests are disturbances which may be of natural origin, such as fires, disease, and earthquakes. Others may be caused by man. Principal pollutants are sediment, organic matter, chemicals (such as pesticides, fertilizers, and fire retardants), nutrients, and bacteria. Moreover, removal of streamside vegetation can cause thermal pollution of streams. The erosion rate from a harvested forest can be 500 times higher than that from an undisturbed forest and 2.5 times greater than that from copland, according to a report by the EPA (1973). The same report also describes methods of predicting and controlling pollution from silviculture activities; these practices should, if followed, adequately contain water pollution.

NONCOAL MINERAL EXTRACTION

Eastern Montana contains several minerals other than coal that are commercially extractable, including oil and gas, sand and gravel, clays, gypsum, uranium, thorium, and chromite. All are potential contributors to water pollution. Currently, oil and gas wells are a widespread source of brine waters, but pollution can be limited to areas near the wells through ponding and injection techniques. Potential problems are the mining of chromite from the Stillwater Complex in Sweetgrass and Stillwater counties, and the extraction of uranium and thorium from Carbon and Bighorn counties or from the Wyoming portion of the watershed.

WYOMING ACTIVITIES

Under the Yellowstone River Compact, Wyoming is entitled to a substantial portion of unappropriated waters of major tributaries to the Yellowstone River, ranging from 40 percent of the Tongue River to 80 percent of the Bighorn River. Although the exact quantities have not been determined, Wyoming estimates its share to be more than 2.4 mmaf/y. Although Wyoming has no firm plans to use this much water, significant diversions and depletions upstream, accompanied by return flows of lower quality than existing streamflows, could degrade water quality of the tributaries, especially the Powder and Tongue rivers and the lower Yellowstone River.

NATIONAL AND STATE POLICIES

Controls have been or can be developed to control most water pollution. Remedies may require treatment of wastewater before discharge, modifications to the process producing the waste, or in an extreme case, curtailment of the pollution-causing activity. All remedies are influenced or controlled by governmental regulations. Thus, the major exogenous factors affecting future water quality of the Yellowstone River may well be policies of state and federal governments. An increasing demand in the future for food and energy could lead to weakening of environmental standards. The combination of additional energy extraction and conversion, expanded agricultural activities in the Yellowstone River Basin, and relaxed controls on environmental pollution could result in a major deterioration of water quality.

RECOMMENDATIONS

1) The study was hindered because of lack of information on irrigation practices in the Yellowstone River Basin. It is suggested that a systematic long-term research program be initiated to collect data on the following: amount of water diverted for irrigation, volume and distribution of return flows, quality of return flows, and the impact of irrigation on streamflow.

2) A good beginning was made on integrating salinity calculations into the state water planning model. Additional work is necessary, however, to refine the salinity modeling, particularly on the lower subbasins.

3) Operations at Colstrip involving wastewater should be carefully monitored to determine the impact of a large energy conversion facility on water quality.

4) In July and August of low-flow years, salinity in the Bighorn River increases significantly. Salinity would be reduced and water quality enhanced if a minimum flow of about 1000 cfs were maintained in the river.

5) Considering the potential adverse impacts on water quality resulting from additional irrigation in the Powder and Tongue subbasins, it is suggested that a more thorough analysis be made of these two basins before substantial new developments are undertaken.

Appendix A

PROJECTIONS OF FUTURE USE

FIGURES

TABLES

In order to adequately and uniformly assess the potential effects of water withdrawals on the many aspects of the present study, projections of specific levels of future withdrawals were necessary. The methodology by which these projections were done is explained in Report No. 1 in this series, in which also the three projected levels of development, low, intermediate, and high, are explained in more detail. Summarized below, these three future levels of development were formulated for energy, irrigation, and municipal water use for each of the nine subbasins identified in figure A-1.

ENERGY WATER USE

In 1975, over 22 million tons of coal (19 million metric tons) were mined in the state, up from 14 million (13 million metric) in 1974, 11 million (10 million metric) in 1973, and 1 million (.9 million metric) in 1969. By 1980, even if no new contracts are entered, Montana's annual coal production will exceed 40 million tons (36 million metric tons). Coal reserves, estimated at over 50 billion economically strippable tons (45 billion metric tons) (Montana Energy Advisory Council 1976), pose no serious constraint to the levels of development projected, which range from 186.7 (170.3 metric) to 462.8 (419.9 metric) million tons stripped in the basin annually by the year 2000.

Table A-1 shows the amount of coal mined, total conversion production, and associated consumption for six coal development activities expected to take place in the basin by the year 2000. Table A-2 shows water consumption by subbasin for those six activities. Only the Bighorn, Mid-Yellowstone, Tongue, Powder, and Lower Yellowstone subbasins would experience coal mining or associated development in these projections.

IRRIGATION WATER USE

Lands in the basin which are now either fully or partially irrigated total about 263,000 ha (650,000 acres) and consume annually about 1,850 hm^3 (1.5 mmaf) of water. Irrigated agriculture in the Yellowstone Basin has been increasing since 1971 (Montana DNRC 1975). Much of this expansion can be attributed to the introduction of sprinkler irrigation systems.

After evaluating Yellowstone Basin land suitability for irrigation, considering soils, economic viability, and water availability (only the Yellowstone River and its four main tributaries, Clarks Fork, Bighorn, Tongue, and Powder, were considered as water sources), this study concluded that 95,900 ha (237,000 acres) in the basin are financially feasible for irrigation. These acres are identified by county and subbasin in table A-3; table A-4 presents projections of water depletion.

Three levels of development were projected. The lowest includes one-third, the intermediate, two-thirds, and the highest, all of the feasibly irrigable acreage.

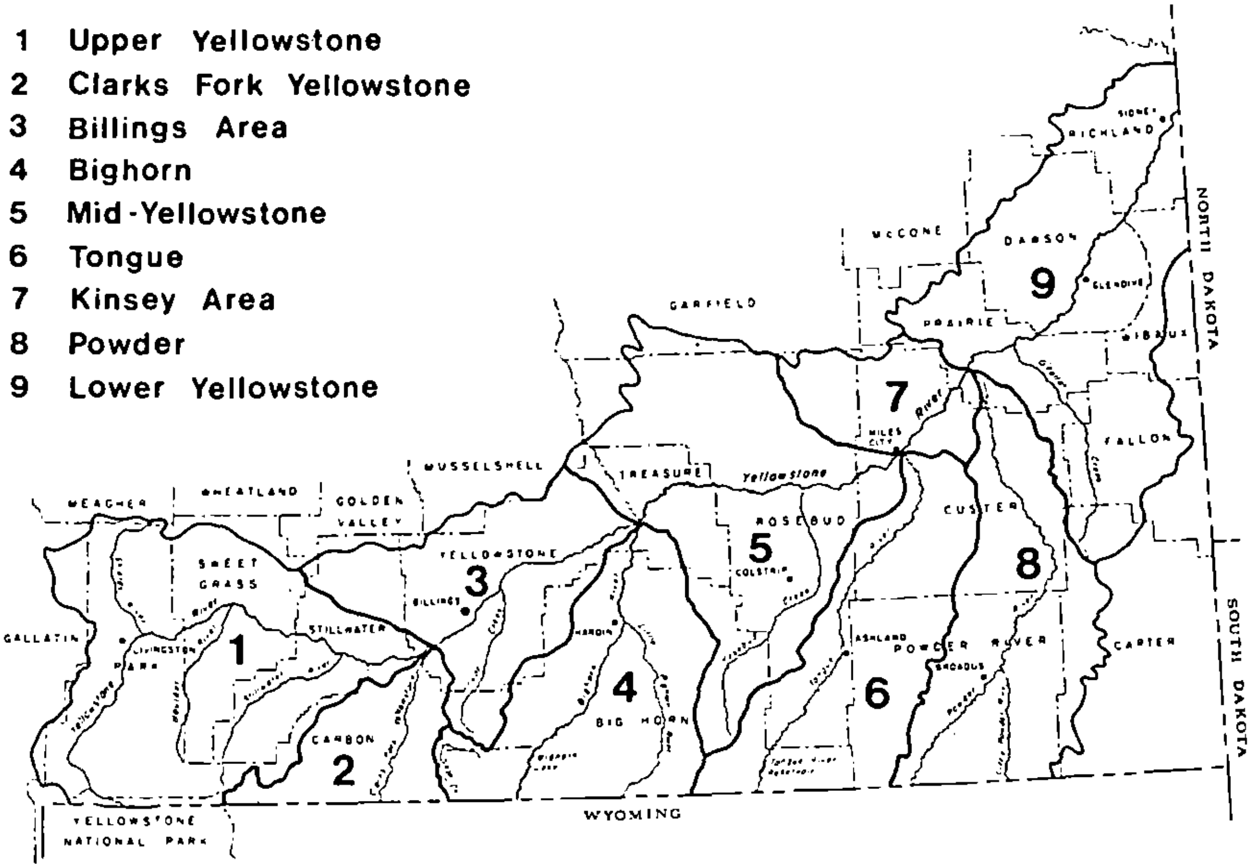

Figure A-1. The nine planning subbasins of the Yellowstone basin.

TABLE A-1. Increased water requirements for coal development in the Yellowstone Basin in 2000.

Level of Development	Coal Development Activity: Electric Generation	Gasification	Syncrude	Fertilizer	Export	Strip Mining	Total
COAL MINED (mmt/y)							
Low	8.0	7.6	0.0	0.0	171.1		186.7
Intermediate	24.0	7.6	0.0	0.0	293.2		324.8
High	32.0	22.8	36.0	3.5	368.5		462.8
CONVERSION PRODUCTION							
Low	2000 mw	250 mmcfd	0 b/d	0 t/d			
Intermediate	6000 mw	250 mmcfd	0 b/d	0 t/d			
High	8000 mw	750 mmcfd	200,000 b/d	2300 t/d			
WATER CONSUMPTION (af/y)							
Low	30,000	9,000	0	0	[a]	9,350	48,350
Intermediate	90,000	9,000	0	0	31,910	16,250	147,160
High	120,000	27,000	58,000	13,000	80,210	22,980	321,190

CONVERSIONS: 1 mmt/y (short) = .907 mmt/y (metric)
1 af/y = .00123 hm^3/y

[a] No water consumption is shown for export under the low level of development because, for that development level, it is assumed that all export is by rail, rather than by slurry pipeline.

TABLE A-2. The increase in water depletion for energy by the year 2000 by subbasin.

Subbasin	INCREASE IN DEPLETION (af/y) Elec. Generation	Gasification	Syncrude	Fertilizer	Export	Strip Mining	Total
			LOW LEVEL OF DEVELOPMENT				
Bighorn	0	0	0	0	0	860	860
Mid-Yellowstone	22,500	9,000	0	0	0	3,680	35,180
Tongue	7,500	0	0	0	0	3,950	11,450
Powder	0	0	0	0	0	860	860
Lower Yellowstone	0	0	0	0	0	0	0
Total	30,000	9,000				9,350	48,350
			INTERMEDIATE LEVEL OF DEVELOPMENT				
Bighorn	0	0	0	0	4,420	1,470	5,890
Mid-Yellowstone	45,000	9,000	0	0	15,380	6,110	75,490
Tongue	30,000	0	0	0	9,900	7,000	46,900
Powder	15,000	0	0	0	2,210	1,670	18,880
Lower Yellowstone	0	0	0	0	0	0	0
Total	90,000	9,000			31,910	16,250	147,160
			HIGH LEVEL OF DEVELOPMENT				
Bighorn	15,000	0	0	0	11,100	2,050	28,150
Mid-Yellowstone	45,000	18,000	29,000	0	38,700	8,710	139,410
Tongue	45,000	9,000	29,000	0	24,860	10,170	118,030
Powder	15,000	0	0	0	5,550	2,050	22,600
Lower Yellowstone	0	0	0	13,000	0	0	13,000
Total	120,000	27,000	58,000	13,000	80,210	22,980	321,190

CONVERSIONS: 1 af/y = .00123 hm^3/y

NOTE: The four subbasins not shown (Upper Yellowstone, Billings Area, Clarks Fork Yellowstone, Kinsey Area) are not expected to experience water depletion associated with coal development.

TABLE A-3. Feasibly irrigable acreage by county and subbasin by 2000, high level of development.

County	Upper Yellowstone	Clarks Fork	Billings Area	Big Horn	Mid Yellowstone	Tongue River	Kinsey Area	Powder River	Lower Yellowstone	County Totals
Park	21,664									21,664
Sweet Grass	10,204									10,204
Stillwater	6,208									6,208
Carbon		2,160								2,160
Yellowstone			19,412							19,412
Big Horn				13,037		2,185				15,222
Treasure					9,591					9,591
Rosebud					11,408	9,727				21,135
Powder River								46,853		46,853
Custer					4,230	10,035	3,092	26,438		43,795
Prairie							1,644	1,914	8,231	11,789
Dawson									18,355	18,355
Richland									10,421	10,421
Wibaux									633	633
BASIN TOTALS	38,076	2,160	19,412	13,037	25,229	21,947	4,736	75,205	37,670	237,472

CONVERSIONS: 1 acre = .405 ha

NOTE: The number of irrigable acres for the low and intermediate development levels are one-third and two-thirds, respectively, of the numbers given here. This table should not be considered an exhaustive listing of all feasibly irrigable acreage in the Yellowstone Basin; it includes only the acreage identified as feasibly irrigable according to the geographic and economic constraints explained elsewhere in this report.

MUNICIPAL WATER USE

The basin's projected population increase and associated municipal water use depletion for each level of development are shown in table A-5. Even the 13 hm^3/y (10,620 af/y) depletion increase by 2000 shown for the highest development level is not significant compared to the projected depletion increases for irrigation or coal development. Nor is any problem anticipated in the availability of water to satisfy this increase in municipal use.

WATER AVAILABILITY FOR CONSUMPTIVE USE

The average annual yield of the Yellowstone River Basin at Sidney, Montana, at the 1970 level of development, is 10,850 hm^3 (8.8 million af). As shown in table A-6, the additional annual depletions required for the high projected level of development total about 999 hm^3 (812,000 acre-feet). Comparison of these two numbers might lead to the conclusion that there is ample water for such development, and more. That conclusion would be erroneous, however, because of the extreme variation of Yellowstone Basin streamflows from year to year, from month to month, and from place to place. At certain places and at certain times the water supply will be adequate in the foreseeable future. But in some of the tributaries and during low-flow times of many years, water availability problems, even under the low level of development, will be very real and sometimes very serious.

TABLE A-4. The increase in water depletion for irrigated agriculture by 2000 by subbasin.

Subbasin	Acreage Increase	Increase in Depletion (af/y)
HIGH LEVEL OF DEVELOPMENT		
Upper Yellowstone	38,080	76,160
Clarks Fork	2,160	4,320
Billings Area	19,410	38,820
Bighorn	13,040	26,080
Mid-Yellowstone	25,230	50,460
Tongue	21,950	43,900
Kinsey Area	4,740	9,480
Powder	75,200	150,400
Lower Yellowstone	37,670	75,340
TOTAL	237,480	474,960
INTERMEDIATE LEVEL OF DEVELOPMENT		
BASIN TOTAL	158,320	316,640
LOW LEVEL OF DEVELOPMENT		
BASIN TOTAL	79,160	158,320

CONVERSIONS: 1 acre = .405 ha
1 af/y = .00123 hm^3/y

NOTE: The numbers of irrigated acres at the low and intermediate levels of development are not shown by subbasin; however, those numbers are one-third and two-thirds, respectively, of the acres shown for each subbasin at the high level of development.

TABLE A-5. The increase in water depletion for municipal use by 2000.

Level of Development	Population Increase	Increase in Depletion (af/y)
Low	56,858	5,880
Intermediate	62,940	6,960
High	94,150	10,620

CONVERSIONS: 1 af/y = .00123 hm^3/y

TABLE A-6. The increase in water depletion for consumptive use by 2000 by subbasin.

Subbasin	Increase in Depletion (af/y)			
	Irrigation	Energy	Municipal	Total
	LOW LEVEL OF DEVELOPMENT			
Upper Yellowstone	25,380	0	0	25,380
Clarks Fork	1,440	0	0	1,440
Billings Area	12,940	0	3,480	16,420
Bighorn	8,700	860	negligible	9,560
Mid-Yellowstone	16,820	35,180	1,680	53,680
Tongue	14,640	11,450	negligible	26,090
Kinsey Area	3,160	0	0	3,160
Powder	50,140	860	360	51,360
Lower Yellowstone	25,120	0	360	25,480
TOTAL	158,340	48,350	5,880	212,570
	INTERMEDIATE LEVEL OF DEVELOPMENT			
Upper Yellowstone	50,780	0	0	50,780
Clarks Fork	2,880	0	0	2,880
Billings Area	25,880	0	3,540	29,420
Bighorn	17,380	5,890	300	23,570
Mid-Yellowstone	33,640	75,490	1,860	110,990
Tongue	29,260	46,900	300	76,460
Kinsey Area	6,320	0	0	6,320
Powder	100,280	18,880	600	119,760
Lower Yellowstone	50,200	0	360	50,560
TOTAL	316,620	147,160	6,960	470,740
	HIGH LEVEL OF DEVELOPMENT			
Upper Yellowstone	76,160	0	0	76,160
Clarks Fork	4,320	0	0	4,320
Billings Area	38,820	0	3,900	42,720
Bighorn	26,080	28,150	480	54,710
Mid-Yellowstone	50,460	139,410	3,840	193,710
Tongue	43,900	118,030	780	162,710
Kinsey Area	9,480	0	0	9,480
Powder	150,400	22,600	1,140	174,140
Lower Yellowstone	75,340	13,000	480	88,820
TOTAL	474,960	321,190	10,620	806,770

CONVERSIONS: 1 af/y = .00123 hm^3/y

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