Pacific Northwest Energy Related
Regional Assessment Program

Potential Impacts of Instream Flow Requirements on Coal Development in the Northern Great Plains

January 1977

Prepared for the U.S. Energy
Research and Development Administration
under contract AT(45-1):1830

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Under Contract EY-76-C-06-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$____; Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.50
026-050	\$5.00
051-075	\$5.50
076-100	\$6.00
101-125	\$6.50
126-150	\$7.00
151-175	\$7.75
176-200	\$8.50
201-225	\$8.75
226-250	\$9.00
251-275	\$10.00
276-300	\$10.25

3 3679 00062 6509

POTENTIAL IMPACTS OF INSTREAM FLOW REQUIREMENTS
ON COAL DEVELOPMENT IN THE NORTHERN GREAT
PLAINS

by
Steven J. Shupe

January 1977

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

SUMMARY

As coal resources are developed in the Northern Great Plains regions, new reservoirs are being considered to meet expanding water demands. The amount of water available for industrial diversion, however, could be limited by regulations that require minimum flow levels to be maintained downstream of the reservoir sites. Computer simulations of potential reservoirs were used to determine to what extent, if any, instream flow requirements might limit the ability of reservoirs to deliver industrial water supplies. Data on instream flow requirements, potential reservoir sites, and historic runoff were input for the Powder River Region of Montana and Wyoming. Results of the simulations compared the maximum amount of water available for industrial diversion with and without requiring instream flow criteria. It was found that the potential impact of instream flow requirements on the water needs associated with coal development is indeed significant.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to those who facilitated the development of this report. David Haisten of the Bureau of Reclamation was extremely helpful in supplying initial data and model input. Bob Anderson of the Montana Department of Natural Resources and Conservation, Clark Judy of the Yellowstone-Tongue APO, and Kit Muller of the Northern Plains Resources Council provided useful information and insight into local issues relating to water resources and coal development. Stuart Brown, Annette Myhres, and John Rupe were invaluable help in preparing and testing the computer model used in the simulations. The editing skills contributed by Sue Gano were also greatly appreciated. And final thanks go to Maurice Warner for providing much pertinent feedback and guidance.

TABLE OF CONTENTS

INTRODUCTION	1
STUDY DESCRIPTION	4
RESULTS OF THE ANALYSES	11
ALTERNATIVE INSTREAM FLOW CRITERIA	16
30-YEAR LOW CRITERIA	16
LEAST-MONTH CRITERIA	18
APPLICATION TO THE MIDDLE FORK RESERVOIR	23
CONCLUSIONS AND RECOMMENDATIONS	27
REFERENCES	28

FIGURES

1	Location of Test Reservoirs	5
2	Arvada Reservoir, Area Capacity Curves	8
3	Simulation of Lower Stateline Reservoir Storage Content at the Start of the Water Year	12
4	Arvada Reservoir	19
5	Lower Stateline Reservoir	20
6	Moorhead Reservoir	21
7	Rockwood Reservoir	22
8	Simulation of Middle Fork Reservoir Storage Content at the Start of the Storage Year	24
9	Shortages in the Middle Fork Reservoir Delivery Commitments.	25

TABLES

1	Runoff Data at the Arvada Reservoir Site Adjusted to the 1970 Depletion Level	7
2	Evaporation Rates	9
3	Reservoir Storage Capacity Data	10
4	Reservoir Simulation Output	11
5	Instream Flow Requirements	14
6	Comparison of Simulation Output: Maximum Continuous Diversion	15
7	30-Year Low Criteria Instream Flow Requirements	17
8	Least-Month Criteria Instream Flow Requirements	18

POTENTIAL IMPACTS OF INSTREAM FLOW REQUIREMENTS ON COAL DEVELOPMENT IN THE NORTHERN GREAT PLAINS

INTRODUCTION

As the United States works to expand its national energy supply base, thick seams of low-sulfur coal become an attractive resource. Consequently, the pressure to develop the coal deposits of the Northern Great Plains has been increasing over the past few years. If fully recovered, these deposits could satisfy a significant portion of America's energy needs for centuries. However, a variety of legal, environmental, and societal issues have arisen to hinder their recovery and to make coal development in the Northern Great Plains a complex matter.

One area in which this complexity is particularly evident is the impact of coal development on water resources. Water is a relatively scarce and certainly valuable commodity in this part of the country. The region's economic strength, as well as its life style, is dependent upon a water supply supporting its agricultural base. Water is also required for domestic use, in recreational activities, and to maintain existing ecosystems. Tying these demands into a legal framework of interstate compacts, native-American water rights, and interbasin regulations creates a complicated situation. Then, when a new set of potential coal-related water demands are added to this system, its complexity transforms into perplexity for the administrators and people of the region.

To date, millions of dollars have been spent for assessing the water resources of the region relative to energy expansion. This research has involved data gathering and synthesis (for example, determining ground-water levels), primary impact analysis (i.e., How might strip mining lower the surrounding ground-water table?) and secondary impact analysis (i.e., How might lowering the water table, and thus causing wells to go dry, affect

cattle grazing?). Secondary impact analyses are the key to providing insight for establishing effective water regulations and allocations. These analyses involve a full examination of the interactions between water use and energy production.

Traditionally, most of the research has been aimed at determining how energy development might influence competing users and, consequently, how it should be regulated. However, consideration must also be given to how alternative water regulations not directly related to energy growth might affect future coal development. One such area of regulation involves the maintenance of minimum streamflow levels, or instream flow requirements.

Instream flow requirements are established to maintain a minimum level of flow in rivers and streams where human activities significantly deplete the natural runoff. The designated minimum flow levels can vary at different points on the same river or change with the time of year. Although their values can relate to such things as navigation and hydropower needs, minimum flow levels generally are established with the aim of protecting the aquatic environment.⁽¹⁾ A variety of methodologies have been formulated by agencies and organizations for establishing these streamflow values. Some employ dissolved oxygen as the guiding parameter; some use a particular fish species; and others consider insect productivity in setting the criteria.⁽²⁾ The lack of a standard method for establishing minimum flow values for ecosystem maintenance has added to the controversy currently surrounding these requirements.

The relative merit of alternative minimum flow criteria or the validity of the requirement concept itself are not discussed here. These are topics that need to be addressed and resolved through further scientific study and analysis. The study described in this paper was formulated to determine if instream flow requirements could have a significant impact on water availability in the Northern Great Plains, thus limiting the level of future coal development. This was accomplished through the application of a reservoir simulation model that estimates the maximum amount of water available on a constant, monthly diversion schedule. Base cases were run on potential reservoirs to determine their maximum industrial diversion values; these were then compared

to simulation results that incorporated minimum flow criteria. Finally this methodology was applied to an actual reservoir proposal to provide a realistic basis for secondary impact analysis.

STUDY DESCRIPTION

The study area selected for analysis was the Powder River Region of southeastern Montana and northeastern Wyoming. Several coal mines and power plants are currently producing in this region, with future expansion very likely. Water is not abundant in this area as rainfall averages only 14 to 16 inches a year. Two rivers, the Powder and the Tongue, drain the majority of the runoff. Each of these rivers experiences considerable seasonal flow variation, with peak flows occurring during late spring and early summer. Also, their total annual flow varies significantly from one year to another.

Reservoirs built on such rivers have great potential benefit in their ability to store seasonal and yearly excesses and then to distribute the water more evenly through time. This benefit is particularly important with respect to the demands of energy facilities, since coal gasification plants and power plants generally require a constant water supply from month to month. The question that then arises is: to what extent would regulating a reservoir's discharge to maintain instream flow requirements affect its ability to deliver a constant water supply to energy facilities?

Four potential reservoirs (Figure 1) were selected for initial analysis of this question. Two are on the Tongue River (Rockwood and Lower Stateline Reservoirs) and two are on the Powder (Arvada and Moorhead Reservoirs). These reservoirs were selected because of their proximity to coal deposits and because they had been previously identified in a major regional coal study.⁽³⁾ The data were applied to a single-reservoir simulation model on a PDP-11/45 computer. The model calculates a monthly water balance for the reservoir, computing the amount of water in storage at the end of each month. It accounts for inflow as reflected in adjusted historic runoff data, and for outflow through evaporation, diversions for energy facilities, controlled discharge for maintaining instream flow requirements, and spill. The following sections explain these parameters as used in the simulation.

TEST RESERVOIRS

- 1 ROCKWOOD
- 2 LOWER STATELINE
- 3 ARVADA
- 4 MOORHEAD

FIGURE 1. Location of Test Reservoirs

Inflow: Historic Runoff Data. The amount of water available for storage at the reservoir was based on historic runoff data collected at gaging stations of the U.S. Geological Survey, near or at the reservoir sites. The Task Force on Depletions of the Missouri River Basin Comprehensive Framework Study and the Bureau of Reclamation adjusted these data to reflect the 1970 level of development. As an example of this adjustment process, consider a situation where a total of 10,000 acre-ft of water was recorded as flowing by a gaging station during May 1950. If between 1950 and 1970 an additional 1,000 acre-ft of May water demand was generated upstream of this station, the adjusted level of runoff for this particular month would be 9,000 acre-ft (10,000 minus 1,000). Table 1 provides an example of this input data.

Runoff data were available for water years 1939 through 1970, thus reservoir operation was simulated for this 32-year period. Assuming no significant long-term climatic change, this simulation period should be representative of future time spans as well, particularly since the historic runoff input data had been adjusted to reflect the 1970 level of water withdrawal. Therefore, results of the simulation concerning water shortages and maximum annual diversions should be valid when applied to future time periods, such as from 1979 through the year 2000.

Outflow: Evaporation. In each month of the simulation the amount of water lost from the reservoir because of evaporation is calculated. The input parameters for these calculations were the evaporation rates in Table 2 and area-capacity curves for each reservoir. Figure 2 shows the area-capacity curve for Arvada Reservoir. To illustrate the use of these data, the following example is given.

In a particular simulation, Arvada Reservoir had 900,000 acre-ft of water in storage at the beginning of June 1956. From Figure 2 the surface

TABLE 1. Runoff Data at the Arvada Reservoir Site Adjusted to the 1970 Depletion Level

YEAR	OCT	NOV	DEC	JAN	FEB	UNITS 1000 AF		MAY	JUN	JUL	AUG	SEP	TOTAL
						MAR	APR						
1939	2.0	5.0	8.5	7.9	4.5	29.8	10.4	21.2	20.8	.5	0.0	.3	110.9
1940	4.9	4.6	7.0	3.8	9.2	18.5	19.5	13.4	20.8	6.3	0.0	1.6	109.6
1941	25.5	4.1	5.8	5.4	7.1	11.4	64.6	79.2	24.2	49.7	52.8	13.6	343.4
1942	16.9	13.4	11.5	5.0	7.2	16.4	29.9	44.6	15.7	3.9	8.4	.6	173.5
1943	6.4	7.6	5.6	6.7	9.4	39.0	41.4	37.8	55.6	10.6	.2	.3	220.6
1944	3.2	5.2	4.3	2.6	3.8	9.2	33.2	97.1	91.9	23.7	3.5	.2	277.9
1945	6.5	7.2	6.9	6.0	8.9	31.9	38.2	35.6	62.3	24.3	10.9	6.7	245.4
1946	9.5	10.5	6.1	9.1	12.5	18.9	23.3	27.0	33.9	21.5	.2	9.4	181.9
1947	8.9	9.5	7.6	5.5	10.2	57.7	18.6	84.3	43.8	20.0	.3	1.1	267.5
1948	5.3	8.6	6.6	5.0	12.8	52.4	13.7	30.5	75.7	23.7	4.4	3.1	241.8
1949	8.0	7.6	5.2	3.6	4.3	53.5	18.3	31.8	37.6	7.1	0.0	.4	177.4
1950	5.6	5.3	1.4	1.8	3.5	13.0	21.4	52.0	17.4	3.2	.4	.3	125.3
1951	6.3	6.5	2.4	3.9	4.8	14.1	8.7	16.9	3.6	.8	4.0	18.0	90.0
1952	7.2	6.2	4.6	2.2	5.8	14.6	21.2	71.9	13.4	10.3	2.2	.2	159.8
1953	1.6	3.9	3.0	4.9	6.6	17.8	9.4	8.1	35.4	3.5	13.5	0.0	107.7
1954	.2	2.9	3.5	3.4	11.9	13.7	15.1	14.3	0.0	3.8	8.2	0.0	77.0
1955	.5	3.6	2.1	2.2	3.6	43.6	29.8	29.0	41.9	8.6	11.7	.6	177.2
1956	1.5	2.4	12.5	5.8	7.2	36.9	14.3	20.2	14.1	5.5	3.9	.1	124.4
1957	0.0	2.2	4.4	3.5	2.3	13.4	13.1	28.4	63.8	14.1	2.4	3.2	150.8
1958	6.0	7.9	6.8	5.2	4.9	12.2	15.4	28.7	21.0	27.8	3.9	0.0	139.8
1959	1.2	5.0	4.1	3.7	3.9	21.6	10.1	28.6	23.2	11.7	0.0	.3	113.4
1960	2.2	2.4	4.2	2.8	5.4	36.8	13.8	6.7	4.6	2.1	1.2	0.0	82.2
1961	0.0	1.7	1.8	2.3	3.2	8.5	15.1	14.6	4.6	3.1	.7	.8	46.4
1962	9.7	6.0	2.4	2.0	25.9	15.3	24.3	124.0	196.7	48.9	14.6	11.5	481.3
1963	23.4	10.3	8.7	7.3	15.1	13.9	13.7	33.9	53.7	10.6	1.6	10.8	203.0
1964	4.0	6.6	4.8	5.5	4.7	12.8	27.3	38.9	102.9	19.9	1.4	.1	228.9
1965	2.7	6.5	5.9	8.8	13.7	29.4	40.4	47.2	65.1	28.6	9.4	5.4	263.1
1966	8.7	7.9	5.1	4.5	5.9	21.0	16.0	18.0	6.9	1.9	0.0	7.1	103.0
1967	3.0	6.2	3.7	4.6	6.8	13.0	10.6	30.8	160.9	47.8	5.5	7.6	300.5
1968	8.5	9.2	4.7	4.6	7.9	21.8	13.6	45.0	127.6	20.8	12.1	11.4	287.2
1969	10.5	8.7	7.0	8.7	7.3	19.2	15.0	18.7	15.9	10.3	.3	0.0	121.6
1970	3.3	6.6	4.5	5.6	9.4	16.8	12.6	68.0	50.3	12.2	.5	.3	190.1
AVE (1919-1970)	10.9	6.7	4.0	3.4	6.1	26.5	28.8	48.2	49.8	23.1	9.7	11.3	227.9

FIGURE 2. Arvada Reservoir, Area-Capacity Curves

area is roughly 16,000 acres. Table 2 shows that during the average month of June, 0.34 ft evaporates per unit area, or 0.34 acre-ft per acre of water surface. Therefore, the model computations subtract 5,440 acre-ft (0.34 ft times 16,000 acres) from the water balance during the month of June 1956 to account for evaporative loss.

TABLE 2. Evaporation Rates

<u>Month</u>	<u>Feet Evaporated per Month per Unit of Water Surface Area</u>
January	0.07
February	0.09
March	0.11
April	0.13
May	0.21
June	0.32
July	0.54
August	0.48
September	0.28
October	0.26
November	0.11
December	0.08

Outflow: Industrial Diversions. The user of the model inputs the value for industrial diversion that is to be subtracted from the water balance on a monthly basis. If the value exceeds the delivery capacity of the reservoir through time, storage drops to minimum capacity and shortages are registered in the model output. To determine the maximum possible diversion, iterations are made on this value to determine where the minimum capacity is approached or reached without any shortages resulting.

Outflow: Instream Flow Requirements. Instream flow requirements, when included in the water balance, are handled by using a control point immediately

downstream of the reservoir. A dummy diversion schedule equal to the minimum flow values for each month is input at this control point. This causes the reservoir to release the exact amount of water needed to supply the dummy diversion schedule, thus simulating maintenance of downstream minimum flow levels.

Outflow: Spill. Spill occurs when the reservoir is filled to maximum capacity and the rate of runoff inflow exceeds the rate of outflow through evaporation, industrial diversions, and controlled releases for instream flow maintenance. Spill occurred most frequently in the simulations during the spring and early summer.

Table 3 shows the storage capacity data used for the reservoirs in the study.⁽³⁾ Maximum capacity represents the maximum volume of water that a reservoir can store. Minimum content is generally defined as dead storage, or the volume of water that lies below the lowest outlet. However, its value sometimes reflects the effect that sediment deposits will have on eventual reservoir capacity. In rivers that carry a large amount of sediment, such as the Powder River, minimum content values are adjusted upward as a function of sediment load to account for decreasing storage capacity through time. Active storage, then, is the difference between maximum and minimum content, and represents the amount of storage space available for regulating the capture and release of water over the useful life of the reservoir.

TABLE 3. Reservoir Storage Capacity Data
(in Acre-ft)

<u>Reservoir</u>	<u>Maximum Capacity</u>	<u>Minimum Content</u>	<u>Active Storage</u>
Arvada	1,255,000	335,000	92,000
Lower Stateline	320,000	4,000	316,000
Moorhead	1,150,000	875,000	275,000
Rockwood	113,000	15,000	98,000

Source: NGPRP, 1974

RESULTS OF THE ANALYSES

For each computer run, it was assumed that the reservoir was filled to maximum capacity at the beginning of water year 1939, then regulated so that it never dropped below minimum content over the next 32 years. Using these operational criteria, the maximum amount of water that could be withdrawn on a regular monthly basis was determined for each reservoir. To provide a basis for comparison, these simulations were first run without considering instream flow requirements.

Table 4 summarizes the key output of these initial runs in which instream flow requirements were not considered. The Lower Stateline Reservoir was shown to have the greatest potential for supplying the water demands of energy facilities. It is capable of delivering 19,900 acre-ft each month, for an annual total of 238,800 acre-ft. Figure 3 is included to illustrate how the content of this reservoir fluctuated throughout the simulation. The critical month in which minimum content was approached at the Lower Stateline site occurred in March 1962 following the extremely dry years of 1960 and 1961. Operational curves for the other three reservoir simulations follow similar patterns.

TABLE 4. Reservoir Simulation Output

<u>Reservoir</u>	<u>Maximum Continuous Diversion (Acre-ft per Year)</u>	<u>Minimum Active Storage Surplus (Acre-ft)</u>	<u>Critical Month</u>
Arvada	141,600	4,300	January, 1962
Lower Stateline	238,800	7,200	March, 1962
Moorhead	133,200	2,700	January, 1962
Rockwood	104,400	5,000	March, 1962

FIGURE 3. Simulation of Lower Stateline Reservoir Storage Content at the Start of the Water Year (with a monthly diversion of 19,900 acre-ft)

It can be seen that a significant volume of water is physically available for supplying the demands of coal-related facilities. Future coal gasification plants built in the Northern Great Plains are expected to each have consumptive water requirements ranging from 7,000 to 15,000 acre-ft per year. Individual annual water demands for proposed power plants and slurry pipelines in this region generally fall in the 10,000 to 20,000 acre-ft range. Since each of the test reservoirs was shown to be capable of delivering several thousand acre-ft of water per month on a continuous basis, the reservoirs would be able to meet the needs of a number of these facilities. This remains true even after applying to the maximum diversion an error factor of 20% that could result from the assumptions and simplifications made in the data base and computer model. Note, however, that these maximum diversion estimates do not reflect any of the legal or institutional aspects that might be involved. The simulations deal only with physical availability of water at these sites, disregarding the role that interstate regulations and existing water rights might play in the supply picture. Also, these values were computed independently of one another in a one-reservoir simulation. Thus, the maximum diversion values for reservoirs on the same river system are not additive.

The next step in the analysis was to determine the volume of water available for diversion while maintaining minimum flow immediately downstream of the reservoir. Table 5 summarizes the instream flow requirement values provided by the Bureau of Sports Fisheries and Wildlife (BSFW). It should be emphasized that the purpose of this study was not to support nor refute these particular instream flow values. They simply provide a convenient and realistic basis for running the comparative simulations.

Table 6 shows the results of the new computer runs compared to the earlier ones that did not incorporate instream flow requirements. It was expected that requiring the reservoir to continuously release a portion of its storage content would somewhat diminish the amount available for monthly diversion. However, the extent to which this diversion value was observed to decrease was surprisingly significant. Even at the site displaying the smallest percentage drop (Arvada Reservoir), the decrease in the maximum

TABLE 5. Instream Flow Requirements
(Cubic Feet per Second)

<u>Downstream of:</u>	<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>
Arvada Reservoir	55	55	200	200	270	270	45	12	12	50	50
Lower Stateline Reservoir	160	160	200	250	500	500	360	100	100	200	200
Moorhead Reservoir	100	100	300	300	450	400	120	30	30	100	100
Rockwood Reservoir	50	50	50	75	200	200	175	125	105	95	60

Source: NGPRP, 1974

available diversion could mean that the reservoir could support far fewer gasification and power plants. Previously, simulations showed Arvada Reservoir capable of delivering 141,600 acre-ft of water each year. But by requiring reservoir discharge to maintain downstream flow, only 66,000 acre-ft/year are available. The greatest loss in available water occurred in the simulation of Lower Stateline Reservoir where the maximum annual diversion dropped by 171,600 acre-ft following application of minimum flow criteria. The largest percentage decrease was experienced in the Moorhead Reservoir simulation where the maximum diversion of 133,200 acre-ft dropped by 86% to 18,000 acre-ft/year. It is apparent through the magnitude of these changes that instream flow requirements indeed have the potential for significant impact on future coal development in the Northern Great Plains.

TABLE 6. Comparison of Simulation Output:
Maximum Continuous Diversion
(Acre-ft per Year)

<u>Reservoir</u>	<u>Without Instream Flow Requirements</u>	<u>With Instream Flow Requirements</u>	<u>Percentage Decrease</u>
Arvada	141,600	66,000	53%
Lower Stateline	238,800	67,200	72%
Moorhead	133,200	18,000	86%
Rockwood	104,400	31,200	70%

ALTERNATIVE INSTREAM FLOW CRITERIA

If instream flow requirements may indeed constrain energy development, the magnitude and timing of any requirements formalized into new laws become critical. The sensitivity of the simulation to different instream flow requirement values was therefore examined. To provide additional utility to this process, the values used in the testing were chosen to address issues that might arise in the instream flow requirement controversy. Two separate logics were followed to provide alternative minimum flow values for use in testing. The first is called the 30-Year Low Criteria and the second is the Least-Month Criteria. These criteria were formulated only for the purposes stated above and are not presented here as being scientifically valid methodologies for establishing instream flow requirements.

30-YEAR LOW CRITERIA

Over a particular time span, critical years and months will confront the ecosystem of a river due to reduced runoff. One year out of the time period will be drier than all the other years. Also, each of the 12 months will have a particular low flow value experienced in the time span. This fact is the basis for the argument that reservoirs should not be required to discharge water at a rate greater than the minimum flow value that will periodically confront the river environment through natural runoff. This logic is the basis for the 30-Year Low Criteria concept.

In the 30-Year Low Criteria, the minimum flow level (greater than zero) experienced respectively in each month over the 30-year period are taken from historical runoff data and are input as the instream flow requirements. The numerals in bold print in Table 1 represent these values at the Arvada Reservoir site using the time frame from 1941 through 1970. A 30-year period was selected for use only because it was consistent with the available data base; any other period of record would suffice just as well for testing purposes. Table 7 summarizes the instream flow requirement values used in the 30-Year Low simulations for each of the four reservoirs.

TABLE 7. 30-Year Low Criteria Instream Flow Requirements
(1000 Acre-ft per Month)*

	<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov</u>	<u>Dec.</u>
<u>Downstream of:</u>												
Arvada Reservoir	1.8	3.2	8.5	8.7	6.7	3.6	0.8	0.2	0.1	0.2	1.7	1.4
Lower Stateline Reservoir	5.6	5.9	7.2	7.5	30.3	20.0	3.8	1.7	1.8	6.8	7.4	5.6
Moorhead Reservoir	1.7	5.1	16.7	5.9	3.9	4.7	1.3	0.4	0.1	1.0	5.4	4.5
Rockwood Reservoir	2.1	1.8	2.2	2.9	15.3	13.5	6.2	4.2	3.5	2.9	2.3	2.3

* 1000 acre-ft per month is roughly equivalent to a constant flow of 16.6 cfs.

LEAST-MONTH CRITERIA

The instream flow requirements of both the BSFW and the 30-Year Low Criteria exhibit large monthly variations. Flow requirements in the spring are generally several times greater than those of the drier months. The Least-Month Criteria was formulated to test the impact of eliminating this variance and holding the requirement constant throughout the year.

The requirement value selected for testing was chosen to be equal to average runoff of the month of least flow. As seen in Table 1, this month is January for the Arvada site, with the average monthly runoff equal to 3,400 acre-ft. Therefore, the instream flow requirement value for the Arvada simulation would be 3,400 acre-ft per month. The minimum flow values used for the other reservoirs in the Least-Month Criteria simulations are found in Table 8.

TABLE 8. Least-Month Criteria Instream Flow Requirements

	<u>Requirement Value</u> <u>(1000 Acre-ft per Month)</u>	<u>Month of Least</u> <u>Average Flow</u>
<u>Downstream of:</u>		
Arvada Reservoir	3.4	January
Lower Stateline Reservoir	6.3	August
Moorhead Reservoir	7.6	September
Rockwood Reservoir	2.8	February

Figures 4 through 7 show the results of the simulations testing the alternative instream flow requirements. Even the maintenance of these two new criteria--criteria which would be considered minimal at best from an ecological standpoint--result in a significant decrease in the amount of water available for industrial supply. Although they are less demanding than the BSFW requirements, these criteria still result in a 30-60% loss of water relative to the maximum possible diversion.

Instream Flow Requirements of Alternative Criteria

Water Available for Industrial Diversion in Thousands of Acre-ft Per Year

FIGURE 4. Arvada Reservoir

Instream Flow Requirements of Alternative Criteria

Water Available for Industrial Use in Thousands of Acre-ft Per Year

FIGURE 5. Lower Stateline Reservoir

Instream Flow Requirements of Alternative Criteria

Water Available for Industrial Use in Thousands of Acre-ft Per Year

FIGURE 6. Moorhead Reservoir

Instream Flow Requirements of Alternative Criteria

Water Available for Industrial Use in Thousands of Acre-ft Per Year

FIGURE 7. Rockwood Reservoir

APPLICATION TO THE MIDDLE FORK RESERVOIR

The next step taken in the study was to apply the analysis to a current project. An opportunity for such an application was found in the Middle Fork Powder River Reservoir proposed for completion in 1979. The draft environmental impact statement on this project released by the Bureau of Land Management (BLM) in early 1976 provided the necessary information for the analysis.⁽⁴⁾ The Middle Fork Reservoir, located in Figure 1, is proposed to operate as a storage reservoir for seasonal irrigation and a constant industrial supply. Allocated to it are annual water rights exceeding 40,000 acre-ft of which 25,000 acre-ft/yr are controlled by companies involved with energy production. It was assumed in the BLM study that these companies will use their water rights to support operation of two coal gasification plants.

The following analysis of instream flow requirement impacts was run using this two-gasification plant assumption. In this study of water diversions for energy facilities, irrigation demands were not considered. However, if shortages are found in the industrial diversion/instream flow analysis, the associated problems would be compounded by irrigation withdrawals.

The initial computer simulation run without instream flow criteria indicated that the 25,000 acre-ft/yr industrial demand could easily be met throughout the 32-year simulation period. In fact, the model showed the Middle Fork Reservoir to be capable of delivering 43,000 acre-ft annually on a constant withdrawal basis. Figure 8 shows the operational curve for this maximum diversion simulation.

Next, the BSWF instream flow requirements were input. These flow values for the stretch downstream of the Middle Fork Reservoir are generally less than those for the four other reservoir sites previously analyzed. A minimum flow of 30 cubic feet per second (cfs) was set for the months of July through January, 40 cfs from February through April, and 60 cfs in May and June.⁽³⁾ However, these flow requirements in conjunction with a 25,000 acre-ft annual diversion were found to greatly exceed the supply capacity of the reservoir. Figure 9 shows the shortages that resulted in

FIGURE 8. Simulation of Middle Fork Reservoir Storage Content at the Start of the Storage Year (with a monthly diversion of 2,100 acre-ft)

FIGURE 9. Shortages in the Middle Fork Reservoir Delivery Commitments (commitments to industrial needs and instream flow requirements)

the simulation. In 1941 and in the years from 1952 through 1962 the reservoir could not supply both the industrial demands and the instream flow requirements. In many of the years, these computed shortages were quite severe with the reservoir operating at a near empty level. It was not until May 1968 of the simulation that the reservoir filled again to full storage capacity of 52,000 acre-ft. Further computer runs showed that in order to prevent these shortages from occurring, industrial diversions would have to be held to a maximum of 16,000 acre-ft per year. This is significantly less than the 25,000 acre-ft/yr allocated.

CONCLUSIONS AND RECOMMENDATIONS

The Middle Fork Reservoir analysis supports the previously stated conclusion that instream flow requirements could have a limiting effect upon the level of coal development in the Northern Great Plains. It is important that this point be taken into consideration in formulating water and energy regulations. Those responsible for establishing minimum streamflow criteria must realize the far-reaching implications of their actions. Standards set arbitrarily high to compensate for a lack of knowledge will be difficult to justify when weighed against the industrial and agricultural tradeoffs. Conversely, this analysis has also brought out the point that care must be taken to avoid adverse environmental impacts potentially caused by large industrial diversions. Allocating water rights to reservoir projects today without considering future instream flow needs could result in severe ecological stresses, and perhaps, lengthy litigation.

These points emphasize the fact that a firm understanding of the aquatic environment must be a prerequisite to establishing instream flow criteria and water allocations. This would include a thorough knowledge of the interactions within the existing ecosystem, and of how flow depletions will affect these processes. Such knowledge could prevent unnecessary limits to expanding energy production and still provide protection to the environment. Even an abundance of scientific fact, however, will not keep final decisions totally free of personal interests and values. Subjectivity is intrinsic to the issues revolving around environmental quality control and economic growth. But knowledge forms the foundation on which effective compromise and fair decisions can be reached. And certainly, a great demand for both compromise and proper decision-making exists today in the coal regions of the Northern Great Plains.

REFERENCES

1. P. L. Beckett, and B. L. Lamb, Establishing Instream Flows; Analysis of the Policy-Making Process in Pacific Northwest. Final Technical Report, Project No. A-077-WASH. Prepared for Office of Water Resources and Technology, U.S. Dept. of Interior, 77 pp, 1976.
2. A. J. Silverman and L. Parrish, Assessment and Implementation of In-Stream Value Studies, Prepared for the Environmental Protection Agency by Montana University, 158 pp, 1974.
3. Northern Great Plains Resources Program (NGPRP), Water Work Group Report, Lead agency: U.S. Bureau of Reclamation, 71 pp with Appendixes, 1974.
4. Bureau of Land Management, Draft, Environmental Impact Statement for the Proposed Reservoir on the Middle Fork of Powder River, 648 pp, 1976.

DISTRIBUTION

No. of
Copies

No. of
Copies

No. of
Copies

OFFSITE

A. A. Churm
ERDA Chicago Patent Group
9800 South Cass Avenue
Argonne, IL 60439

D. S. Ballantine
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

R. P. Blaunstein
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

W. W. Burr
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

R. L. Butenhoff
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

C. E. Carter
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

C. W. Edington
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

W. O. Forster
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

G. J. Rotariu
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

D. H. Slade
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

J. Swinebroad
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

W. H. Weyzen
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

R. W. Wood
ERDA Division of Biomedical
and Environmental Research
Washington, DC 20545

W. E. Mott
ERDA Division of Environmental
Control Technology
Washington, DC 20545

M. Reilly
ERDA Division of Fossil Energy
Washington, DC 20545

H. L. Hollister
Deputy Assistant Administrator
for Environment and Safety
Washington, DC 20545

J. L. Liverman
ERDA Assistant Administrator
for Environment and Safety
Washington, DC 20545

J. Coleman
ERDA Office of Environment
Policy Analysis
Washington, DC 20545

B. W. Wachholz
ERDA Office of Environmental
Policy Analysis
Washington, DC 20545

E. S. Burton
ERDA Office of Planning,
Analysis and Evaluation
Washington, DC 20545

N. F. Barr
ERDA Division of Technology
Overview
Washington, DC 20545

W. G. Belter
ERDA Division of Technology
Overview
Washington, DC 20545

R. D. Cooper
ERDA Division of Technology
Overview
Washington, DC 20545

P. H. Gearhart
ERDA Division of Technology
Overview
Washington, DC 20545

R. R. Newton
ERDA Division of Technology
Overview
Washington, DC 20545

H. R. Wasson
ERDA Division of Technology
Overview
Washington, DC 20545

A. B. Joseph
Office of Nuclear Regulatory
Research
U.S. Nuclear Regulatory
Commission
Washington, DC 20555

F. G. Lowman
Office of Nuclear Regulatory
Research
U.S. Nuclear Regulatory
Commission
Washington, DC 20555

E. E. Held
Office of Standards Development
U.S. Nuclear Regulatory
Commission
Washington, DC 20555

27 ERDA Technical Information
Center

J. B. Robertson
Federal Energy Administration
Room 1992
Federal Building
915 Second Avenue
Seattle, WA 98174

L. E. Coate
U.S. Environmental Protection
Agency, Region X
Seattle, WA 98101

E. Croke
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

L. J. Hoover
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

R. Meier
Brookhaven National Laboratory
Upton, NY 11973

P. Palmedo
Brookhaven National Laboratory
Upton, NY 11973

W. Siri
University of California - LBL
Lawrence Berkeley Laboratory
Berkeley, CA 94720

No. of
Copies

W. Robison
University of California - LLL
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

E. Hammil
Los Alamos Scientific
Laboratory
P.O. Box 1663
Los Alamos, NM 87545

R. Malenfant
Los Alamos Scientific Laboratory
University of California
P.O. Box 1663
Los Alamos, NM 87545

S. J. Auerbach
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge TN 37830

W. Fulkerson
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

Col. Charles A. Debelius
District Engineer
Alaska District
Corps of Engineers
Anchorage, AK 99510

R. Estess
State Clearinghouse
Division of Policy Development
and Planning
Office of the Governor
Pouch AD
Juneau, AK 99801

J. Lowell Jensen
Public Utilities Commission
1100 MacKay Building
338 Denali Street
Anchorage, AK 99501

W. C. McConkey, Director
Division of Energy and
Power Development
Department of Commerce and
Economic Development
MacKay Building
338 Denali Street
Anchorage, AK 99501

G. Martin
Department of Natural Resources
11th Floor, State Office Bldg.
Pouch M
Juneau, AK 99811

No. of
Copies

M. F. Thomas
Regional Engineer
Bureau of Power
555 Battery Street, Room 415
San Francisco, CA 94111

D. Guss
Bureau of State Planning and
Community Affairs
State House
Boise, ID 83720

K. D. Smith
Public Utilities Commission
472 W. Washington Street
Boise, ID 83720

R. J. Vissia
Regional Director
Pacific Northwest Region
(Columbia River Basin)
Federal Building,
U.S. Court House
550 W. Fort Street
Boise, ID 83724

R. N. Wise
Bureau of State Planning
and Community Affairs
State House
Boise, ID 83720

R. Hulme
State Clearinghouse
Office of Budget and
Program Planning
232 Capitol Building
Helena, MT 59601

M. O. Mortensen
Energy Advisory Council
c/o Lt. Governor's Office
Capitol Building
Helena, MT 59601

J. Nybo
Energy Advisory Council
c/o Lt. Governor's Office
Capitol Building
Helena, MT 59601

W. Opitz
Public Service Commission
1227 11th Avenue
Helena, MT 59601

B. Roberts
State Land Use Planning Bureau
Department of Community Affairs
Capitol Post Office
Helena, MT 59601

No. of
Copies

A. C. Tsao
Energy Planning Division
Department of Natural Resources
and Conservation
32 South Ewing
Helena, MT 59601

H. Brauner
Conservation and Development
Commission
1175 Court Street N.E.
Salem, OR 97301

Charles Davis
Public Utility Commissioner
Labor and Industries Bldg.
Salem, OR 97310

Col. C. D. Gilkey
District Engineer
Portland District
Corps of Engineers
2850 S.E. 82nd Ave. (97266)
P.O. Box 2946
Portland, OR 97208

Maj. Gen. W. E. Peel
Division Engineer
North Pacific Division
Corps of Engineers
210 Custom House
Portland, OR 97209

F. D. Miller
Oregon Department of Energy
528 Cottage, N.E.
Salem, OR 97310

Dr. K. Woods
Energy Facility Siting Division
Department of Energy
528 Cottage, N.E.
Salem, OR 97310

W. Young
Intergovernmental Relations
Division
Office of the Governor
240 Cottage Street, S.E.
Salem, OR 97310

F. S. Adair
Washington State Department of
Commerce and Economic
Development
Olympia, WA 98504

Col. N. P. Conover
District Engineer
Walla Walla District
Corps of Engineers
Bldg. 602, City-County Airport
Walla Walla, WA 99362

No. of
Copies

Col. Raymond J. Elneigl
District Engineer
Seattle District
Corps of Engineers
1519 Alaskan Way South
Seattle, WA 98134

N. Lewis
Assistant Director
Office of Program Planning
and Fiscal Management
State Planning Division
House Office Building
Olympia, WA 98504

R. Polson
Energy Facilities Site
Evaluation Council
820 East Fifth Avenue
Olympia, WA 98504

E. T. Shaw
Utilities and Transportation
Commission
Highways-Licenses Building
Olympia, WA 98504

E. Adams, Director
Idaho Energy Office
State House
Boise, ID 83720

K. Sherman
Washington State Energy Office
1000 Cherry
Olympia, WA 98504

M. Walsh
Department of Ecology
State of Washington
Olympia, WA 98504

A. J. Eliopoulos
Public Service Commission
Supreme Court Building
Cheyenne, WY 82002

D. B. Freudenthal
State Planning Coordinator's
Office
Office of the Governor
State Capitol
Cheyenne, WY 82002

D. Hoffman
Mineral Development Division
Department of Economic Planning
and Development
720 West 18th Street
Cheyenne, WY 82002

F. C. Blood
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

No. of
Copies

R. S. Gens
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

J. Hoozen
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

J. C. Loosli
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

C. M. Moore
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

M. Katz
Northwest Energy Policy Project
1096 Lloyd Building
700 N.E. Multnomah Street
Portland, OR 97232

R. Lewis
Northwest Energy Policy Project
1096 Lloyd Building
700 N.E. Multnomah Street
Portland, OR 97232

W. E. Bruner
Pacific Northwest Regional
Commission
1205 Washington
Vancouver, WA 98660

D. J. Lane
Pacific Northwest River Basins
Commission
1 Columbia River
P.O. Box 908
Vancouver, WA 98660

Dr. O. Osborne
Oregon State University
Electrical Engineering
Department
Corvallis, OR 97331

Dr. R. Wensink
Oregon State University
Agricultural Engineering
Department
Corvallis, OR 97331

Dr. J. Jaksch
Corvallis Environmental
Research Laboratory
Corvallis Environmental
Protection Agency
Corvallis, OR 97331

No. of
Copies

J. Brar
Washington State University
Pullman, WA 99163

G. Hinman
Washington State University
Pullman, WA 99163

R. T. Miller
Vice President
Engineering and Gas Control
Northwest Natural Gas Company
123 N.W. Flanders Street
Portland, OR 97209

H. S. Johnson
Portland General Electric Co.
621 S.W. Alder Street
Portland, OR 97205

G. A. Perrault
Portland General Electric Co.
621 S.W. Alder Street
Portland, OR 97205

C. L. Sauvie
Portland General Electric Co.
621 S.W. Alder Street
Portland, OR 97205

J. L. Williams
Portland General Electric Co.
621 S.W. Alder Street
Portland, OR 97205

R. A. Duncan
Coordination Engineer
Northwest Power Pool
920 S.W. 6th Ave., Rm. 1210
Portland, OR 97204

H. Kosmata
Washington Public Power Supply
System
3000 George Washington Way
Richland, WA 99352

D. Renberger
Washington Public Power Supply
System
3000 George Washington Way
Richland, WA 99352

R. Tillson
Washington Public Power Supply
System
3000 George Washington Way
Richland, WA 99352

R. Woodruff
Washington Public Power Supply
System
3000 George Washington Way
Richland, WA 99352

No. of
Copies

D. N. Morris
The Rand Corporation
1700 Main Street
Santa Monica, CA 90406

J. W. Ellis
Puget Sound Power and
Light Company
Puget Power Building
Bellevue, WA 98009

L. E. Hall
Puget Sound Power and
Light Company
Puget Power Building
Bellevue, WA 98009

B. C. Thomas
Puget Sound Power and
Light Company
Puget Power Building
Bellevue, WA 98009

T. E. Browne
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

R. Crow
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

M. Greenburger
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

L. Henning
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

H. A. Kornberg
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

M. Searle
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

No. of
Copies

S. Boris
Teknekron Corp.
2118 Milvia Street
Berkeley, CA 94704

J. W. LaFond
City of Seattle
Department of Lighting
1015 Third Avenue
Seattle, WA 98104

R. Sheehan
City of Seattle
Department of Lighting
1015 Third Avenue
Seattle, WA 98104

J. McFadden
Energy Inc.
Box 736
Idaho Falls, ID 83401

K. Blackburn
Old West Regional Commission
Fratt Building, Suite 306A
Billings, MT 59101

G. Culp
Culp, Dwyer, Guterson, and
Grader
Hoge Building
Second and Cherry
Seattle, WA 98104

B. Goldhammer
Loyde Building
700 NE Multnomah
Portland, OR 97232

H. C. Elmore
Pacific Northwest Utilities
Conference Committee
P.O. Box 1231
Wenatchee, WA 98801

D. J. Lewis
Public Service Building
920 S.W. Sixth
Portland, OR 97204

R. A. Hofacker
Montana Power Company
40 East Broadway
Butte, MT 59701

R. H. Bendio
Idaho Power Company
P.O. Box 70
Boise, ID 83721

H. W. Harding
Washington Water Power Company
P.O. Box 3727
Spokane, WA 99220

No. of
Copies

H. G. Curtis
Public Power Council
P.O. Box 1307
Vancouver, WA 98660

Scott Alstrom
Western States Water Council
220 South Second East, Suite 200
Salt Lake City, UT 84111

J. T. Stiles
Pacific Power and Light
Portland, OR 97204

W. Rogers, Jr.
Western Interstate Nuclear Board
P.O. Box 15038
Lakewood, CO 80215

L. Harris
Western Aluminum Producers
Association
P.O. Box 8484
Portland, OR 97207

W. L. Guy
Western Governors' Regional
Energy Policy Office
4730 Oakland St.
Denver, CO 80239

K. Muller
Northern Plains Resource Council
418 Stapleton Building
Billings, MT 59101

J. Binanado
Regional Planner
Bureau of Land Management
P.O. Box 30157
Billings, MT 59107

W. Tomlinson
Environmental Library
Rm 208A Natural Sciences
University of Montana
Missoula, MT 59801

R. Doell
U.S. Geological Survey
354 Middlefield Road
Menlo Park, CA 94025

Battelle-Northwest
Human Affairs Research Center (HARC)

M. G. Curry
M. Green
J. A. Hebert
S. M. Nealey
M. Mertaugh
D. J. Merwin
M. E. Olsen
R. E. Schuller

No. of
Copies

ONSITE

ERDA Richland Operations Office

R. W. Gottschalk
G. L. Liffick
R. H. Lindsey

70 Battelle-Northwest

W. J. Bair
S. M. Brown
J. B. Burnham (10)
D. B. Cearlock
J. W. Currie
A. E. Davis
D. W. Dragnich
L. E. Erickson
D. W. Fraley
T. J. Foley
J. C. Fox
T. P. Harrington
E. R. Hill
J. J. Jacobsen
T. P. Kula
A. R. Olson
S. Marks
W. A. Reardon
D. S. Renne
W. H. Rickard
R. H. Sauer
S. J. Shupe (10)
J. A. Strand
W. H. Swift
W. L. Templeton
D. W. Uresk
B. E. Vaughan
M. L. Warner
G. L. Wilfert
Economics Library (20)
Technical Information Files (3)
Technical Publications