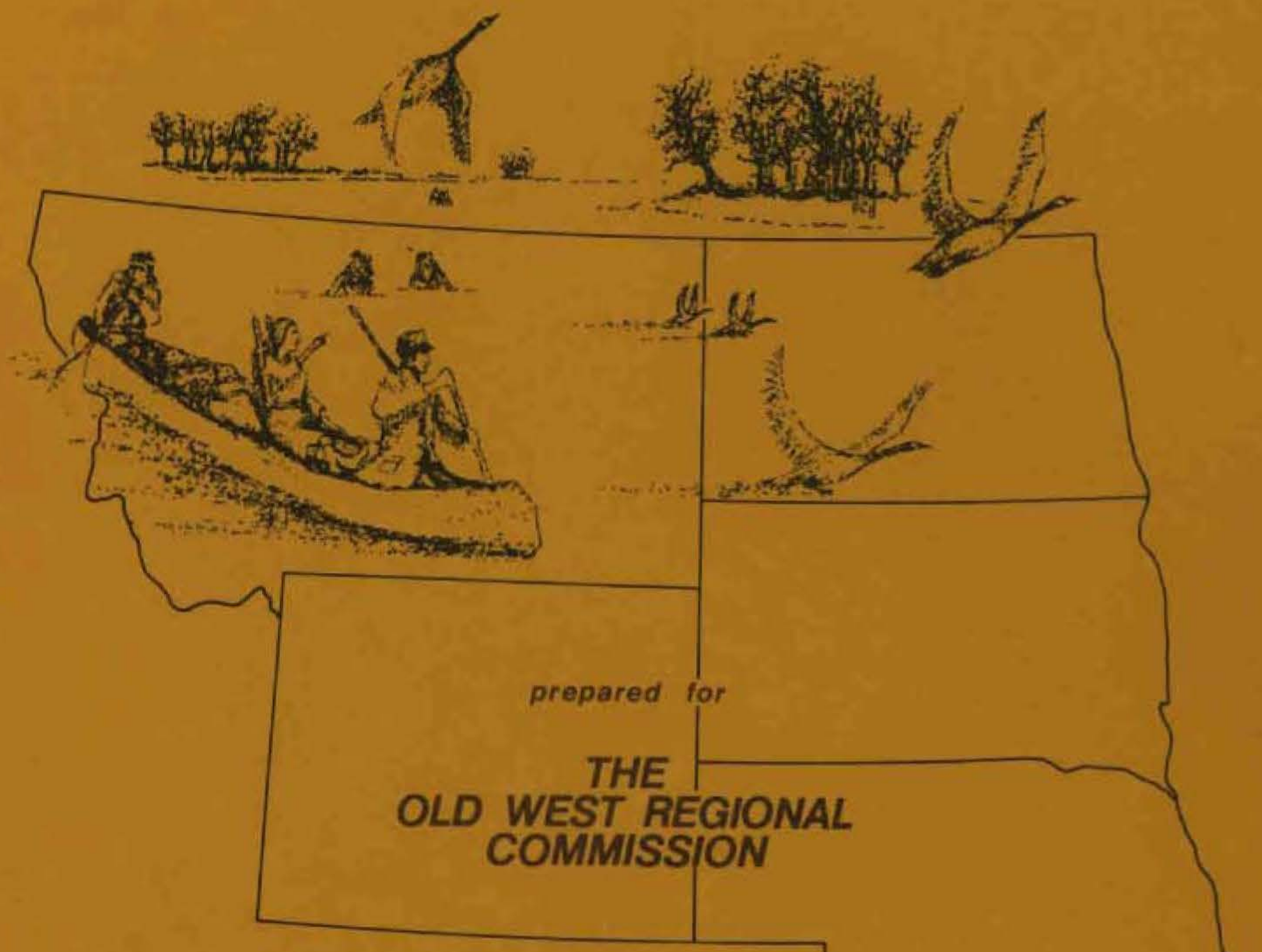
The economics of altered streamflow in the Yellowstone River Basin, Montana

YELLOWSTONE IMPACT STUDY

TECHNICAL REPORT NO. 11



prepared for

THE OLD WEST REGIONAL COMMISSION

by

DNRC WATER RESOURCES DIVISION — JULY 1977

MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION

The economics of altered streamflow in the Yellowstone River Basin, Montana

by

Staff of the Water Resources Division

of the

Montana Department of Natural Resources and Conservation

TECHNICAL REPORT NO. 11

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conducted by
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July 1977

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

a	acre
af	acre-feet
af/y	acre-feet per year
b/d	barrels per day
cfs	cubic feet per second
ft	feet
gpm	gallons per minute
ha	hectares
hm^3	cubic hectometers
hm^3/y	cubic hectometers per year
km	kilometers
km^2	square kilometers
kwh	kilowatt hours
LP	linear programming
mmaf	million acre-feet
mmaf/y	million acre-feet per year
mmt/y	million tons per year
mw	megawatts
t/a	tons per acre
t/d	tons per day
TDS	total dissolved solids

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.

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This report was reviewed by and guidance received from Ted J. Doney, Director of the Montana Department of Natural Resources and Conservation (DNRC), Orrin Ferris, Administrator of the DNRC's Water Resources Division, and Carole Massman of the DNRC's Special Staff.

Other DNRC personnel providing assistance were Janet Cawlfield, Lynda Howell, and Barbara Williams, typists. Graphics were coordinated and performed by Gary Wolf, with the assistance of D.C. Howard, who designed and executed the cover.

The original work summarized on pages 35 through 39 of this report was taken from reports No. 3, 6, 7, 8, 9, and 10 of this series, written by: Duane Klarich and Jim Thomas (Report No. 3), Montana Department of Health and Environmental Sciences; Peter Martin (Report No. 6), Tom Hinz (Report No. 7), Allen A. Elser and Robert C. McFarland (Report No. 8), and Max Erickson (Report No. 10), all of the Montana Department of Fish and Game; and Mike Brown, Norm Barnard, and Mel McBeath (Report No. 9), all of the Montana DNRC.

The section of the report entitled "Legal Constraints to Water Use in the Yellowstone River Basin" was prepared by Al Bielefeld, Field Solicitor for the U.S. Department of the Interior in Billings, and reviewed and edited by Ted J. Doney, Director of the DNRC.

Appendix B of this report, "Linear Programming Model," was adapted from a draft written by Phil Threlkeld concerning a model developed by him and Satish Nayak, both of the Montana DNRC.

Introduction

The purpose of this report is to discuss the economic consequences of the impacts resulting from lowered streamflows in the Yellowstone River Basin. Included are an economic description of the study area, a summary of the conclusions made in other reports in this series (see "The Study," pages 3 and 4) and a literature survey of economic methodologies for evaluting the impacts of lowered streamflow. Legal and institutional constraints on water use in the basin are surveyed.

An economic evaluation of the impacts of lowered streamflows should investigate both benefits and costs of these withdrawals. The material summarized from the other reports examines only the costs of altered streamflow. In this report, an evaluation of the benefits to agriculture of additional depletions is made by estimating the consequences for agriculture of an instream flow reservation, resulting in an analysis of the net impact of additional withdrawals from the Yellowstone River.

The study area is shown in figure 1. Billings is the largest city and economic hub of the basin.

Agriculture, the basin's largest industry, is declining in relative importance. Coal mining is growing rapidly; so is manufacturing. Population increases and employment trends indicate that the recent surge of economic growth is continuing.

Growth rates basin-wide are similar to national averages, although Billings and Colstrip are developing more rapidly. Decreases in rural population and agricultural employment opportunities continue throughout the region.

Because most economic data is available by county rather than by river basin, the study area consists of the thirteen counties (figure 1) which approximate the boundaries of the Yellowstone River Basin.

YELLOWSTONE RIVER BASIN

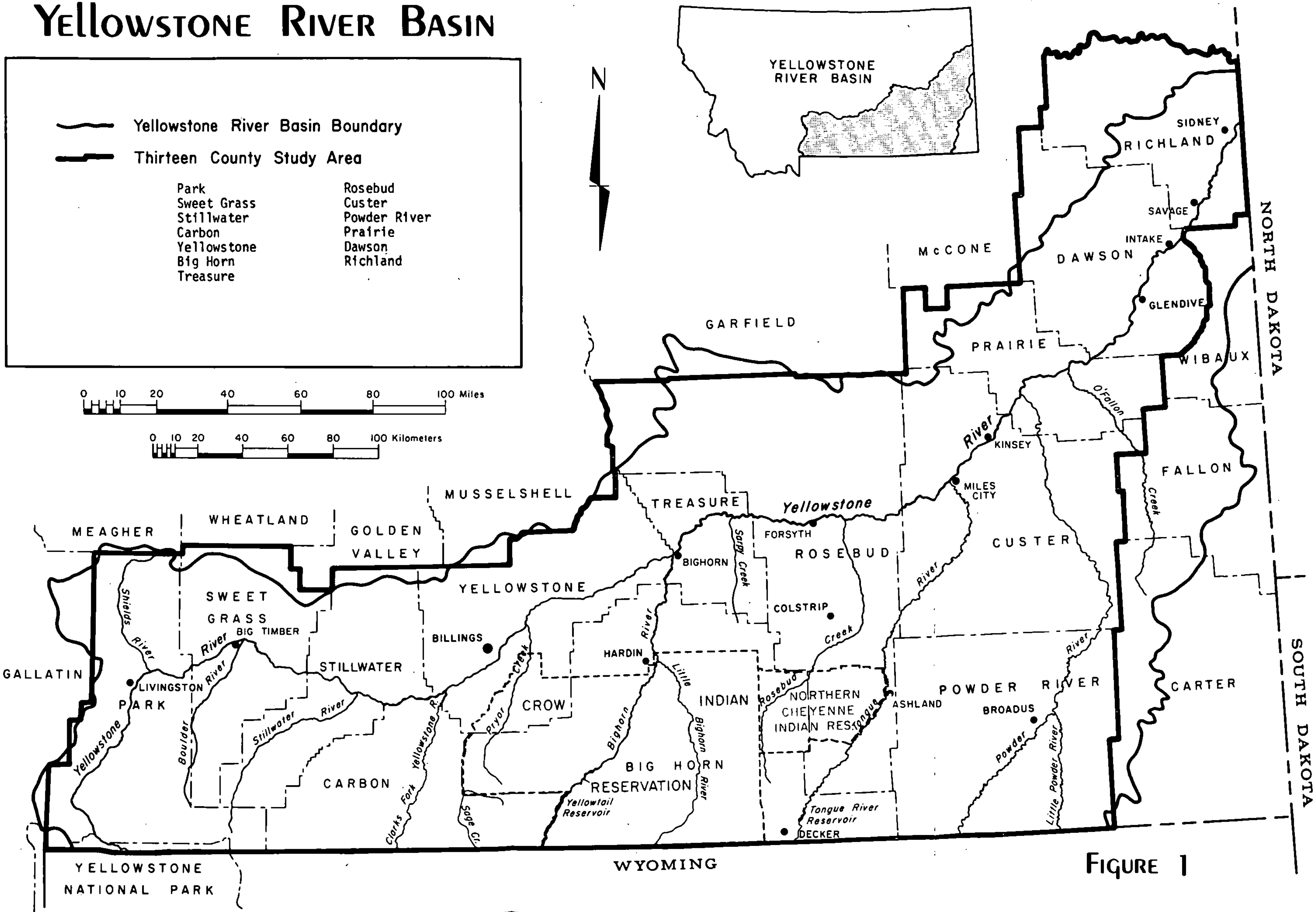

FIGURE 1

Economic overview of the Yellowstone River Basin

INCOME

Personal income in the basin is growing faster than for the nation as a whole, primarily because of increased earnings, both direct and indirect, from coal mining. Incomes from manufacturing and railroads are also above the state average, while the increases in farm earnings are down relative to the rest of the state and the nation. From 1970 to 1974, personal income in Rosebud County increased 68 percent, while personal income in the Yellowstone Basin increased 47 percent. Per-capita income in the Yellowstone Basin is higher than the state average. Within the basin, per-capita income tends to be higher in the downstream counties (Montana DNRC 1976).

EMPLOYMENT

Agriculture, mining, manufacturing, and railroads are the basic industries in the basin. Table 1 shows the number of persons employed in each for 1950, 1960, and 1970.

TABLE 1. Employment in the Basic Industries in the Yellowstone Basin, 1950, 1960, and 1970.

	Employment			Percentage of Total[a]		
	1950	1960	1970	1950	1960	1970
Agriculture, Forestry and Fisheries	14,214	10,177	7,853	65.0	53.6	51.0
Mining	611	1,024	852	2.8	5.4	5.6
Manufacturing	2,834	4,757	4,414	12.9	25.0	28.7
Railroads	4,187	3,013	2,253	19.1	15.8	14.6
TOTAL BASIC EMPLOYMENT	21,846	18,971	15,382	100.0	100.0	100.0

SOURCE: U.S. Department of Commerce 1952, 1961, and 1971.

NOTE: The U.S. Census Bureau classifies agriculture, forestry, and fisheries together. In the Yellowstone Basin, employment in forestry and fisheries is very small, making these figures an adequate measure of agricultural employment.

[a]Percentages may not add to 100 because of rounding.

Although the number of jobs in agriculture is still larger than the number in other sectors, a steady decline is apparent. New jobs in basic industries have occurred primarily in mining and manufacturing. However, data on basic employment should be interpreted cautiously because, statewide and nationally, the employment level in basic industries has been falling relative to derivative employment--partially because worker productivity, due to improved technology, has increased rapidly in many basic industries.

New basic jobs are occurring in a few specific locations. New mining jobs within the basin have been primarily located at the coal mines at Sarpy Creek, Colstrip, and Decker; most of the new manufacturing jobs have been in the Billings area.

Table 2 illustrates the rapid growth of coal mining in Montana, and table 3 shows the number of jobs at each mine site. From 1972 to 1974, employment in Rosebud County, site of substantial coal development, increased 26 percent, and employment in the basin went up by 13 percent. However, some portion of this rapid growth may be temporary, and employment will probably be reduced upon completion of the construction of electrical generating facilities at Colstrip. Agricultural employment in the basin fell from 65 to 51 percent of total employment between 1950 and 1970. The impact of this loss in jobs was felt primarily outside of Yellowstone County. The loss of 990 agricultural jobs in Yellowstone County was partially compensated by an increase of 854 manufacturing jobs, but the basin outside of Yellowstone County lost 5,371 jobs in agriculture and gained only 456 manufacturing jobs.

TABLE 2. Coal Extracted in Montana, 1960-75.

Year	Tons Extracted
1960	301,273
1961	358,848
1962	365,850
1963	336,548
1964	344,636
1965	377,248
1966	415,410
1967	364,509
1968	555,271
1969	1,024,885
1970	3,517,158
1971	7,097,127
1972	8,264,405
1973	10,729,019
1974	13,555,150
1975	22,087,188

SOURCE: Montana Energy Advisory Council 1976

TABLE 3. Coal Mining in Yellowstone River Basin, 1976-77

Mine Name	Operator	County	County Seat	Number of Employees	Tonnage Produced	
					1976	1977
Absaroka	Morrison-Knutsen Co., Inc.	Big Horn	Hardin	108	4,083,094	4,529,058
Decker	Decker Coal Co.	Big Horn	Hardin	300	10,051,090	10,390,419
Divide Mine	Victor Carlson Jack H. Carlson	Musselshell	Roundup	3	8,728	7,050
P.M.	P.M. Coal Mining Co.	Musselshell	Roundup	[a]	8,251	8,677
Coal Creek	Bob Schmidt	Powder River	Broadus	[a]	1,612	16,011
Savage	Knife River Coal Mining Co.	Richland	Sidney	20	312,280	302,426
Big Sky	Peabody Coal Co.	Rosebud	Forsyth	70	2,390,809	2,312,334
Rosebud	Long Construction	Rosebud	Forsyth	338	9,324,007	9,827,461

SOURCE: Montana Bureau of Mines and Geology 1977 and Montana Coal Council 1978.

[a] Unknown.

POPULATION

Table 4 shows that nearly half of the basin's population lives in the Billings area, and over half lives in the two regional centers of Billings and Miles City.

From 1960 to 1970, the basin's overall population remained about the same, but the number of urban dwellers (defined as those living in towns of at least 2,500 persons) increased eight percent, while the number of rural dwellers fell by ten percent. The population of Billings during this time increased by 16 percent. Following the national trend, outmigration has been moderate to high in the rural areas; lack of employment opportunities is probably a major cause of rural population decline in the basin. Progress in farm technology has decreased the number of workers needed for agricultural operations.

However, job opportunities began increasing in the late 1960's, and from 1970 to 1974 the basin's population began to grow again. From 1968 to 1971, employment opportunities increased six percent, but from 1971 to 1974 they increased 13 percent (U.S. Bureau of Economic Analysis unpublished). The largest increase in population was in Rosebud County (29.3 percent), due to the development at Colstrip.

AGRICULTURAL ACTIVITY

Most of the water taken from the Yellowstone for agriculture is used to irrigate pasture and crops for cattle feed. Farms and ranches within the basin are generally much larger than the state-wide average. Major grain crops are wheat, barley, and oats; these are usually grown on nonirrigated land. Sugar beets and dry beans are grown only on irrigated land, but most irrigated land is devoted to hay production. About two-thirds of farm income results from the sale of livestock and livestock products, and the remaining one-third from the sale of crops.

TABLE 4. Population trends in the Yellowstone Basin by county 1960, 1970, and 1974.

County	1960			1970			Percentage Change 1960-1970			July 1, 1974	Percentage Change 1970-1974
	Total	Urban[a]	Rural	Total	Urban[a]	Rural	Total	Urban[a]	Rural	Total	
Park	13,168	8,229	4,939	11,197	6,883	4,314	-15.0	-16.4	-12.7	11,900	7.9
Sweet Grass	3,290	-0-	3,290	2,980	-0-	2,980	- 9.4	-0-	- 9.4	3,000	0.7
Stillwater	5,526	-0-	5,526	4,632	-0-	4,632	-16.2	-0-	-16.2	5,100	10.1
Carbon	8,317	-0-	8,317	7,080	-0-	7,080	-14.9	-0-	-14.9	7,700	8.8
Yellowstone	79,016	65,313	13,703	87,367	76,651	11,716	10.6	15.8	-14.5	95,600	9.4
Big Horn	10,007	2,789	7,218	10,057	2,733	7,324	0.5	- 2.0	1.5	10,400	3.4
Treasure	1,345	-0-	1,345	1,069	-0-	1,069	-20.5	-0-	-20.5	1,200	2.3
Rosebud	6,187	-0-	6,187	6,032	-0-	6,032	- 2.5	-0-	- 2.5	7,800	29.3
Custer	13,227	9,665	3,562	12,174	9,023	3,151	- 8.0	- 6.7	-11.5	12,100	- 0.6
Powder River	2,485	-0-	2,485	2,862	-0-	2,862	15.2	-0-	15.2	2,300	- 7.4
Prairie	2,318	-0-	2,318	1,752	-0-	1,752	-24.4	-0-	-24.4	1,800	2.7
Dawson	12,314	7,058	5,256	11,269	6,305	4,964	- 8.5	-10.7	- 5.6	10,900	3.3
Richland	10,504	4,564	5,940	9,837	4,543	5,294	- 6.3	- 0.5	-10.9	9,900	0.6
TOTAL	167,704	97,618	70,085	168,308	105,138	63,170	0.3	7.7	- 9.8	179,700	6.7

SOURCE: U. S. Department of Commerce 1961 and 1971; U. S. Bureau of Economic Analysis unpublished.

[a]Urban dwellers live in a community with more than 2,500 inhabitants.

Methods

The economic evaluation of water withdrawals is performed by comparing the value of water for instream uses with the value of water when it is withdrawn for consumptive use. The optimal allocation of water between instream uses and withdrawals is that allocation that maximizes the sum of the net benefits from instream uses and out-of-stream uses. Two important observations allow definition of the optimal allocation of water between competing uses.

First, the value of additional withdrawals is subject to diminishing returns, meaning that there is an inverse relationship between the price farmers are willing to pay for water and the quantity of water available. Second, withdrawals reduce the total value of uses and activities that depend on instream flows. The "Impacts of Water Withdrawals" section of this report on page 35 suggests that small incremental withdrawals would not have a significant effect on recreational values and wildlife habitats but that large withdrawals would reduce recreational opportunities and adversely affect the wildlife. It is likely that additional withdrawals of equal increments would impose increasing costs on activities dependent on instream flows--in other words, the losses to recreation and wildlife would increase at an increasing rate per unit of withdrawals. Figure 2 plots these relationships.

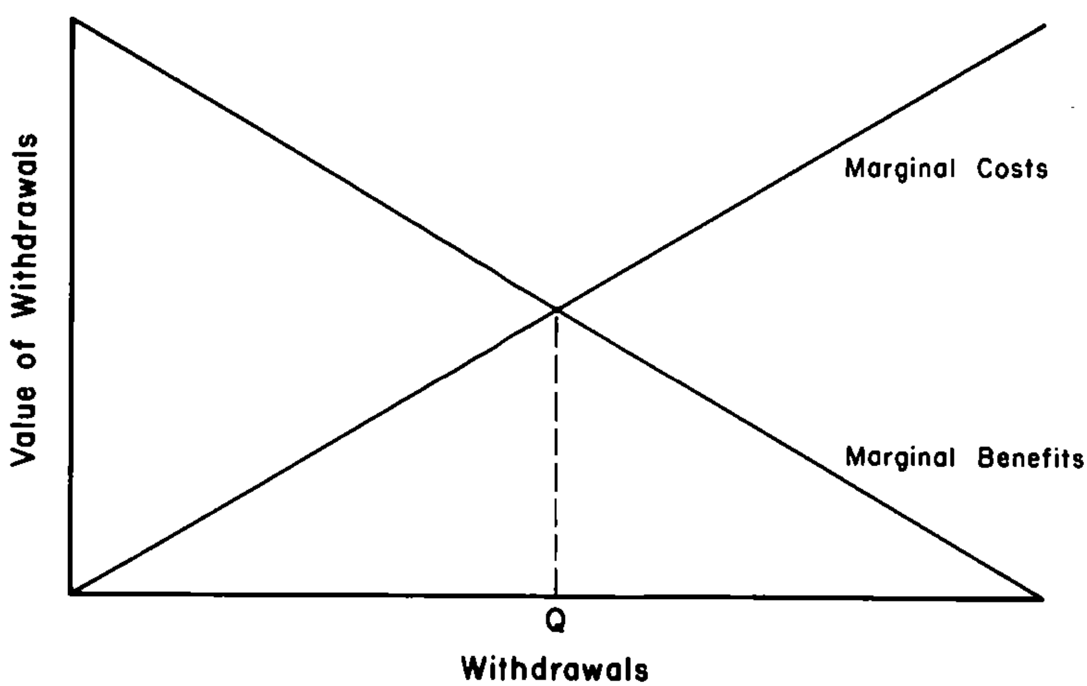

Figure 2. Relationships of withdrawals to cost and benefits.

The line labelled marginal benefits is the demand curve for water withdrawn from the river for consumptive uses. It has a negative slope because there are diminishing returns to increments of water in these alternative uses. The demand curve for water in these uses is the marginal benefits curve because the price consumptive users would be willing to pay for additional increments of water is equal to the incremental or marginal benefits they would receive from the water.

The line labelled marginal costs is shown with a positive slope, implying that additional incremental withdrawals would impose increasing costs on activities dependent on instream flows. If the increase in costs were proportional to withdrawals, the marginal costs curve would be horizontal; if the increase in costs were less than proportional to withdrawals, the marginal costs curve would have a negative slope. The optimal allocation of water between instream and consumptive uses is the quantity Q, where the marginal costs of withdrawals are equal to the marginal benefits. For any level of withdrawals less than Q, the benefits of some additional level of withdrawals exceeds the costs to instream uses of these withdrawals. Conversely, for any level of withdrawals greater than Q, the costs of these withdrawals exceed the benefits, and they should not be made.

The costs of increased withdrawals discussed in this chapter are described in the "Impacts of Water Withdrawals" section of this report on page 35 . Dollar values have been placed on some of these costs; most, however, have not been quantified and are treated qualitatively.

The benefits of increased withdrawals are the sum of the demand curves for the various sectors that take water for consumptive uses. Agricultural use is the major consumptive use dealt with in the analysis; a linear programming (LP) model is used to estimate the value of water for agricultural users.

The LP model was originally developed to estimate the costs imposed on farmers by the instream-flow reservation requested by the Montana Fish and Game Commission for the Yellowstone River Basin. (Under the Montana Water Use Act of 1973, the State of Montana or the United States Government or any appropriate political subdivision or agency of either may apply for a reservation of water for existing or future beneficial consumptive use or to maintain a minimum flow, level, or quality of water. See Montana DNRC 1976. The Montana Fish and Game Commission made its original Yellowstone Basin reservation request in 1974; that request was used in the LP model developed by Snyder and discussed on pages 27 through 33 . In October of 1976, the Fish and Game Commission submitted a revised, slightly higher reservation request, which was used in the Yellowstone Impact Study's LP modeling). The LP model solves for the cropping pattern and water allocation that maximize agricultural profits and divides the Yellowstone Basin into seven subbasins (figure 3). The model was rerun with Yellowstone Impact Study cost and revenue data, and the benefits of incremental increases in water supplies available for agricultural withdrawal were calculated.

The objective function values are the net profits per acre (total revenue minus variable costs) for the cropping strategy for individual crops in each subbasin. The cropping strategies identify the months through which each crop can be irrigated and are used to allow for partial irrigation in subbasins where water is scarce.

Yellowstone River Basin

Subbasins Used in the Yellowstone Impact Study Linear Programming Model

UY	Upper Yellowstone
BI	Billings Area
BH	Bighorn
MY	Mid-Yellowstone
TO	Tongue
PO	Powder
LY	Lower Yellowstone

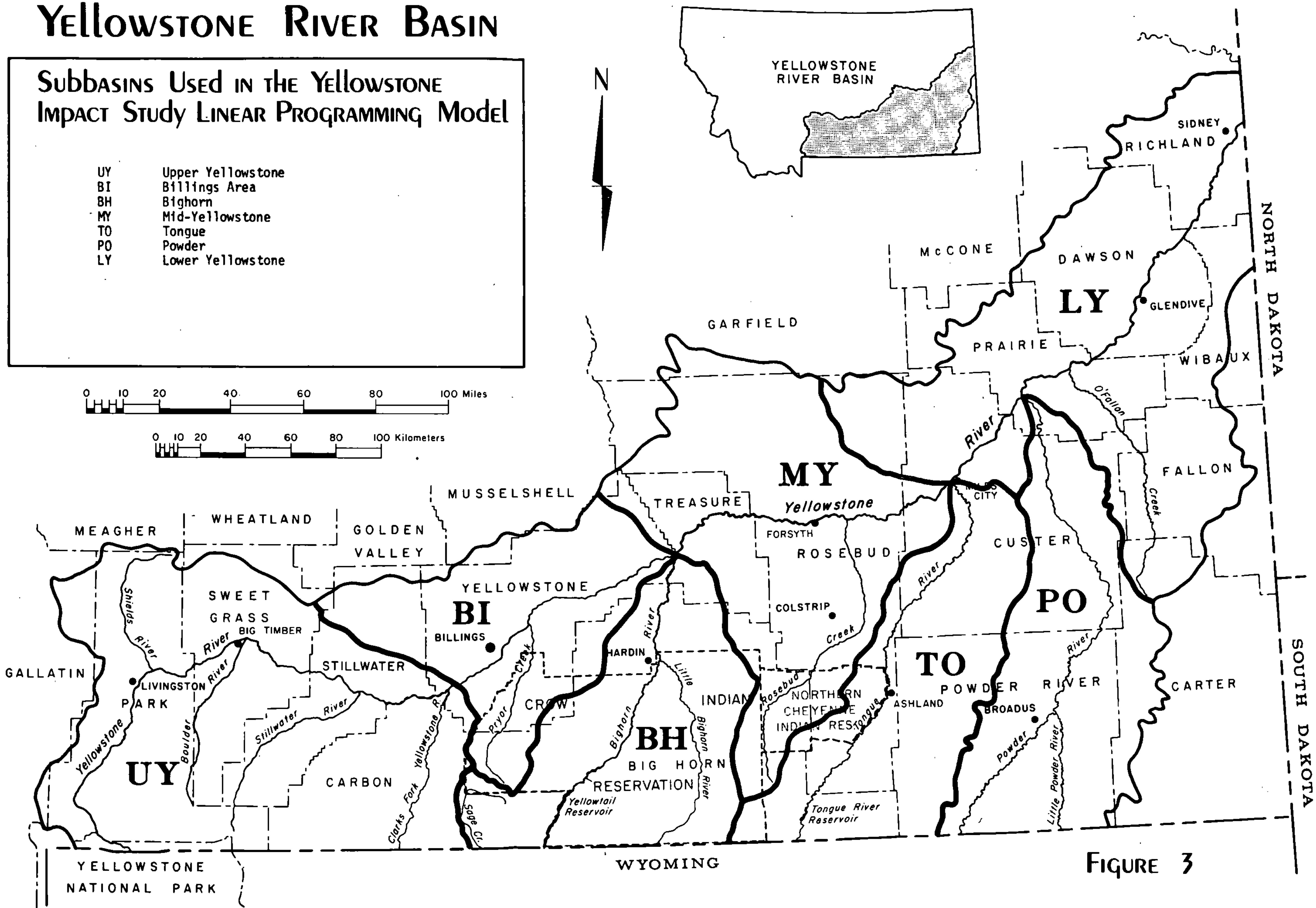

FIGURE 3

For example, pasture can be irrigated by any of the following schedules:

1) only once in the spring;
2) in the spring and again in July;
3) in the spring and again in July and August; or
4) through the entire irrigation season.

May 1-June 30 are the "spring" of the irrigation season.

The model maximizes the sum of profits for each cropping strategy and crop in each subbasin, subject to five types of constraints. The inflow constraints limit water availability to the estimated inflows into each subbasin. The instream constraints require that sufficient water be left instream to satisfy the Montana Fish and Game Commission water reservation request. The model is run with these constraints set at 100 percent, 90 percent, 75 percent, 50 percent, 25 percent, and 0 percent of the Fish and Game Commission's 1976 reservation request.

The crop constraints limit total acreage to 1975 acreage in estimating the current value of water. The acreage constraints for 2000 are calculated by adding the projected increases in acreage for each subbasin as calculated in Report No. 1 of this series to the acreage constraints used for the 1975 run. Cropping patterns were allowed to vary no more than 10 percent from historical cropping patterns. Mass conservation constraints defined outflow to any lower subbasin to be the inflows of the subbasin above minus agricultural use within the upper subbasin.

The model solves for the maximum profits and the optimal cropping pattern given the constraints. It also solves for the shadow prices of the constraints--the amount agricultural profits would increase if the constraint were relaxed by one unit. The marginal benefits of agricultural withdrawals are calculated by making repeated runs with different instream-flow constraints. As the constraints are relaxed, profits increase. The increase in profits is the value to farmers of relaxing the constraint. Each run of the model generates a fixed quantity of profits given a specified set of instream flow constraints and quantity of water available for irrigation, which is the total flow less the instream constraints. The benefit of an incremental increase in water availability is the increase in agricultural profits resulting from that increment of water.

For a more detailed discussion of the LP model, see appendix B.

Literature Review

The literature reviewed for this report is discussed below in four sections. Section I summarizes the literature relevant to reports 6, 7, 8, and 10 in this series, which deal with furbearers, migratory birds, fish, and recreation, respectively. Section II evaluates recent literature concerning the economic evaluation of water quality. Section III reviews alternative techniques for estimating the value of water for irrigation. Section IV discusses techniques for evaluating the demand for industrial water uses.

I. FISH AND WILDLIFE; RECREATION

The benefits or advantages of maintaining the existing populations of fish, furbearers, and birds can be classified as (1) benefits to recreationists and (2) benefits to fish and wildlife. Economic evaluation of these benefits requires estimating their importance so that it can be compared with the costs incurred in preserving them. The economic literature usually has evaluated these benefits as a part of a benefit-cost analysis of public investment in water resources. In this context, benefits are measured by the willingness of beneficiaries to pay for outputs, and costs are measured by the willingness of persons to pay to keep resources in alternative use.

The central problem is difficulty in the estimation of the beneficiaries' willingness to pay for recreational opportunities. Typically, recreational activities are either unpriced or priced at some arbitrary minimal cost that gives no indication of their real value to users. The lack of market prices and the necessity of evaluating investments in recreation have produced numerous techniques for estimating these benefits. Knetsch and Davis (1972) have described several techniques of benefit-cost analyses of recreation, among them the following methods: gross expenditure, market value of fish, alternative cost, market value of recreation, interview, and travel cost.

GROSS EXPENDITURE METHOD

This method uses the costs incurred by the recreationist as a measure of the benefits from the recreation, an approach defended by asserting that if the recreation were not worth the expenditures they would not have been made. This method is subject to two criticisms. First, the benefits are overstated because some of the expenditures would occur in the absence of recreational activity. Expenditures for food, for example, should not be counted because these costs are necessary in any circumstance. Secondly, it attempts to measure only the average rather than the marginal value of experience. There may be an abundance of alternative sites for similar recreational experiences, so that, although the value of the recreational activity is high, additional sites for this activity are not needed, and would therefore have a low value to recreationists. Proper evaluation of an investment in a recreational site or activity compares the costs of the investment to the additional or specialized improvements in recreational opportunities.

MARKET VALUE OF FISH METHOD

In this method, the recreational value of fishing is evaluated at the market value of the fish caught. This method ignores the distinction between fishing as recreation and fishing for food or as an occupation. A catch increases satisfaction for sport fishermen, but is not the sole criterion of the value of the activity.

ALTERNATIVE COST METHOD

The cost method is best summarized in the "Principles and Standards" (U.S. Water Resources Council 1973) used by federal agencies.

> The cost of the most likely alternative means of obtaining the desired output can be used to approximate total value when the willingness to pay or change in net income methods cannot be used. The cost of the most likely alternative means will generally misstate the total value of the output of a plan. This is because it merely indicates what society must pay by the next most likely alternative to secure the output, rather than estimating the real value of the output of a plan to the users. This assumes, of course, that society would in fact undertake the alternative means. Because the planner may not be able to determine whether alternative means would be undertaken in the absence of the project, this procedure for benefit estimation must be used cautiously.

MARKET VALUE METHOD

The market value method uses a schedule of charges which are estimates of the market value of the recreational activity. Total recreational value for the activity is calculated by multiplying the value of an activity (for example, one fisherman day) by the expected number of activities (annual number of fisherman days).

The advantages of this method are the ease of calculation of these benefits and the fact that the values used are estimates of charges that users might be willing to pay for the activites. Shortcomings are that values do not consider differences in the quality or uniqueness of certain recreational activities and that the method uses average values for activity days when the benefits of additional opportunities are the marginal value of the incremental opportunities.

INTERVIEW METHOD

Another technique, used by Davis (Knetsch and Davis 1972), is the interview method which estimates willingness to pay by asking a carefully selected sample of users a set of questions designed to discover the maximum price they would be willing to pay for the recreational activities. This study evaluated outdoor recreation in the Maine Woods. Davis asked questions on household income, years of experience in the area, and length of stay in the area, in addition to questions designed to provide an estimate of willingness to pay. Regression equations were estimated with willingness to pay as the dependent variable; household income, years of experience in the area, and length of stay in the area were considered as independent variables. A demand curve was then derived by plotting the number of visits per household that would occur at each price. Total benefits were calculated by summing the products of all prices and associated number of visits per household.

Unlike the other methods discussed, the objections to the interview method are practical rather than theoretical. The users interviewed may bias the results downward if they feel they may be charged the price they say is the activity's value to them. It is also possible that they will overstate the value in order to make a case that an area should be preserved in its present use.

A recent study (Horvath 1974), designed to establish an economic evaluation of wildlife, resulted in a survey linking wildlife-oriented recreation with the potential or actual values received, calculated in dollars. Values assigned by a random sampling of 12,068 households in the southeastern U.S. were divided into three categories: a day of fishing had a monetary value of $42.93; a day of hunting, $47.09; and a day of wildlife enjoyment, $70.41.

Although other studies in this present economic report place lower values on these types of recreation, the Horvath study found that participants placed higher monetary values on them than did nonparticipants, a situation which is not always acknowledged.

TRAVEL COST METHOD

The travel cost method was first suggested to the National Park Service in 1947 and more fully developed by Clawson and Knetsch (1966) in Economics of Outdoor Recreation. The travel cost method derives a demand curve for the recreation experience by using travel cost data as a proxy or substitute for price. The method requires data on travel costs, use rates for users in different locations, distance from the user's home to the recreational site and population of the areas from which the users come. The site is shown on a map, and concentric circles are drawn around the site; the average distance and travel cost from each circle or zone are calculated. Populations and visit rates as a percentage of population are calculated for each zone. From this data the annual number of visits is calculated as a function of travel costs to the different zones. Next a demand curve is estimated by raising costs a constant amount in each circular zone and calculating the decreased number of visitors that results from each increase in costs. The incremental additions to travel costs are a proxy for increases in admission prices. With each simulated increase in the admission prices, the expected number of visits decreases. The prices used for the demand curve are the simulated admission prices, and the quantities are the number of visits that are expected at each price.

Statistical analysis using a regression equation is used to estimate the demand curve for the recreational opportunities at a site. Total willingness to pay is found by integrating the area under the estimated demand curve.

Burt and Brewer (1971) revised this method to account for the effects the availability of substitute sites will have on the estimated benefits of a specific proposed site. The travel cost method is the most sophisticated and theoretically desirable method. However, data requirements are greater than for the other methods and considerable econometric skills are required. Copeland et al. (1976) have summarized the major difficulties with this method as follows.

Four problems with the travel-cost method have been identified.

(1) The central assumption of the model is that people in the inner zones will respond to an increase in the admission price by reducing their visit rates to the visit rates observed by people in outer zones whose travel costs are the same as the travel cost plus admission price paid by inner zone users. This will only be true if people in the different zones have the same incomes, tastes, and preferences. This assumption can be relaxed only by explicitly including additional variables in the regression equation. Proxy variables to account for varying tastes and preferences are difficult to define and evaluate.

(2) When a single trip includes multiple destinations, the joint costs common to all destinations cannot be attributed solely to the site being studied. An allocation of joint costs requires additional data, and no theoretically adequate method exists to make this allocation.

(3) Time spent traveling to the site may be considered a cost or an enjoyable part of the total recreation experience, and an estimate of time costs is difficult and imprecise.

(4) The travel cost method is not easily used to evaluate river-based recreation because there is no unique distance from the users residence to the river but rather a range of distances to different points along the river.

DIFFICULTIES IN ESTIMATING THE IMPACT OF REDUCED STREAMFLOWS ON THE QUALITY OF RECREATION

Two problems prevented a quantitative evaluation of the loss in recreational value that would result from lowered streamflows. Biological and physical data were not available to adequately describe the physical and biological impact of lowered flows on the mainstem. Without adequate description of the proposed change, an evaluation of the change was not possible. In addition, the recreation methodologies discussed previously were designed to evaluate the total value of a recreational resource rather than the decremental loss to the total value that would result from physical change. An adequate method to discuss the decremental change is not available.

II. WATER QUALITY

Baumol and Oates (1975) and numerous other writers (for example, Thompson 1973 and Freeman et al. 1973) have discussed the theoretical problem of external costs and the use of taxes or pollution charges to correct the misallocation resulting from external costs. An external cost is a cost of an individual or firm action that directly and adversely affects the production opportunities or consumption opportunities of other parties. Irrigation in the Yellowstone offers a prime example of such external costs. Return flow from each irrigated field increases the salinity of the river water and imposes costs on downstream irrigators whose water quality declines. Upstream irrigators do not bear the full costs of their decision to expand irrigation because there is no requirement that they compensate downstream irrigators for the costs imposed on them. Private costs of upstream irrigators are lower than the social costs which include the costs to downstream irrigators. Because upstream irrigators don't bear the full costs of their irrigation decisions, they have an incentive to expand irrigation beyond the optimum output.

Valantine (1974) identified two methods for measuring the agricultural costs of increasing salinity. They are (1) the costs of maintaining existing yields as salinity increases and (2) the loss of income resulting from a decline in yields because no corrective action is taken.

Existing yields can be maintained by leaching out the salts with additional irrigation, installation of a drainage system, conversion to sprinkler irrigation, or the dilution of river water with higher quality water from another source.

The loss of income resulting from a decline in revenues because declines in the salinity levels in the root zone are not prevented is either the loss due to declines in the yields of existing crops or the loss resulting from a switch to less profitable salt-resistant crops. Clearly a farmer faced with increasing salinity suffers increased costs no greater than the least-cost alternative mentioned above. Valantine cites a 1971 EPA study which concluded that accepting a decline in yields would result in the minimum penalty cost to farmers in the study area, the Colorado River Basin, although most farmers were installing expensive drainage systems and irrigation systems.

In discussing different methods of estimating the dollar losses resulting from increased salinity Valantine estimated the costs of the different alternatives. Costs of drainage systems and ditch lining were discussed. In Valantine's opinion, the best method for estimating the costs of salinity on irrigators was developed by Sun, who developed a complex mathematical model which derived the net regional income from the different levels of salinity.

A study by Pincock (1969) made projections of the salinity damages in the Wellton-Mohawk Irrigation District in Yuma County, Arizona. Study procedures were:

1) develop total dissolved solids projections (TDS) for 1980 and 2010;
2) relate salinity levels in the root zone to irrigation water quality and leaching percentages;
3) get experimental data relating salinity in the root zone to the quality of irrigation water and the leaching percentage;
4) relate salinity in the root zone to crop yields;

5) estimate crop water requirements;
6) develop budgeted costs and returns for different cropping patterns and crop rotations;
7) estimate total agricultural output for the district given cropping pattern, crop budgets and salinity effects; and
8) estimate net salinity damages.

Pincock concluded that in this district no changes in cropping patterns were justified and that salinity damages would be insignificant in 1980 and produce about $460,000 net damages in 2010, which would be about one percent of the value of the projected total gross output.

III. ESTIMATING THE VALUE OF WATER FOR IRRIGATION

The value of water for irrigation depends on the increase in crop yields resulting from the additional water and the price these crops bring on the market. Economic theory (Ferguson 1969) says that a farmer will increase the quantity of water used for irrigation up to the point where the cost of the water is equal to the increase in revenues produced by irrigation. The quantity of water demanded is inversely related to its price or cost. An increase in the price or cost of water will reduce the quantity used. Five methods are available to estimate the value of water in agriculture.

GENERAL METHODS

The first method is simply to observe the prices at which water is bought and sold. Hartman and Seastone (1970) observe that within some ditch companies active water rental markets occur; these prices increase over the irrigation season and are considered useful measures of the value of water in these areas.

A second, pursued in a study done at Colorado State University (Hartman and Anderson 1964), estimated the value of water by applying regression analysis to farm sales data. The selling prices of farms were regressed on farm acreage, the average number of acre-feet of water delivered per season, and the assessed value of improvement. They concluded that the "regression analysis of this study indicates that water is an important enough consideration in the total farm price to permit statistically significant estimates to be made of the values." They found that the values estimated from the regression were significantly lower than reported sales prices of water in the study area.

A third method for estimating the value of irrigation water is to use farm budgets to calculate the increase in profits resulting from a switch from dryland agriculture to irrigated agriculture. The increase in profits per acre divided by the water requirements per acre is the value of an acre-foot of water for the land for which the budget was prepared.

The fourth method, linear programming, is described below.

LINEAR PROGRAMMING METHODS

Examples of methods which use linear programming (LP) to estimate the value of water within a region include a Colorado study (Hartman and Whittelsey 1961), a study of the Yakima Valley (Butcher et al. 1972), and an evaluation of the Yellowstone Basin (Snyder 1976). The LP methods calculate the maximum possible agricultural profits, given constraints of the availability and productivity of land, cropping patterns, prices and water supplies. By making successive runs of the model with incremental changes in the constraints specifying the availability of water, the change in profits is calculated as a function of the quantity of water supplied. The value of an incremental addition to the water supply of a region is the increase in profits it produces. Dividing the changes in profits due to additional water by the quantity of the addition gives the per-unit value of the increment.

The Yakima study used a mathematical program with a nonlinear objective function and estimated the optimal allocation of water between municipal, agricultural, and hydropower uses. Instream uses were modeled indirectly by constraints on instream flows.

A linear program was used by Snyder in the study of the Yellowstone Basin to estimate the impact that instream-flow requirements and diversion for the coal industry would have on the marginal value of water for irrigation. The model maximizes agricultural profit subject to inflow constraints, land constraints, constraints of the cropping pattern, instream flow constraints, and withdrawals for the coal industry. The purpose of the model is to calculate the maximum agricultural profits obtainable with a given set of constraints and then estimate marginal values of water to irrigation by tightening the instream flow constraints and solving for the reduction in agricultural profits that results.

The model divides the Yellowstone Basin into five areas. Figure 4 shows the boundaries of the areas. Area 1 includes Park and Sweet Grass counties, Area 2 includes Carbon, Stillwater and Yellowstone counties, Area 3 is Big Horn County, Area 4 is comprised of Treasure, Rosebud, Custer and Powder River counties, and Area 5 includes Prairie, Dawson and Richland counties. As shown in figure 5, a schematic diagram of the basin as modeled, each area includes irrigation; in addition, Area 4 also includes a coal mining activity.

The objective function maximizes the sum of the product of per-acre profits for each crop and cropping strategy in each area and the number of acres for each crop, cropping strategy, and area. The mathematical formulation of the objective function is:

$$\text{Maximize } Z = \sum P_{ijk}Q_{ijk}$$

where: Z = total profits in the study area

P_{ijk} = the return over variable costs in the i^{th} area for the j^{th} crop which was irrigated through the k^{th} period.

Q_{ijk} = the number of acres in the i^{th} area in which the j^{th} crop was irrigated k^{th} period.

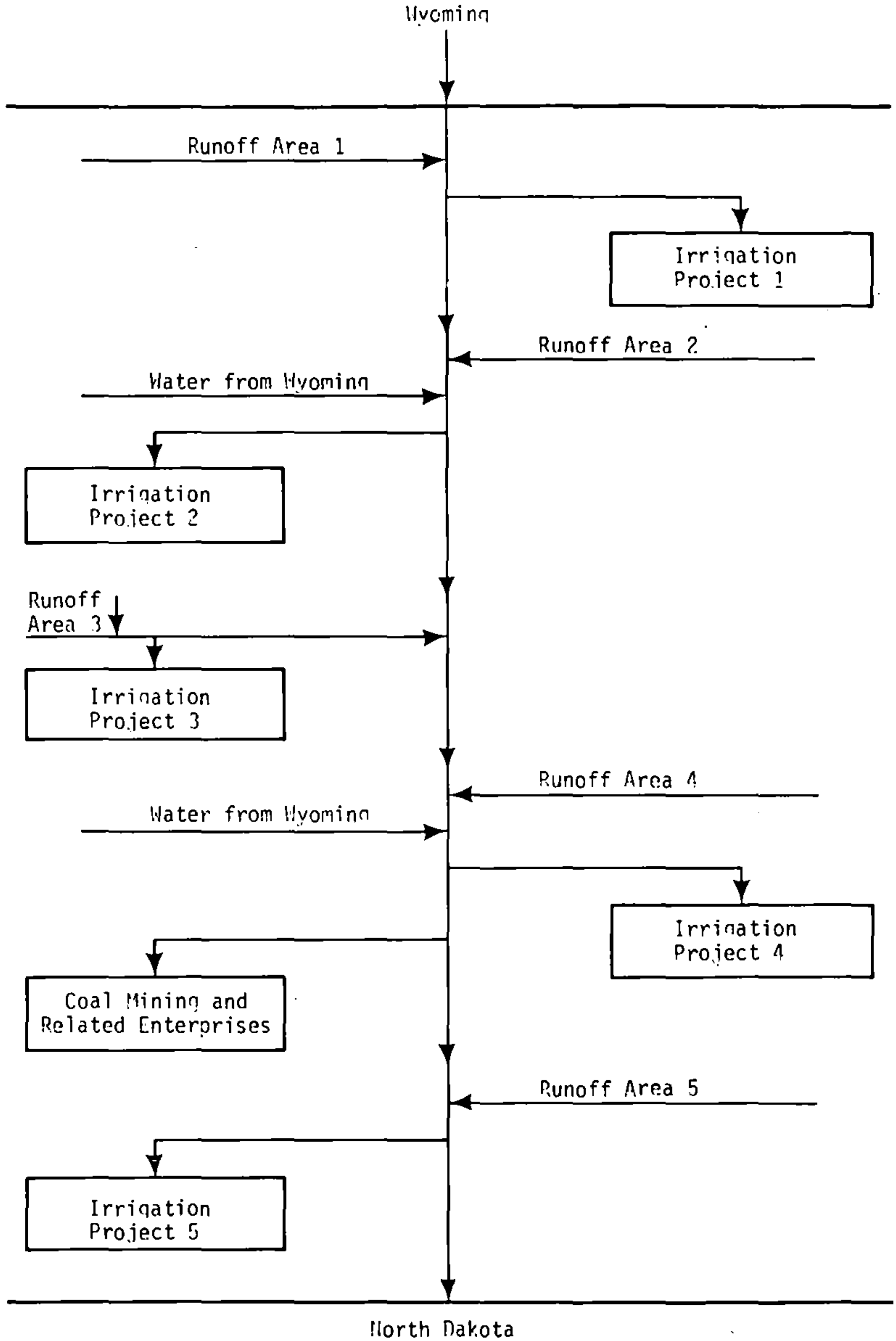

Figure 5. Schematic diagram of Yellowstone Basin for Snyder's linear programming model.

Yellowstone River Basin

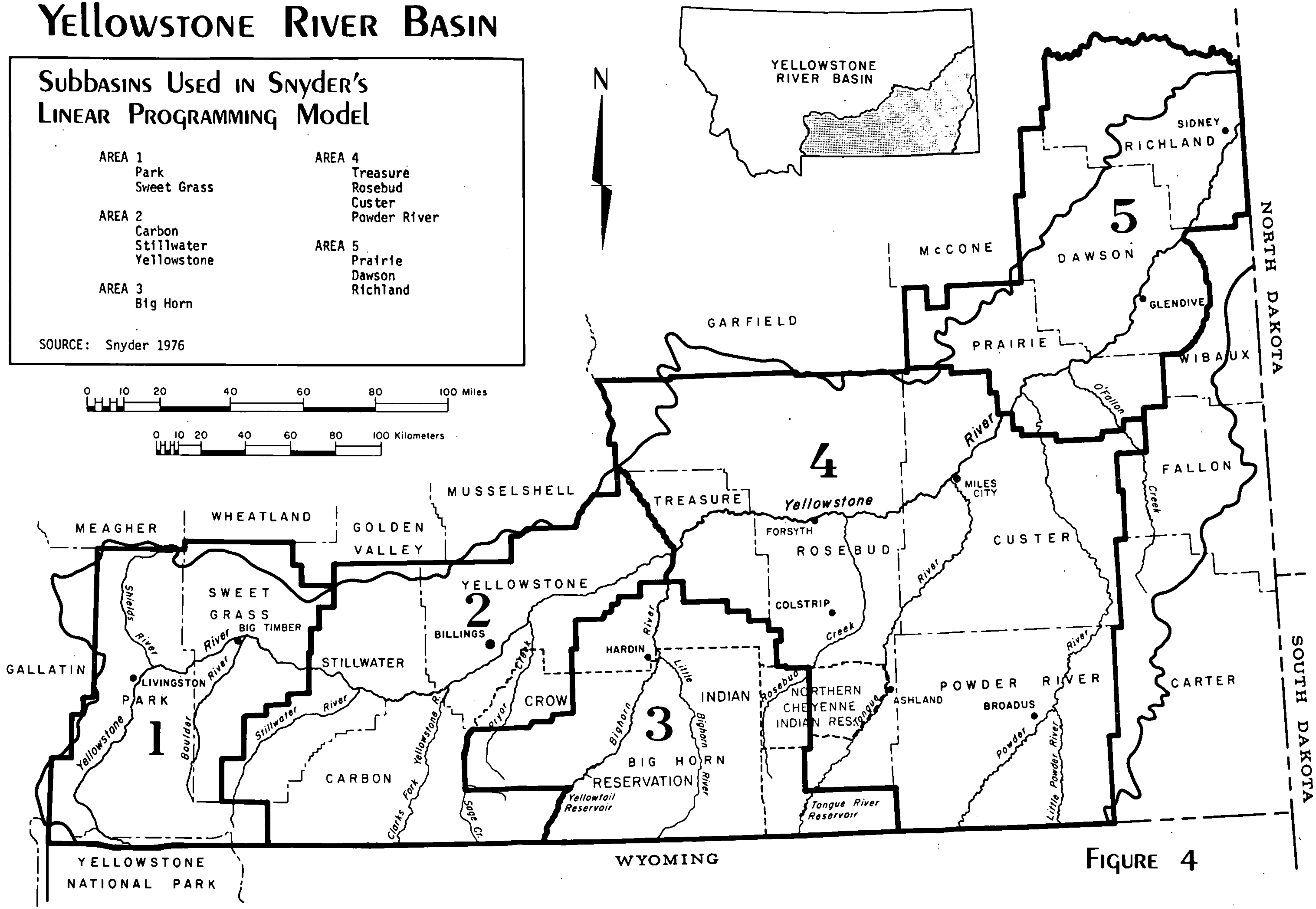

FIGURE 4

Per-acre profits are the difference between revenue from the crop and the variable costs required to produce the crop. Variable costs include labor costs, power costs, seeds, and capital costs. The constraints on water availability are the actual inflows and flows between areas for each of the 10 years studied. The constraints on land availability restrict acreage of each crop to historical cropping patterns plus or minus 10 percent. The minimum-flow constraints require that specified quantity must be transferred from the area with the constraint to the area downstream.

Instream flow constraints were imposed in areas 2, 4, and 5. These constraints represent the water reservation requests made by the Montana Fish and Game Commission (page 16). The model was run with instream constraints set at 100, 75, 50, 25, and 0 percent of the Fish and Game Commission 1974 reservation request.

Snyder concluded that the instream requests would reduce the quantity of water available to future irrigators and increase the marginal value of water for irrigation. Present irrigation would not be affected because the reservation claim on water would be junior to existing rights.

To estimate the marginal values, a frequency distribution with alternative levels of water reservation over a 44-year period for the Yellowstone River was calculated. The expected or average value of water for the ten-year period being studied was calculated by multiplying the probability of the occurrence of each class of flows by the value per acre-foot associated with each level of instream flow constraints and coal diversions.

The sum of these values is the estimate of the marginal value of water at a given level of instream flow constraints. By repeating this procedure at different levels of instream constraints, a function relating marginal values of water to instream flow constraints is estimated. Figure 6 shows this when calculated on the assumption that diversions for the coal industry are 3000 acre-feet/month. The marginal value of an acre-foot of water is the increase in agricultural profits that would occur if one more acre-foot was available. Figure 6 shows that an increase in instream constraints increases the marginal value of water. This occurs because, when less water is available for irrigation, marginal increases in the water supply will be used to irrigate high-quality land growing relatively high-value crops. When more water is available, marginal values decline because the additional water goes on poor soil and lower valued crops. Marginal values are not shown for constraints set at 75 percent and 100 percent of the Fish and Game Commission reservation. In some years model inflows to certain subbasins were less than the instream flow constraints; hence, there was no feasible solution.

IV. EVALUATING THE DEMAND FOR INDUSTRIAL WATER

Stroup and Townsend (1974) estimated the values of water for electric generation in the northern Great Plains area. Water values were calculated by estimating the difference in annual cost between wet and dry cooling towers on coal-fired electric generating plants. Cooling towers are required to reduce the temperatures and lower the outlet pressure on the turbines. A

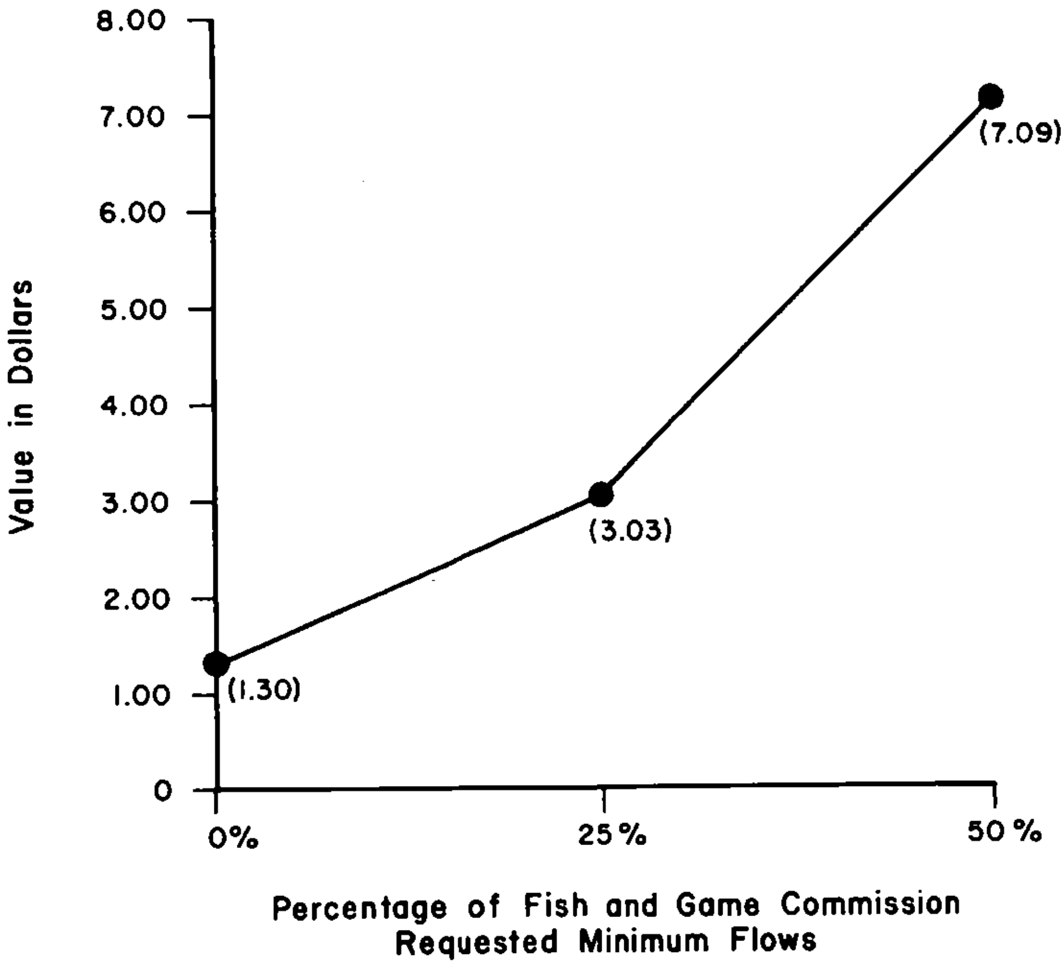

Figure 6. Expected marginal values of an acre-foot of water in irrigated agriculture resulting from using Snyder's linear programming model to impose minimum flows on the Yellowstone River.

wet cooling tower works by spraying water in the tower and allowing evaporation to provide cooling. A dry cooling tower circulates water through a closed system of piping similar to a giant car radiator, and the cooled water is recirculated through the plant.

A dry-cooled plant requires a larger capital investment and higher OM&R costs than a wet-cooled plant. Dry cooling is economically preferable to wet cooling only when water is so costly that the additional investment required by a dry-cooled plant is more than offset by the savings that result from decreased water consumption.

Stroup and Townsend used two different methods to estimate the maximum price per acre-foot that a generating plant with a wet cooling tower could pay and still find wet cooling cheaper than the dry cooling option. This break-even price is the value of water for these firms because at any price less than the break-even price wet cooling is cheaper than dry cooling, while for any price above the break-even point water costs are so high that dry cooling is the cheaper cooling method. One method estimated the average difference in annual cost between wet and dry cooling and divided that figure by the annual water use of the wet-cooled plant. By this method the break-even point for dry towers is $197.09/af. The second method estimates the opportunity cost of the power foregone due to the loss in efficiency of a dry-cooled plant that results when the plant is less efficient in warm weather. At 8 mills/kwh the break-even cost of water is $106/af.

The researchers conclude that the value of water used to cool thermal electric generating plants is between $100/af and $200/af. This value will vary with climatic conditions at the site and may change as more experience is gained with dry-cooled plants.

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 the three projected levels of development, low, intermediate, and high, are also 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.

COSTS

The purpose of this section is to briefly summarize the impacts of lowered flows that were predicted by reports No. 3, 6, 7, 8, 9, and 10 in this series. These impacts, largely negative, are the principal opportunity costs of agricultural withdrawals.

These costs will be compared on pages 39 to 43 with the benefits to farmers of increased withdrawals. This estimation of future impacts was based on the three projected levels of development discussed above. For the most part, the physical impacts of this projected development on the basin's environment were small. That, among other reasons, made difficult the quantification of the impacts, and the following discussion is mostly qualitative.

FURBEARERS AND MIGRATORY BIRDS

Alterations in channel morphology present the major threat to habitats and populations of furbearers (Report No. 6 in this series) and native waterfowl (Report No. 7). Of the principal furbearers, beaver, mink, and muskrat, beaver are most vulnerable to changes in water level. High water can flood dams and wash away food caches; low levels expose the animals to predation and, in combination with cold temperatures, can result in caches being frozen down. A braided channel provides a favorable habitat for beaver, and changes in channel morphology that would reduce the number and size of the islands would adversely affect beaver.

The stabilization of bars and islands and the increased density of vegetation due to reduced flood flows and reduced furbearer population would damage nesting sites and increase predation. Reduced fish populations would probably reduce the populations of birds that prey on fish. Additional irrigation would increase feeding areas and attract more migrant fieldfeeding ducks and geese, but hunter pressure would also increase.

Koch (Report No. 2 of this series) concluded that historical depletions in the basin have been on the order of estimated future depletions and that the physical appearance of the mainstem of the Yellowstone has not been altered appreciably. It is likely, then, that future depletions, if confined to diversion and pumping rather than onstream storage, would have a similarly small impact. Thus, the projected withdrawals would not appreciably affect the habitat for furbearers and birds.

Table 5 summarizes information on trapping income in the basin. Trapping does not make a noticeable contribution to income in the region. In 1972, personal income in the Yellowstone Basin was $112,989,000. The average income mentioned in table 5 is gross income, and the contribution of trapping to personal income in the area consists of gross income minus trapping costs. Trapping costs have not been estimated.

TABLE 5. Average trapping income, Fish and Game Regions 5 and 7, 1960-1974.

Animal	Average Price	Annual Average Catch	Average Annual Income	Number of Trappers
Beaver	$10.33	2410	$24,895.00	124
Mink	10.52	872	9,173.00	107
Muskrat	.91	3559	3,221.00	120
TOTAL			$37,289.00	

FISHERIES

Report No. 8 in this series studied the Tongue River to determine the impacts that differing levels of reduced flows would have on the Tongue River fishery. In the low level of development the report concluded that rearing flows in the fall would be inadequate 3 years out of 4. Rearing flows would be inadequate 9 years out of 10 in the intermediate and high levels of development. The low-level projection would have a minimal impact in winter, while the intermediate impact is described as "high" and the impact of the high-level projection is described as "severe." The impacts of the low, intermediate, and high levels of development on the fishery during the spring are summarized as minimal for the low-level projection, high for the intermediate level, and severe for the high level.

No studies were done on the other fisheries in the Yellowstone Basin.

RECREATION

An evaluation of the costs of reduced recreational values (Report No. 10

of this series) would require additional information on various conditions, such as how reduced fish populations would affect fishing success and how reduced fishing success would affect the value that fishermen place on fishing.

Table 6 summarizes impacts lowered flows would have on the five recreational sections studied.

TABLE 6. Impact on lowered flows on recreation in the Yellowstone River Basin.

Activity	River Sections[a]				
	1	2	3	4	5
Boating	-2	-2	-2	-3	-2
Rockhounding	-1	-1	-1	-1	-3
Fishing					-3
Waterskiing				-1	
Swimming	-2	-3			
Access	+3	+3	+3	+3	+3
TOTALS	-2	-3	0	-2	-5

NOTE: Each number in the table is the product of an impact modification number and the weight (or importance), based on current use, attached to each activity in each area. A negative number means that lowered flows decrease recreational values, while a positive number means that lowered flows improve recreational opportunities. All study sections are along the mainstem of the Yellowstone River. Activities not shown in table 6, such as walking for pleasure and picknicking, are not expected to be affected by reduced flows and are not listed here.

[a]The five river sections are:
1. Big Timber to the mouth of the Clarks Fork River
2. Mouth of Clarks Fork River to the mouth of the Bighorn River
3. Mouth of the Bighorn River to the mouth of the Tongue River
4. Mouth of the Tongue River to the mouth of the Powder River
5. Mouth of the Powder River to North Dakota border

Access is an essential complement of the recreational pursuits. The costs of these losses are the lowest of either the costs of eliminating the recreational losses or the decline in the value of recreational activity that occurs because mitigation of the adverse impacts is too costly. For example, the costs of poorer fishing due to reduced fish populations is the lower cost of either successfully restocking the fishery or the decline in the value of recreational fishing because catches are down.

EXISTING MUNICIPAL AND AGRICULTURAL USERS

In order to determine any adverse effects that a decrease in the accessibility of water, as a result of reduced flows, would have on the existing municipal and agricultural water users in the Yellowstone River Basin, the Yellowstone Impact Study included an investigation of the diversion systems of three municipalities and a number of agricultural users.

Billings, Miles City, and Glendive, the municipalities studied, draw their water supplies directly from the Yellowstone River. Using the projections of future development explained in appendix A, the future service populations and Yellowstone River water surface elevations for each of the three water supply systems were compared with the amount of electrical power now being used by the plants, the amount of water now pumped from the river, the cost of chemically treating the water, and recent streamflow records. This analysis showed that the cost of providing municipal water for Billings, Miles City, and Glendive will increase in the future, as shown in table 7. The increase, though, will occur primarily because of increased water consumption due to population growth and because of probable increases in the price of electricity; the reduced water surface elevations, as projected for the three levels of development, would have an insignificant impact on municipal water system costs.

TABLE 7. Percentage of increase in operation cost over present costs for each projected level of development.

City	Low	Intermediate	High
Billings	53	53	60
Miles City	85	93	146
Glendive	32	33	33

Four pumping and twelve gravity irrigation diversions were examined to determine the effect of lowered streamflow on each diversion. The efficiency of the irrigation pumping plants studied is greatly reduced during extremely low river flows. In other words, when flows in the river decrease, pumping costs increase. For the projected levels of development, pumping costs would increase from 0.2 percent for one site at the low level of development to 11.1 percent for another at the high level of development.

Three of the gravity irrigation diversions selected for study possess diversion dams across the river. These diversions have no problems getting water into the distribution system when flows in the river are low because their headgates are below the crest of the diversion dams. Therefore, if necessary, these projects could physically divert all of the water from the river when flows in the river are less than the capacity of the canal--although existing water rights downstream would probably make it illegal to do so. Nine gravity irrigation diversions were studied which do not include diversion dams. These have only minor headgate structures built at the head end of the canals. Most have problems getting sufficient water during low streamflows in the Yellowstone River even at the present level of development. These problems would increase in intensity and frequency at the projected levels of development. Among the solutions to these water accessibility problems are: provision of adequate instream flow in the river; installation of permanent, impervious diversion dams in the main river channels opposite the side channels that the diversions are now on; and channelization of the river so that most of the flow is directed toward the diversion.

WATER QUALITY

The conclusions of the water quality portion of the Yellowstone Impact Study (Report No. 3 of this series) are:

1) The Upper Yellowstone Subbasin and the Bighorn Subbasin would experience relatively minor degradation of water quality under all three levels of development. Eighty percent of the additional agricultural development and all of the future energy development is projected to occur in eastern Montana, so only that portion of the basin east of Billings was analyzed for changes in water quality.

2) The Tongue Subbasin and the Powder Subbasin would experience significant deterioration of water quality under all levels of development. Waters in the lower portions of each basin would be of questionable value for most beneficial uses.

3) The Mid-Yellowstone Subbasin and the Lower Yellowstone Subbasin would sustain moderate increases in salinity under the low and intermediate levels of development.

4) The Lower Yellowstone Subbasin would experience no significant effects at lower levels of development, and major reduction in water quality at the high level of development.

The negative effects would be more severe under the high level of development--especially in dry years and during August through October of average years. Degradation would not be severe enough to preclude use of the water for common beneficial uses, but more refined and expensive management and treatment practices may be required.

The costs imposed on agriculture by lowered water quality are the lower of either the decreased value of the crops grown because yields are lower or the increased costs required to avoid the loss of crop values. Likewise, the costs of a decline in water quality for municipal users are the lower of either the costs of the damage done by the degraded water or the costs of maintaining water quality standards. Possible damages include reductions in the useful lives of utility distribution pipes, water using devices, and heating systems, the cost of increased use of bottled water, and damages to parks, gardens, and home plantings.

BENEFITS

The linear programming model estimates the reduction in agricultural profits resulting from instream flow constraints which reduce the quantity of water available to irrigators. The value of withdrawals to irrigators is calculated as the amount farmers would be willing to pay to secure a reduction in the instream-flow constraints. Their collective willingness to pay in order to achieve an incremental reduction in the instream-flow constraint is equal to the reduction in profits that they suffer due to that increment of the instream-flow constraint. If, for example, an increase of 10 percent in the instream constraint cost irrigators $500,000 in lost profits because less water was available, then irrigators would be willing to pay up to $500,000 to avoid the increase; $500,000, therefore, is the value of this water to the irrigators.

The LP model was run with two sets of inflow constraints, two sets of acreage constraints, and six sets of instream constraints. The inflow constaints correspond to flows that are equaled or exceeded 50 percent of the years and flows that are equaled or exceeded 90 percent of the years. Acreage constraints used were those corresponding to 1975 irrigated acreage and the estimated irrigated acreage in 2000.

The model was run with instream flow constraints corresponding to 100 percent, 90 percent, 75 percent, 50 percent, 25 percent, and 0 percent of the 1976 Montana Fish and Game Commission reservation request (see page 16) for each of the following combinations of flows and acreage constraints:

1) 50th-percentile flows
   1975 acreage

2) 50th-percentile flows
   2000 acreage

3) 90th-percentile flows
   1975 acreage

4) 90th-percentile flows
   2000 acreage

No estimation of water values with 90th-percentile flows was possible because the instream constraints exceeded the available inflows in one or more subbasins in some periods, and an LP solution was infeasible.

Table 8 shows impact on agricultural profits of different levels of instream-flow constraints with 50th-percentile flows and current irrigated acreage.

TABLE 8. Impact on agricultural profits of different levels of instream constraints: 1975 irrigated acreage.

Percentage of Instream Flow Constraint	Agricultural Profits	Short Term Profit Lost Due To Increased Instream Constraints
0	$117,691,299	0
25	117,691,299	0
50	117,691,299	0
75	117,691,299	0
90	117,691,299	0
100	117,735,909	$44,610

The decrease in profits of $44,160 that occurs when the instream constraint is increased from 90 percent to 100 percent is due to a slight shortage in the Bighorn Subbasin. This decrease is only .04 percent of total estimated profits in the Yellowstone Basin, confirming that in a year with 50th-percentile flows the instream constraints require that less water be maintained instream than is left after current irrigation needs are met.

Less obvious is the conclusion that the marginal value of water for irrigation is currently about zero. Unappropriated water is available for the cost of filing for a permit to appropriate water; for farmers along the river there are no economical uses for the water, even though it is freely available. The benefits of withdrawals above current level are presently zero.

Table 9 shows the impact on agricultural profits of different levels of instream-flow requirements with 50th-percentile flows and the number of acres that are expected to be under irrigation in 2000.

TABLE 9. Impact on agricultural profits of different levels of instream constraints: irrigated acreage projected to 2000.

Percentage of Instream Flow Constraint	Agricultural Profits	An Increase in this Instream Constraint Reduces Short Term Profits by
0	$145,744,493	0
25	145,717,946	26,547
50	145,635,874	82,072
75	145,524,041	111,833
90	145,373,792	150,249
100	144,210,838	1,162,954

Table 10 is derived from Table 9 and shows the amount irrigators would be willing to pay to secure a one-percent reduction in the instream-flow constraint for each of the separate intervals estimated.

TABLE 10. Values to irrigators of one-percent reduction in instream-flow constraint.

Percentage of Fish and Game Commission Constraint	Short-term Value to Irrigators of 1 Percent Reduction in the Instream Constraint
100-90	$116,295
90-75	10,017
75-50	4,473
50-25	3,282
25- 0	1,062

Table 11 shows the volumes of water in acre-feet that make up one percent of the instream constraint for each basin and time period.

TABLE 11. One percent of instream constraint.

Time Period	Subbasins[a]						
	UY	BI	BH	MY	TO	PO	LY
Winter[b]	8,545	12,868	12,231	27,999	1,194	8,445	31,415
Spring[c]	12,912	16,619	5,354	30,458	725	967	32,690
July	5,339	5,777	2,141	8,566	249	122	9,375
August	2,598	2,951	1,722	4,305	94	24	4,305
September	1,785	2,201	1,547	4,165	100	23	4,165

[a]See figure 3.
[b]December 1-May 1
[c]May 1-June 30

Comparison of table 10 with table 11 shows that the marginal value to irrigators of these increments of flow is low relative to the volume of water involved with a one-percent change in the instream requirements. This is because the instream constraints reduce the number of irrigated acres only in August and September and reduce only the water available for irrigating pasture. The instream constraints used did not seriously restrict irrigated agriculture in the Yellowstone Basin.

The profits are the difference between the total revenue obtained from the sale of the crops and the variable costs of growing the crops. The estimated decline in profits is the decline that would occur if water constraints were suddenly imposed in the spring and the capital investments in irrigation equipment lay idle during the irrigation season. These annual losses would be less in the long run because, if a permanent scarcity of water existed, farmers would be able to reduce their losses by selling equipment that is useful only for irrigated crops and adjusting to an operation with less irrigation. In other words, the costs imposed by instream constraints overstate the annual costs that would occur if farmers could anticipate the water availability over a period of years and adjust the nature of their operations.

The distinction between the total value of the water for irrigation and the marginal value must be clearly understood. The total value of water is estimated to be the total agricultural profits as listed in table 12 while the marginal value is the increase in profits that would result from a small increase in the supply of water.

EVALUATION

The purpose of an evaluation is to compare the advantages and disadvantages of a proposed action and to determine whether the advantages outweigh the disadvantages. The advantages of increased water withdrawals are the value of additional water for irrigation, municipal, and industrial expansion and improved recreational access. The disadvantages include increased pumping costs for irrigation and towns and reduced recreational values for fishing , boating, swimming, and waterskiing. Lower levels of water quality raise costs for irrigated agriculture and municipal water users.

An evaluation of these diverse consequences clearly requires a common denominator for comparison of the advantages and disadvantages of increased withdrawals. An economic evaluation weights these consequences by society's willingness to pay to receive the benefits or avoid the losses. It would have to be determined whether the people who benefit from increased withdrawals would be willing to pay more to maintain the withdrawals than the people bearing the costs of withdrawals would be willing to pay to prevent the increased withdrawals. Incremental withdrawals are socially desirable only as long as the people who benefit from these withdrawals value their gains to be worth more than the value that the persons who suffer losses place on those losses. Two further observations make clear the enormity of this task of evaluation.

First, the evaluation compares two different states of society. What would life be like in the study area if current flow levels are maintained? What would life be like if flows are reduced? How would reduction in flow levels affect the value people place on their water-dependent activities?

Second, the evaluation measures comparatively the benefits and costs of withdrawals to the people who will occupy the Yellowstone Basin in the future. The scenarios used to determine the size of the projected withdrawals assume increased irrigation and a highly developed industrial sector in 2000. Will an industrial society with a larger population value the recreational opportunities available with instream flows more than current consumptive users value the use of that water?

Immediately one is impressed with the enormity of the task and the lack of information necessary to complete the task. The Yellowstone Impact Study has provided some useful information regarding the consequences of increased withdrawals, but not enough is known to be able to evaluate the economic desirability of increased withdrawals.

Legal constraints to water use in the Yellowstone River Basin

This section summarizes the legal constraints to water use in the Yellowstone River Basin. Legal constraints can include a wide range of laws and legal doctrines; for purposes of this section, however, only those constraints which may have a direct affect on water use are listed. Therefore, the list is not intended to be exhaustive. Refer also to Report No. 4 in this series, The Adequacy of Montana's Regulatory Framework for Water Quality Control.

The term "legal constraints" should not be misconstrued to mean laws or legal doctrines which hinder water use. Superficially, those listed may indeed hinder the use of water. However, laws and legal doctrines are developed in a free society to provide order. Laws regulating or affecting water use are examples. A specific example is the Montana Water Use Act, which regulates the appropriation of water. Through such regulation, the process of acquiring rights to the use of water is more orderly, and in the end that regulation may actually promote the use of water.

The legal constraints listed below include constraints resulting from court decisions as well as statutory and constitutional constraints.

FEDERAL LEGAL CONSTRAINTS

1. Reclamation Act of 1902, as amended and supplemented (32 Stat. 388; 43 U.S.C. 431, 524 and 423e). Irrigable lands to which irrigation water from a federal reclamation project can be delivered is generally limited to 160 acres in the ownership of a single person or entity or 320 acres in the ownership of husband and wife.

2. Winters Doctrine. Lands within an Indian reservation or other federal lands withdrawn from the public domain (such as most federal forest lands) hold a reserved right to use the waters which are within, crossing, abutting or beneath the reservation. This reserved right, even though unexercised, enjoys a continuing priority as of the date the reservation was established. The quantity of the reserved right is that amount of water needed to serve the purposes for which the reservation was established. Arizona v. California, 373 U.S. 546, at 601 (1963).

Reserved water rights (commonly called "Winters Doctrine rights", stemming from the U.S. Supreme Court case of Winters v. United States, 207 U.S. 564 (1908) which originated the concept) are largely unquantified in any definite source. Further, there is continuing debate and litigation attempting to define the scope of these rights. Since the quantity or legal scope of reserved rights is uncertain, many states, including Montana, are unable to accurately determine the amount of water remaining for allocation under state law, particularly near federally reserved lands or Indian reservations. No problem is a bigger source of consternation to state water rights and water planning officials.

Litigation to adjudicate federal and Indian reserved water rights on the Tongue and Bighorn river drainages in Montana has been brought in federal court in Billings under three separate lawsuits. The litigation, instigated by the United States Government and by the Crow and Cheyenne tribes, is at this point only in the preliminary stages. It will be years before the cases are ultimately decided, but the actions are valid evidence of the problems unquantified and unknown reserved water rights can create. If the federal government and the tribes succeed in their claims, many existing water users under state law may be precluded from future use of water. In addition, the Department of Natural Resources and Conservation has reports of several potential water users in the Tongue and Bighorn drainages who have taken a "wait and see" attitude, rather than apply for future water development.

Until they are eventually quantified and defined, either by litigation, agreement, or Congressional action, reserved water rights will undoubtedly be a major constraint on water use in the Yellowstone River basin.

3. The Federal Power Act of 1920, as amended (41 Stat. 1063; 16 U.S.C. 791a *et seq.*), requires nonfederal entities who propose to construct a power or navigation facility to secure a license issued by the Federal Energy Regulatory Commission before any construction which will affect either (a) waters over which Congress has jurisdiction or (b) public lands or reservations of the United States.

4. The Fish and Wildlife Coordination Act, as amended (72 Stat. 563; 16 U.S.C. 661 *et seq.*), requires that any public or private agency proposing to impound or divert water or to modify any stream must consult the U.S. Fish and Wildlife Service and take appropriate action to prevent loss or damage to fish and wildlife resources.

5. The Yellowstone River Compact (65 Stat. 663), entered into by the states of Montana, Wyoming, and North Dakota, provides for the division of waters of the four major tributaries of the Yellowstone River between Wyoming and Montana and forbids the diversion of water from the Yellowstone River Basin without the unanimous consent of Wyoming, Montana, and North Dakota.

Under Article V of the Compact, the waters of the four tributaries are divided as follows, based on streamflows at their mouths:

1) Clarks Fork Yellowstone River

to Wyoming	60%
to Montana	40%

2) Bighorn River

to Wyoming	80%
to Montana	20%

Under this law, permits from the Corps of Engineers are also required before any dredge or fill activities may begin in water covered by the Act. (These are known as Section 404 permits. Nearly all waters of the Yellowstone River and its tributaries are covered.)

9. The Clean Air Act, as amended (81 Stat. 485; 42 U.S.C. 1857 et seq.) provides for the establishment and enforcement of air quality standards by the Environmental Protection Agency in cooperation with the affected states.

10. The National Environmental Policy Act of 1970 (NEPA) (83 Stat. 852; 42 U.S.C. 4321 et seq.) requires that where federal funds or property are involved, the development of natural resources must be preceded by an analysis and weighing of the environmental impacts of such development.

11. The Wilderness Act of September 3, 1964 (78 Stat. 890; 16 U.S.C. 1131, et seq.), prohibits permanent roads and improvements (except as authorized by the President) within any wilderness area designated by the Act or by subsequent legislation.

12. The Historic Sites, Buildings and Antiquities Act of 1935, as supplemented and amended (74 Stat. 220; 16 U.S.C. 469 et seq.). The presence of historical or archaeological data within the site of any federal or federally licensed or assisted activity may require that the activity be preceded by a survey by the Secretary of the Interior to determine if such data shall be recovered and preserved.

13. The Endangered Species Act of 1973 (87 Stat. 884; 16 U.S.C. 1531 et seq.) requires that federal agencies take such action necessary to ensure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of endangered species or result in the destruction or modification of the habitat of such species.

14. The Surface Mining Control and Reclamation Act of 1977 (91 Stat. 445; 18 U.S.C. § 1114; 30 U.S.C. §§ 1201 et seq.) imposes limitations on the surface mining of coal and other minerals, not only with respect to surface reclamation and surface owner's consent, but also with respect to designating areas which cannot be surface mined.

MONTANA LEGAL CONSTRAINTS

1. The Montana Water Use Act of 1973 (Sec. 89-865 et seq., R.C.M. 1947) provides that after July 1, 1973, a right to the use of Montana waters may be initiated only through application for a permit from the Montana Department of Natural Resources and Conservation. The Act stipulates that the use of water for slurry of coal outside Montana's borders is not a beneficial use (Sec. 89-867(2), R.C.M. 1947). Although it has never been tested in court, this law is probably superceded in the Yellowstone River Basin by the Yellowstone River Compact, which specifically authorizes the diversion of water in one signatory state for use in another.

2. Moratorium on Yellowstone River Appropriations. Effective March 12, 1974, a three-year moratorium was established on Yellowstone River Basin appropriations exceeding 20 cfs or for reservoir impoundments exceeding 14,000 acre-feet (Secs. 89-8-103 through 89-8-105, R.C.M. 1947). The 1977 Montana Legislature extended the moratorium through December 31, 1977. In December 1977, the Montana Supreme Court extended the Moratorium.

3. Reservations of Water. The Montana Water Use Act of 1973, in Sec. 89-890, R.C.M. 1947, provides for the reservation of water by agencies of the state of Montana and of the federal government. These reservations can include instream uses and must be approved by the Montana Board of Natural Resources and Conservation. Over 30 applications were received on the Yellowstone River Basin alone; these applications are currently scheduled to be acted upon by the Board before the expiration of the Yellowstone Moratorium.

Depending upon the decision of the Board, water reservations under the provision could be a constraint to future water use in the Yellowstone River Basin in Montana. For example, the Montana Department of Fish and Game has applied for an instream flow of approximately 8.2 mmaf at Sidney. If that application were granted by the Board, other future uses of water would be limited.

4. The Montana Environmental Policy Act of 1971 (Sec. 69-6501 *et seq.*, R.C.M. 1947) provides, similarly to NEPA, that state agency actions which may significantly affect the quality of the human environment shall be preceded by an analysis and weighing of the environmental impact of such actions.

5. The Montana Major Facility Siting Act (Sec. 70-801 *et seq.*, R.C.M. 1947) requires that a certificate of environmental compatability and public need be issued by the Board of Natural Resources and Conservation as a condition to the construction of facilities for the generation or transportation of electricity, gas, or liquid hydro-carbon products; for the transport of water, when such transport is associated with a major facility; for the enriching of uranium; for the conversion of coal; for the use of geothermal resources; or for *in situ* gasification of coal.

6. The Montana Floodway Management Act of 1971 (Sec. 89-3501 *et seq.*, R.C.M. 1947) provides for the designation of flood plains and floodways by the Board of Natural Resources and Conservation and the subsequent regulation from obstructions of such areas by local governing bodies. Several areas in the Yellowstone Basin have been so designated.

7. The Montana Water Pollution Act (Sec. 69-4801 *et seq.*, R.C.M. 1947) forbids the pollution of state waters and requires a permit from the Montana Department of Health and Environmental Sciences for any activity which is likely to cause such pollution.

8. The Montana Air Pollution Act (Sec. 69-3906 *et seq.*, R.C.M. 1947) authorizes the Montana Board of Health and Environmental Sciences to establish and enforce air quality standards and to require permits for any facility that may contribute to air pollution.

electric generating plants and concluded that the value of this water fell within a range of $100 to $200 per acre-foot.

The Yellowstone Impact Study's evaluation of the impacts of the withdrawals resulting from the three projected levels of development summarized in appendix A was performed qualitatively. These impacts are considered to be the costs of additional withdrawals and can be compared to the benefits of additional withdrawals for agriculture, summarized below.

The projected depletions would have no significant impacts on furbearers and birds because channel morphology would be unlikely to change. The impacts of lowered flows on the Tongue River fisheries are described as "minimal" for the low level of development, "high" for the intermediate, and "severe" for the high. Lowered flows would adversely affect boating, rockhounding, fishing, waterskiing, and swimming, while improving access for all recreational activities. Lowered flows would not have a significant impact on the pumping costs for the municipal water supply systems of Billings, Miles City, and Glendive. Lowered streamflows would pose a water-accessability problem only for those gravity diversions which cannot control water levels in the river at the headgates. Irrigation pumping costs could increase up to 11 percent during low-flow months if the depletions projected in the high level of development occurred.

For all three levels of development, water quality degradation would be minor in the Upper Yellowstone and Bighorn subbasins. Significant deterioration would occur in the Tongue and Powder subbasins with all levels of development. The Mid-Yellowstone and the Lower Yellowstone subbasins would suffer moderate or greater increases in salinity if the projected depletions occurred.

The benefits of additional withdrawals for agriculture were estimated with a linear programming model which maximized agricultural profits subject to constraints on water availability and irrigated land. The objective function maximized profit per acre for different crops and cropping strategies in each of seven subbasins. Objective function values are the difference between total revenue and variable costs, meaning that the model estimates only the short-term costs of decreased water availability. The acreage constraints restricted crop acreages to total 1975 acres or projected acreages for the year 2000 in each subbasin, and cropping patterns were allowed to vary no more than 10 percent from historical cropping patterns. The water availability constraints allowed only the difference between modeled inflows and the instream constraint to be developed for irrigation. The value of water for irrigation was estimated by the decrease in agricultural profits resulting from a decrease in water availability.

The results obtained from the LP model were that the maximum instreamflow constraint considered would decrease agricultural profits in the basin in the year 2000 from $145,744,493 (the amount of agricultural profits if no instream constraint is imposed) to $144,210,838--a net decrease of $1,162,954. Irrigators in the basin would be willing to pay $116,295 to secure a one-percent reduction in this instream constraint if the instream constraint imposed were between 90 and 100 percent of the maximum considered. For percentages of the instream constraint between 0 and 90 percent, the reduction in agricultural profits would be less, and irrigators would be willing to pay much smaller amounts to secure the one-percent reduction.

Because the instream constraints would reduce the number of irrigated acres only in August and September and would reduce only the water available for irrigating pasture, the marginal value to irrigators of the increments of flow used as instream constraints is low. The instream constraints used did not seriously restrict irrigated agriculture in the Yellowstone Basin.

LEGAL CONSTRAINTS ON WATER USE

Constitutional mandates, legal decisions, and laws--both federal and state--constrain the municipal, industrial, and agricultural use of water in the Yellowstone River Basin by requiring water uses to conform to agreed-upon goals and priorities established in the public interest through due process of law. The summary of federal and state laws and doctrines in this report is not exhaustive; Report No. 4 in this series, The Adequacy of Montana's Regulatory Framework for Water Quality Control, explores the Montana legal framework for water use in greater detail.

FEDERAL CONSTRAINTS

Perhaps the biggest constraint on water use in the Yellowstone River Basin is an unknown--namely, the scope of reserved water rights stemming from the U.S. Supreme Court's decision, Winters v. United States (1908). The Winters Doctrine, as extracted from the ruling and modified by subsequent decisions, states that federal or Indian land reserves withdrawn from the public domain (such as most federal forest land) hold a reserved right to the use of water within, crossing, abutting, or beneath the reservation. Whether or not exercised, the reserved right has continuous priority for an amount of water needed to serve the purposes for which the land reservation was established. Because the size of these reserved water rights is uncertain (they are potentially great), many states (including Montana) cannot gauge the amount of water remaining for allocation under state law, particularly near federally reserved land or Indian reservations.

Litigation in federal court to adjudicate federal and Indian reserved water rights under the Winters Doctrine in the Tongue and Bighorn river basins will be years in deciding the ultimate scope of the reserved rights. Success of this litigation, brought by the U.S. Government and by the Crow and Cheyenne Tribes, would affect many existing Montana water uses regardless of the extent of water rights under the law.

Other federal constraints on the use of water in Montana include the general environmental-preservation policy of the United States expressed in the National Environmental Policy Act and other acts regulating a variety of activities directly or indirectly affecting the use and diversion of water. These include constructing facilities for power generation, dams and diversions, and navigation facilities, or applying for permits for activities that affect water and air quality, the integrity of wilderness, the preservation of archeological and historical sites, and endangered species. Of particular interest is the new federal power to regulate strip mining and subsequent land reclamation under the 1977 Surface Mining Control and Reclamation Act.

A federally supervised agreement among the states of Montana, Wyoming,

Appendixes

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.

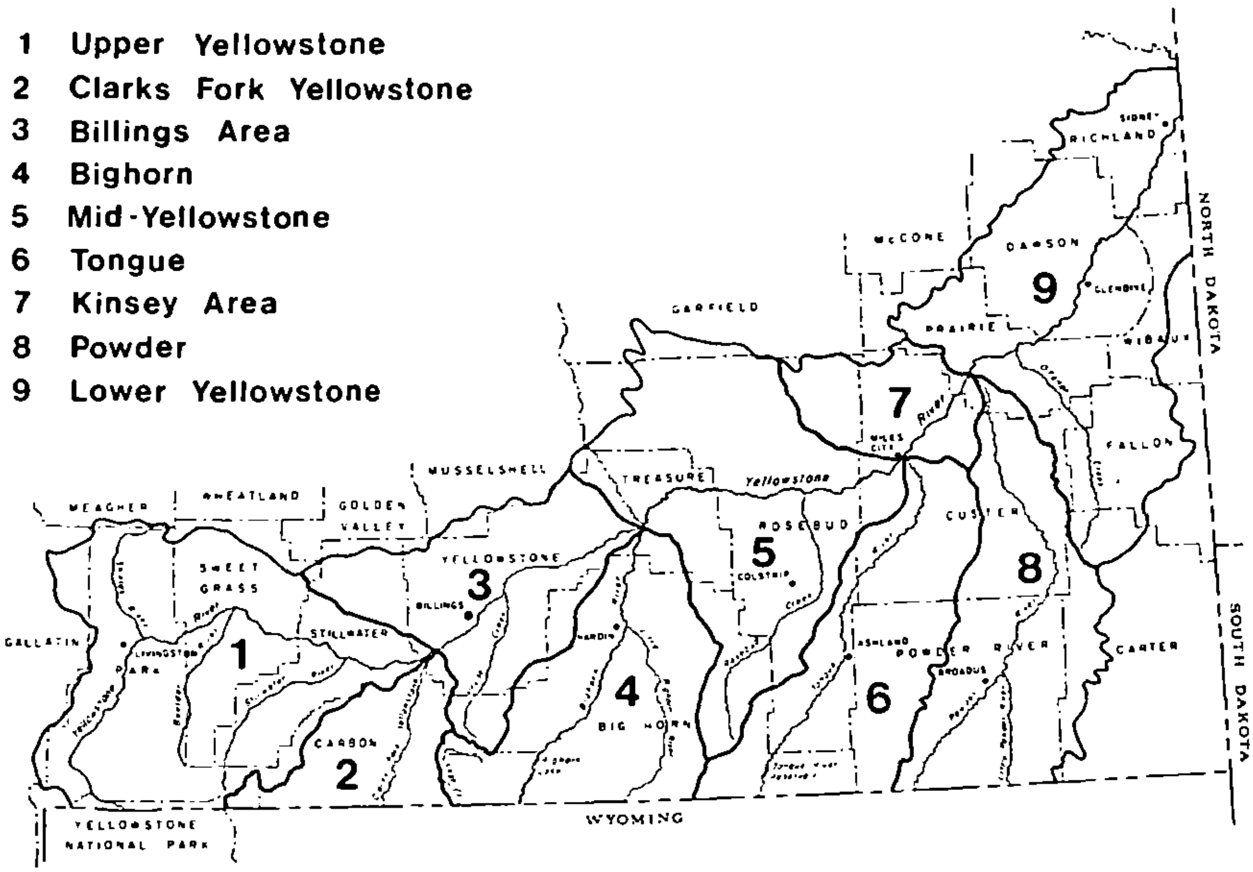

Figure A-1. The nine planning subbasins of the Yellowstone basin.

TABLE A-1. Increased water requirements for coal development in the Yellowstone Basin in 2000.

Level of Development	Coal Development Activity						Total
	Electric Generation	Gasification	Syncrude	Fertilizer	Export	Strip Mining	
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	Gasifi-cation	Syn-crude	Ferti-lizer	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
Yellow-stone			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	26,433		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

Appendix B

LINEAR PROGRAMMING MODEL

FIGURES

TABLES

INTRODUCTION

The linear programming model used for this report was developed by the Montana Department of Natural Resources and Conservation (1977) to estimate the losses that instream flow reservations would impose on irrigated agriculture in the Yellowstone Basin. It is a more elaborate version of a model developed by Snyder (1976) for the same purpose. The model maximizes agricultural profits in the basin subject to constraints on the availability of water and land and existing cropping patterns. Agricultural profits are the sum of the per-acre profits for each crop in each subbasin multiplied by the number of acres of each crop. Water constraints are inflows minus instream constraints; the land constraints restrict irrigation to existing or projected future acreage and cropping patterns. The model includes seven subbasins within the Yellowstone Basin (shown in figure 3 on page 17):

UY	Upper Yellowstone	TO	Tongue River
BI	Billings	PO	Powder River
BH	Big Horn	LY	Lower Yellowstone
MY	Mid Yellowstone		

The boundaries of these seven subbasins correspond to the boundaries of the nine subbasins used in the Yellowstone Impact Study development projections (figure A-1 of appendix A on page 59), with the exceptions that the Clarks Fork Yellowstone subbasin is included here in the Upper Yellowstone subbasin and the Kinsey in the Lower Yellowstone.

Because data on cropping patterns is available from the Montana Department of Agriculture (1976) by county rather than by drainage subbasin, it was necessary to aggregate county data in order to arrive at subbasin cropping figures. The following groupings were used:

Upper Yellowstone Subbasin: Sweet Grass, Park, Stillwater, and Carbon counties.
Billings Subbasin: Yellowstone County.
Bighorn Subbasin: Big Horn County.
Mid-Yellowstone Subbasin: Treasure County plus 73 percent of Rosebud County and 26 percent of Custer County.
Powder Subbasin: 82 percent of Powder River County and 58 percent of Custer County.
Tongue Subbasin: 18 percent of Powder River County, 27 percent of Rosebud County, and 16 percent of Custer County.
Lower Yellowstone Subbasin: Prairie, Dawson, and Richland counties.

Figure B-1 is a schematic diagram of the basin as modeled. The model includes, for each subbasin, an inflow, diversion for crops, minimum flow constraint, and outflows (which equal the inflows for the subbasin below.)

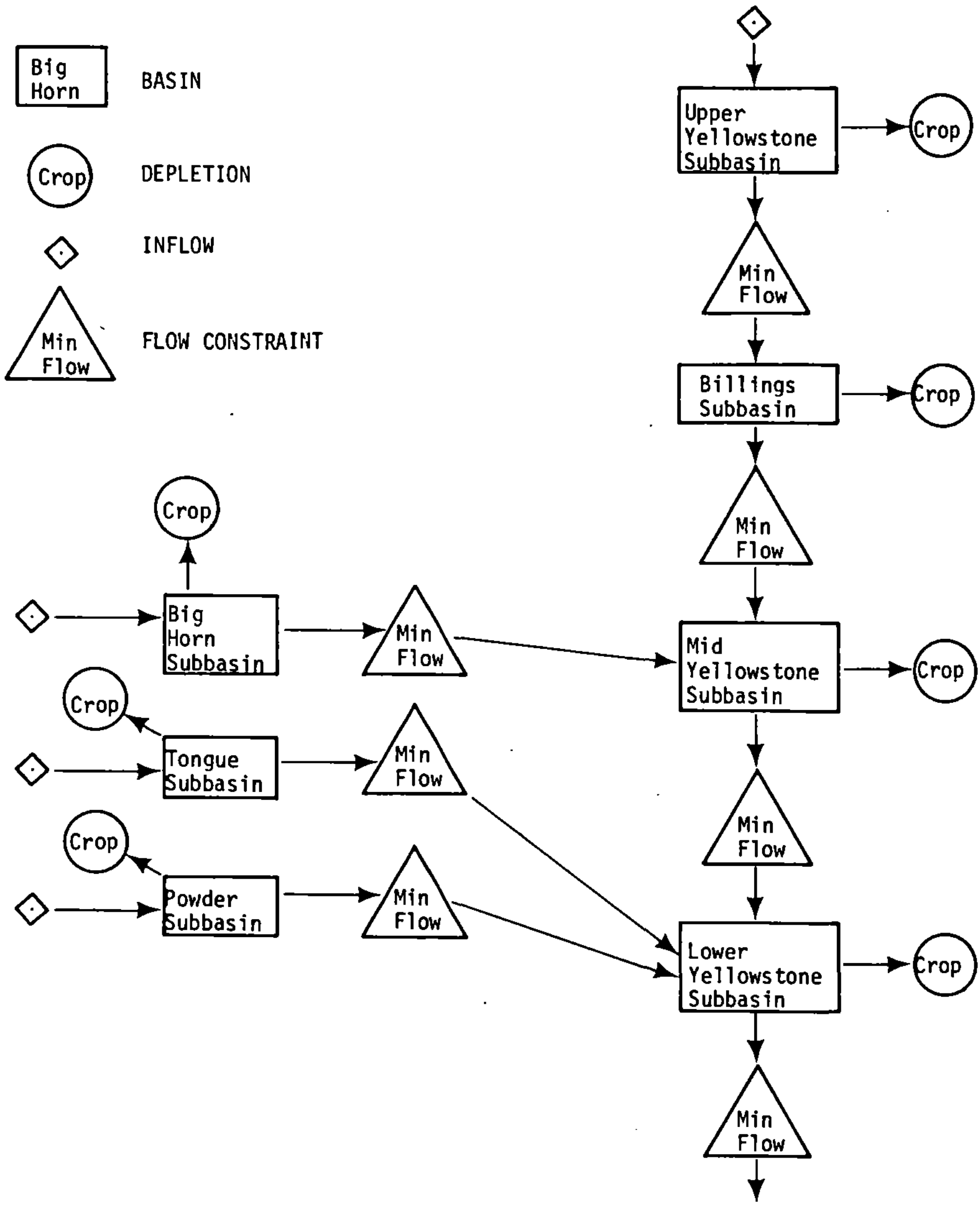

Figure B-1. Agricultural optimization model.

OBJECTIVE FUNCTION

The model maximizes agricultural profits in the Yellowstone Basin by maximizing the objective function:

$$\text{Maximize } Z = \sum P_{ijk}Q_{ijk}$$

where: Z = total profits in the study area

P_{ijk} = the profits per acre in the i^{th} subbasin for the j^{th} crop as grown with the k^{th} irrigation strategy.

Q_{ijk} = the number of acres in the i^{th} subbasin used for growing the j^{th} crop when grown with the k^{th} irrigation strategy.

Per-acre profits are crop revenues minus variable costs. Variable costs include the costs of seeds, labor, and harvesting and are defined as the costs that would be avoided if the crop were not planted in the spring. Specifically excluded are capital costs such as acquisition costs for a sprinkler system.

The crops grown in each subbasin conform to current cropping patterns.

The five crops included in the model are listed with their abbreviations.

AL	Alfalfa
SB	Sugar Beets
CS	Corn Silage
BA	Barley
PA	Pasture

The cropping pattern used is the one reported in Montana Department of Agriculture 1976, with the exception that the acreage of irrigated pasture was derived by subtracting the Montana Department of Agriculture 1976 acreage from DNRC's estimates of total irrigated acreage, under the assumption that any irrigated land not used for producing crops is used as pasture. The crops included in the model in several cases are composite crops, and cost and revenue figures reflect the average value of several related crops. The crop in the model called corn silage includes all silage crops, including ensiled hay and beet tops. The crop called barley includes all irrigated grains--barley, winter wheat, durum wheat, spring wheat, and oats. Alfalfa is considered to include all hay. The crop labeled sugar beets includes both sugar beets and dry beans.

Each crop can be irrigated with different strategies. An irrigation strategy is defined by the number of consecutive periods a crop is irrigated. The irrigation strategies are defined in table B-1.

The irrigation strategies available for each crop differ and were defined to include only strategies which were economically feasible and/or biologically pertinent. For example, sugar beets require full-season irrigation for adequate sugar production; grain crops, on the other hand, are harvested in July, thus not requiring late-season irrigation. The growth curve for corn silage indicated that a single irrigation would produce minimal results. Table B-2 shows the irrigation strategies used with each crop.

TABLE B-1. Irrigation strategies used in the LP model.

Irrigation Strategy	Time of Irrigation
0	crop is grown without irrigation
1	crop is irrigated only in the spring
2	crop is irrigated in the spring and July
3	crop is irrigated in the spring, July, and August
4	crop is irrigated in all periods

TABLE B-2. LP Model: Crop/Irrigation Strategies

Irrigation Strategy	Crop				
	AL	SB	CS	BA	PA
0	x		x	x	x
1	x			x	x
2	x		x	x	x
3	x		x		x
4	x	x	x		x

Objective function values were calculated by preparing partial farm budgets for all the irrigation strategies identified for each crop in each subbasin. Data for the full-irrigation strategies were taken from Report No. 1 in this series, except that a pasture alternative was included. The pasture alternative was treated the same as the alfalfa hay alternative except that yields were reduced to 14.5 tons/acre and the selling price was lowered to $36 per ton to account for the lower protein content of grasses. Only the variable costs and returns listed in Report No. 1 were included in the model.

Separate farm budgets were prepared for the dryland alternatives from data provided by the U.S. Bureau of Reclamation which was compatible with the budgets for the irrigated alternatives. Dryland yields were obtained from estimates published in soil survey reports (USDA 1967, 1971, 1972, 1976).

Variable farm costs and returns for the partial-irrigation strategies were assumed to vary directly with expected yields. Thus, yields for the partial-irrigation strategies were set at intermediate levels based on growth curves developed by the Montana Agricultural Experiment Station as quoted in Snyder (1976). Table B-3 lists the yields, costs and returns for each crop and irrigation strategy.

Irrigation cost data, which include only the variable costs of pumping water to the farm and operating a center-pivot sprinkler system, were taken from Report No. 1 in this series for the average lift and distance reported for each subbasin. Partial-irrigation costs were assumed to vary directly with crop water requirements as calculated from the Irrigation Guide for Montana (USDA 1973). Table B-4 lists the irrigation costs used in this study, and table B-5 combines all the cost and return data and lists the resultant net profits used in the objective function.

TABLE B-3. LP Model: Crop Yields, Variable Costs, and Returns

Crop	Irrigation Strategy	Yield (tons)	Cost ($)	Return ($)	Net Farm Return ($)
Alfalfa	0	1.5	13	60	47
	1	3.1	26	125	99
	2	4.0	34	161	127
	3	4.3	35	173	137
	4	5.0	42	201	159
Sugar Beets	4	21/10.5[a]	127	830	711
Corn Silage	0	9	41	152	111
	2	13.0	53	288	170
	3	19.5	89	329	240
	4	21.0	96	354	258
Barley	0	33/7[b]	20	74	54
	1	60/13[b]	36	134	98
	2	74/16[b]	44	165	121
Pasture	0	1.3	12	43	31
	1	3.0	28	99	71
	2	3.6	34	118	84
	3	4.1	33	135	97
	4	4.5	42	148	105

[a]First number equals tons of beets; second number equals tons of ensiled tops.

[b]First number equals bushels of grain; second number equals tons of straw.

TABLE B-4. LP Model: Irrigation Costs ($)

Crop	Irrigation Strategies	Subbasin						
		UY	BI	BH	MY	TO	PO	LY
Alfalfa	0	0	0	0	0	0	0	0
	1	6	7	6	7	6	6	7
	2	12	14	13	14	12	12	14
	3	17	21	18	19	17	17	20
	4	19	23	21	22	20	20	23
Sugar Beets	4	17	21	19	20	18	18	20
Corn Silage	0	0	0	0	0	0	0	0
	2	6	8	7	8	7	7	8
	3	12	14	13	13	12	12	14
	4	14	16	14	15	14	14	16
Barley	0	0	0	0	0	0	0	0
	1	5	7	6	7	6	6	7
	2	10	12	11	11	10	10	12
Pasture	0	0	0	0	0	0	0	0
	1	5	6	5	6	5	5	6
	2	10	12	11	11	10	10	12
	3	14	17	15	16	14	14	16
	4	17	20	18	19	17	17	20

TABLE B-5. LP Model: Objective Function Values ($/acre)

Crop Strategy	Subbasin						
	UY	BI	BA	MY	TO	PO	LY
AL0	47	47	47	47	47	47	47
AL1	93	92	93	92	93	93	92
AL2	115	113	114	113	115	115	113
AL3	120	116	119	118	120	120	117
AL4	140	135	138	137	139	139	136
SB4	694	690	692	691	693	693	691
CS0	111	111	111	111	111	111	111
CS2	164	162	163	162	163	163	162
CS3	228	226	227	227	228	228	226
CS4	244	242	244	240	244	244	242
BA0	54	54	54	54	54	54	54
BA1	93	91	92	91	92	92	91
BA2	111	109	110	110	111	111	109
PA0	31	31	31	31	31	31	31
PA1	66	65	66	65	66	66	65
PA2	74	72	73	73	74	74	72
PA3	83	80	82	81	83	83	81
PA4	89	86	88	87	89	89	86

INFLOW CONSTRAINTS

Each subbasin was modeled by a series of mass conservation equations whereby water flowing out of the subbasin equaled inflow minus water consumptively used within the subbasin. Water requirements were limited to consumptive use only, since data were not available to model the timing and location of return flows. Each subbasin was modeled by the equation:

$$I - A - \emptyset = 0 \qquad (1)$$

where: I = inflows from all sources

A = agricultural water use

$\emptyset$ = outflow to next lower subbasin

The model was first calibrated using 1975 water data generated by the water model described in Report No. 1 of this series and 1975 agricultural statistics (Montana Department of Agriculture 1976) disaggregated by subbasin. This initial calibration was designed to correct the model for miscellaneous inflows from small tributaries and for nonmodeled consumptive uses such as municipal and industrial use. The miscellaneous inflows were then used to modify the inflow factor shown in equation 1, above.

Inflows to four of the subbasins (Upper Yellowstone, Bighorn, Tongue River and Powder River) are exogenous to the model. These inflows from Wyoming were modified by the miscellaneous flows and used as a right-hand-side (RHS) constraint in the model. Inflows to the remaining three subbasins were based on the outflows of the next upstream basin(s) as modified by miscellaneous flows.

The model was run with two levels of inflows. Fiftieth-percentile inflows are the inflows that are equaled or exceeded 50 percent of the years. Ninetieth-percentile inflows are the inflows that are equaled or exceeded 90 percent of the years.

Flows were measured in acre-feet per time period. Five time periods are used in the model, as shown in table B-6. The time periods were primarily based on irrigation requirements, but, since streamflow data were available only on a monthly basis, some adjustments were made.

TABLE B-6. Time periods used in the LP Model

Time Period	Interval	Abbreviation
Winter	Oct. 1-April 30	W
Spring	May 1-June 30	M
July	July 1-July 31	J
August	August 1-August 31	A
September	September 1-September 30	S

Miscellaneous flows were assumed to vary proportionately with the mainstem flows. Therefore, miscellaneous inflows for the 90th-percentile runs were calculated by multiplying the ratio of 90th-percentile flows to 50th-percentile flows by the estimated 50th-percentile runoff. In other words, it is assumed that if, for example, 90th-percentile flows in the mainstem are 40 percent of 50th-percentile flows, then runoff occurring in a 90th-percentile year will be 40 percent of runoff occurring in a 50th-percentile year. Table B-7 shows historical outflows and table B-8 shows the estimated miscellaneous inflows.

TABLE B-7. LP Model: Historical Outflows (acre-feet)

Time Period	Subbasin						
	UY	BI	BH	MY	TO	PO	LY
50th-Percentile Flows							
Winter	1,353,162	1,427,092	1,223,121	2,799,926	119,410	129,974	3,141,526
Spring	2,385,198	2,373,054	745,296	3,313,794	125,250	164,107	3,460,945
July	899,400	906,166	312,406	1,240,724	25,204	27,601	1,244,322
August	244,700	247,691	172,343	428,158	11,541	4,164	431,778
90th-Percentile Flows							
Winter	1,022,900	1,036,390	806,944	1,946,339	50,963	52,055	2,067,846
Spring	1,553,700	1,535,328	268,713	1,803,924	26,043	37,011	1,786,826
July	475,300	481,261	58,461	547,511	3,135	2,889	532,541
August	218,800	211,401	78,132	275,029	1,107	861	237,778
September	173,800	172,160	98,694	252,952	1,190	535	218,388

TABLE B-8. LP Model: Net Inflows from Miscellaneous Sources (acre-feet)

Time Period	Subbasin						
	UY	BI	BH	MY	TO	PO	LY
50th-Percentile Flows							
Winter	1,353,162	73,930	1,223,121	129,713	119,410	129,297	92,216
Spring	2,485,568	25,679	771,935	226,083	174,040	198,218	-103,823[a]
July	1,014,330	52,786	344,027	57,827	39,178	64,267	- 904[a]
August	411,621	33,393	166,181	18,455	19,362	33,402	5,545
September	283,715	20,021	182,419	21,827	15,184	17,559	5,999
90th-Percentile Flows							
Winter	1,022,900	53,690	806,944	104,071	50,963	52,055	60,699
Spring	1,619,080	16,614	278,318	123,072	36,188	44,704	-201,097[a]
July	536,036	28,034	64,378	25,518	4,873	6,727	- 2,112[a]
August	278,573	21,890	90,767	11,081	2,767	3,119	2,954
September	201,511	13,916	104,464	12,895	1,566	2,256	3,034

[a]For the Lower Yellowstone Subbasin, negative values are shown in the spring and July because the calibration showed a net depletion, rather than inflow, for those time periods.

CROPPING AND ACREAGE CONSTRAINTS

Table B-9 shows the per-acre water requirements for each crop, time period, and subbasin used in the model. These figures, multiplied by the number of acres of each crop in a particular subbasin (table B-10), yield the agricultural water use figure (A) in equation 1 on page 72.

TABLE B-9. LP Model: Crop Water Requirements (acre-feet/acre)

Crop	Section	Subbasin						
		UY	BI	BH	MY	TO	PO	LY
AL	M	.45	.49	.49	.57	.53	.53	.57
	J	.50	.52	.52	.57	.55	.55	.57
	A	.41	.43	.43	.47	.45	.45	.47
	S	.17	.18	.18	.24	.21	.21	.24
SB	M	.20	.21	.21	.25	.24	.24	.25
	J	.49	.52	.52	.55	.54	.54	.55
	A	.49	.52	.52	.56	.54	.54	.56
	S	.21	.23	.23	.30	.27	.27	.30
CS	M	.09	.12	.12	.15	.14	.14	.15
	J	.40	.43	.43	.48	.46	.46	.48
	A	.41	.43	.43	.47	.45	.45	.47
	S	.12	.14	.14	.17	.16	.16	.17
BA	M	.43	.46	.46	.55	.51	.51	.55
	J	.51	.52	.52	.53	.53	.53	.53
PA	M	.39	.41	.41	.48	.44	.44	.44
	J	.41	.42	.42	.46	.44	.44	.46
	A	.34	.36	.36	.40	.33	.38	.40
	S	.20	.21	.21	.26	.24	.24	.26

Table B-10 shows the acreage constraints used in the model during calibration runs. The actual acreages in each crop in 1975 as reported by the Montana Department of Agriculture (1976) were used as constraints when the model was calibrated, with the exception of irrigated pasture, as explained on page 68. In subsequent runs the same cropping pattern was used, but the constraints allowed the acreage in any crop to increase or decrease up to 10 percent of the historical pattern. These maximum and minimum constraints for the runs corresponding to estimated acreage in 1975 and 2000 are shown in table B-10. The acreages given in table B-10 for the year 2000 are based on the intermediate level of development discussed in appendix A.

TABLE 8-10. LP Model: Cropping and Acreage Constraints

Subbasin and Crop	Percentage of Acres in the Subbasin	Calibration Run and 1975 Acreage			2000 Acreage		
		Number of Acres	Maximum Acres[a]	Minimum Acres[a]	Total Acres	Maximum Acres[a]	Minimum Acres[a]
UYSB	4	8,750	9,614			11,679	
UYBA	7	17,400		15,600			16,722
UYAL	69	163,500	179,850			201,461	
UYCS	2	5,100	5,610			5,839	
UYPA	18	43,860		39,474			43,000
TOTAL	100	238,610			265,430		
BISB	11	10,620	11,682			13,654	
BIBA	14	14,400		12,960			14,218
BIAL	15	14,600	16,060			18,619	
BICS	10	10,000	11,000			12,412	
BIPA	50	50,280		45,252			50,778
TOTAL	100	99,900			112,840		
BHSB	3	2,130	2,343			2,419	
BHBA	14	9,300		8,370			9,235
BHAL	50	32,600	34,860			40,310	
BHCS	13	8,600	9,460	10,773		10,480	
BHPA	19	11,970					12,533
TOTAL	100	64,600			73,290		
MYSB	9	6,089	6,676			8,873	
MYBA	18	12,410		11,169			14,520
MYAL	26	18,047	19,852			25,634	
MYCS	17	11,789	12,968			16,761	
MYPA	31	21,334		19,201			25,006
TOTAL	100	69,649			89,629		
TOSB	3	838	922			1,390	
TOBA	15	4,004		3,604			5,686
TOAL	31	8,523	9,375			14,361	
TOCS	13	3,439	3,783			6,022	
TOPA	39	10,681		9,613			17,782
TOTAL	100	27,485			42,115		
POSB	2	1,473	1,620			2,484	
POBA	6	3,586		3,227			6,097
POAL	26	16,230	17,853			32,291	
POCS	7	4,572	5,029			8,694	
POPA	59	36,905		33,215			
TOTAL	100	62,766			112,906		59,953
LYSB	24	22,430	24,673			31,178	
LYBA	23	21,700		19,530			24,447
LYAL	20	19,000	20,900			25,932	
LYCS	12	10,800	11,880			15,589	
LYPA	21	19,070		17,163			22,321
TOTAL	100	93,000			118,100		

[a]Only binding constraints are reported in the columns headed "Maximum Acres" and "Minimum Acres."

INSTREAM-FLOW CONSTRAINTS

As a final constraint on the model, several instream flow requirements were formulated to simulate potential water use by other sectors of the economy, such as municipalities, industry, or fish and wildlife. Six levels of instream flow requirements were used, which varied from 0 to 100 percent of the Montana Fish and Game Commission's 1976 reservation request (see page 16). Because of differences in the data bases and subbasin boundaries used by the Montana DNRC and the Fish and Game Commission, modifications of the Fish and Game Commission's figures were required in some subbasins to permit feasible modeling. Table B-11 shows the instream constraints used in the model.

SUMMARY OF MODEL FORMULATION

The objective of the model was to maximize net profits from agricultural production in the basin subject to constraints on: (1) available land resources, (2) anticipated cropping patterns, (3) available water, and (4) alternative uses of the water. The model was first calibrated to current conditions (1975). The calibration was designed to balance the water use/availability equation and to account for all water not specifically defined in the model. The model was then run using all possible combinations of:

1) Two natural flow patterns (50th- and 90th-percentile flows)
2) Two levels of agricultural development (1975 and 2000)
3) Six levels of instream-flow constraints (0 to 100 percent of the Montana Fish and Game Commission's 1976 reservation request)

OUTPUT

Output of the LP model contains three types of information: the value of the objective function, the number of acres of each crop and cropping strategy, and the shadow price of each constraint. The shadow price of a constraint is the amount the value of the objective function would increase if the constraint were relaxed by one unit. The results of the LP model are described on pages 39 to 42 of this report.

TABLE B-11. LP Model: Instream Flow Constraints (acre-feet)

Time Period	Percentage of Fish and Game Commission Reservation Request				
	100	90	75	50	25
			UPPER YELLOWSTONE		
Winter	854,477	754,029	640,857	427,238	213,619
Spring	1,291,239	1,162,115	968,429	645,619	322,809
July	533,951	480,566	400,463	266,976	133,488
August	259,834	233,851	194,876	129,917	64,959
September	178,512	160,660	133,884	89,256	44,628
			BILLINGS		
Winter	1,286,875	1,158,188	965,156	643,438	321,719
Spring	1,661,949	1,495,754	1,246,462	830,975	415,487
July	577,784	520,005	433,338	288,892	144,446
August	295,140	265,626	221,355	147,570	73,785
September	220,165	198,149	165,124	110,083	55,041
			BIG HORN		
Winter	1,223,121	1,223,121	1,055,785	703,857	351,928
Spring	535,410	481,869	401,557	267,705	133,852
July	214,164	192,747	160,623	107,082	53,541
August	172,200	154,890	129,150	86,100	43,050
September	154,700	139,230	116,025	77,350	35,675
			MID-YELLOWSTONE		
Winter	2,799,926	2,799,926	2,345,509	1,563,673	781,836
Spring	3,045,889	2,741,299	2,284,416	1,522,944	761,472
July	856,656	770,990	642,492	428,328	214,164
August	430,500	387,450	322,875	215,250	107,625
September	416,500	374,850	312,375	208,250	104,125
			TONGUE		
Winter	119,410	108,351	90,292	60,195	30,097
Spring	72,580	65,322	54,435	36,290	18,145
July	24,990	22,491	18,742	12,495	6,247
August	9,467	8,520	7,100	4,734	2,367
September	10,054	9,049	7,540	5,027	2,513
			POWDER		
Winter	844,500	76,005	63,338	42,225	21,112
Spring	96,770	87,098	72,577	48,485	24,192
July	12,290	11,001	9,218	6,145	3,072
August	2,460	2,214	1,845	1,230	615
September	2,330	2,142	1,785	1,190	595
			LOWER YELLOWSTONE		
Winter	3,141,526	2,245,954	2,371,628	1,581,086	790,543
Spring	3,269,052	2,931,046	2,445,039	1,630,076	815,015
July	937,500	843,750	703,125	463,750	234,375
August	430,500	387,450	322,875	215,250	107,625
September	416,600	374,850	312,375	208,250	104,125

Literature cited

Baumol, W.J. and W. Oates. 1975. The theory of environmental policy. Prentice-Hall Inc.: Englewood Cliffs, NJ. 272 pp.

Burt, O. and D. Brewer. 1971 (September). Estimation of net social benefits from outdoor recreation. Econometrica 39. 813-27.

Butcher, W., N. Whittlesey and J. Orsborn. 1972. Economic value of water in a systems context. National Water Commission: Arlington, VA. 179 pp.

Clawson, M. and J.L. Knetsch. 1966. Economics of outdoor recreation. Johns Hopkins University Press: Baltimore, MD. 328 pp.

Copeland, M., R. Stroup, and R. Ricker. 1976. Problems in estimating the fish, wildlife, and recreational value of the Yellowstone River. Dept. of Economics, Montana State University: Bozeman. 38 pp.

Ferguson, C.E. 1969. Microeconomic theory. Richard D. Irwin Inc.: Homewood, IL. 521 pp.

Freeman, A. M., R. Havemen, and A. Kneese. 1973. The economics of environmental policy. John Wiley and Sons, Inc.: New York, NY. 184 pp.

Hartman, L.M. and R.L. Anderson. 1964. Estimating irrigation water values: a regression analysis of farm sales data from northeastern Colorado. Technical Bulletin 81. Agricultural Experiment Station, Colorado State University: Fort Collins. 28 pp.

Hartman, L.M. and D. Seastone. 1970. Water transfers: economic efficiency and alternative institutions. Johns Hopkins University Press: Baltimore, MD. 127 pp.

Hartman, L.M. and N. Whittlesey. 1961. Marginal values of irrigation water. Technical Bulletin 70. Agricultural Experiment Station, Colorado State University: Fort Collins. 28 pp.

Horvath, J.R. 1974. Economic survey of southeastern wildlife and wildlife-oriented recreation. In: Transactions of the thirty-ninth North American wildlife and natural resources conference. Wildlife Management Institute: Washington, D.C.

Knetsch, J.L. and R.K. Davis. 1972. Comparisons of methods for recreation evaluation. In: Economics of the environment, ed. by R. and N. Dorfman. W. W. Norton and Company: New York, NY. 426 pp.

Krall, J.L. 1971 (February). Annual alfalfa for irrigated forage production. Progress report. Circular No. HL-71-1. Montana Agricultural Experiment Station, Montana State University: Bozeman.

Montana Bureau of Mines and Geology. 1977. Directory of mining enterprises for 1976. Montana College of Mineral Science and Technology: Butte.

Montana Coal Council. 1978 (April). Annette Warren. Personal communication.

Montana Department of Agriculture. 1976 (December). U.S. Department of Agriculture Statistical Reporting Service cooperating. Montana agricultural statistics. Vol. XVI: county statistics, 1974 and 1975. Helena. 88 pp.

Montana Department of Community Affairs. 1976 (December). Economic conditions in Montana: a report to the Governor. Research and Information Systems Division: Helena. 35 pp.

Montana Department of Natural Resources and Conservation. 1976. Yellowstone River Basin: draft eis for water reservation applications. Two volumes. Water Resources Division: Helena. 412 pp.

________. 1977 (January). The future of the Yellowstone River. . .? Water Resources Division: Helena. 107 pp.

Montana Energy Advisory Council. 1976 (June). Montana energy position paper: a Montana Energy Advisory Council staff report by T.H. Clack, Jr. Helena. 56 pp.

North Central Power Study Coordinating Committee. 1971. North central power study: report of Phase 1. Volume 1. Bureau of Reclamation: Billings. 80 pp.

Pincock, G. 1969 (February). Assessing impacts of declining water quality on gross value output of agriculture: a case study. Water resources research 5: 1-12.

Rocky Mountain Association of Geologists. 1972. Geologic atlas of the Rocky Mountain Region: United States of America. Denver, CO. 331 pp.

Snyder, J. 1976. The economics of alternative uses of water in the Yellowstone basin. Unpublished M.S. Thesis, Montana State University, Bozeman. 192 pp.

State Conservation Needs Committee. 1970. Montana soil and water conservation needs inventory. Soil Conservation Service, Bozeman. 172 pp.

Stroup, R. and S. Townsend. 1974. Water use and coal development in eastern Montana: water availability and demands. Montana State University Joint Water Resources Research Center: Bozeman.

Thompson, D. 1973. The economics of environmental protection. Winthrop Publishers, Inc.: Cambridge, MA. 278 pp.

U.S. Bureau of Economic Analysis. Unpublished data. Regional economic information system.

U.S. Department of Commerce. 1952. Bureau of the Census. U.S. census of the population: 1950, general characteristics, Montana. P-B26. U.S. Government Printing Office: Washington, D.C.

_________. 1961 Bureau of the Census. U.S. census of the population: 1960, general social and economic characteristics, Montana. PC(1)-28C. U.S. Government Printing Office: Washington, D.C.

_________. 1971. Bureau of the Census. U.S. census of the population: 1970, general social and economic characteristics, Montana. PC(1)-C28. U.S. Government Printing Office: Washington, D.C.

U.S. Department of Agriculture (Soil Conservation Service). 1967 (February). Montana Agricultural Experiment Station cooperating. Soil survey: Treasure County, Montana. Series 1957, No. 22. U.S. Government Printing Office: Washington, D.C. 173 pp. plus maps.

U.S. Department of Agriculture (Soil Conservation Service and Forest Service) and U.S. Department of the Interior (Bureau of Land Management). 1971 (June). Montana Agricultural Experiment Station cooperating. Soil survey: Powder River Area, Montana. U.S. Government Printing Office: Washington, D.C. 99 pp. plus maps.

U.S. Department of Agriculture (Soil Conservation Service) and U.S. Department of the Interior (Bureau of Indian Affairs). 1972 (March). Montana Agricultural Experiment Station cooperating. Soil survey of Yellowstone County, Montana. U.S. Government Printing Office: Washington, D.C. 133 pp. plus maps.

U.S. Department of Agriculture (Soil Conservation Service). 1973. Irrigation guide for Montana. Portland, OR.

_________. 1976 (January). Montana Agricultural Experiment Station cooperating. Soil survey of Dawson County, Montana. U.S. Government Printing Office: Washington, D.C. 72 pp. plus maps.

U.S. Water Resources Council. 1973. Principles and standards for planning water and related land resources. U.S. Government Printing Office: Washington, D.C.

Valantine, V. 1974. Impacts of Colorado River salinity. Journal of the Irrigation and Drainage Division, ASCE. Vol. 100, No. IR4.

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