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RESERVOIR ECOSYSTEMS AND WESTERN COAL DEVELOPMENT IN THE UPPER MISSOURI RIVER

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RESERVOIR ECOSYSTEMS AND WESTERN COAL DEVELOPMENT IN THE UPPER MISSOURI RIVER

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ABSTRACT

This report summarizes the results of a literature and field survey conducted in 1976 to develop a data base for evaluating the impacts of predicted energy developments in the Northern Great Plains on the aquatic resources of Lakes Fort Peck and Sakakawea, the two uppermost of six main stem Missouri River reservoirs. Various future developments are predicted to deplete the average Missouri River flow at Sioux City, Ia. over 40% by 2000, and in drought years the flow would be completely allocated.

Although limited, the data available indicated that with proper design and operating procedures, development of the region's coal resources can occur without significantly affecting these reservoirs' ecosystem. In the absence of adequate controls the localized impacts could be serious. Most impacts can be mitigated, but the suitability and adequacy of alternatives must be determined on a site/activity specific basis. Increased contributions of heavy metals to these reservoirs should be avoided because existing levels of metals in fish flesh approach or exceed federal standards. Selection of the best method for disposing of solid and liquid wastes must be determined for each individual site. Except for potential toxic and/or metal contaminants, the impact of gaseous effluents will be negligible because of the large dilution factor and high buffering capacity of the water. Proper placement of water intake structures in reservoirs and strongly discouraging their installation in tributary streams would minimize impingement and entrainment of fish.

Although the impacts of individual developments should not be underestimated, the cumulative effects from all water depletions and return flows, primarily from irrigation, will have a greater impact on reservoir biota than site-specific effects. Cumulative effects are discussed in relation to water quality and the fishery of the reservoirs. Recommendations to minimize site-specific impacts on a reservoir ecosystem and future research needs are described.

This report was submitted in fulfillment of OBS-0-33-76 and EPA-USFWS IAG-06-FO 79 by the North Central Reservoir Investigations under the joint sponsorship of the U. S. Fish and Wildlife Service and the U. S. Environmental Protection Agency. Work was completed as of June 1977.

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We are especially grateful for the many ideas, advice, and editorial assistance of the remaining staff of North Central Reservoir Investigations and our Project Officers, Lee Ischinger and Denis Nelson for their help and patience with our many problems. However, we are solely responsible for the interpretation and projections contained in this report, which are primarily based on our experience and understanding of reservoir ecosystems.

CHAPTER 1

EXECUTIVE SUMMARY

The national need for increased energy production has focused attention on the vast deposits of low sulfur coal available in the Northern Great Plains. Various uses of these coal deposits have been suggested, including mine-mouth steam-electric generating plants, coal gasification/liquefaction facilities, and interregional coal exportation using rail or slurry pipelines.

Water availability and cost will to a large degree control the type, extent, and location of future resource development in the Northern Great Plains. The largest and most dependable water source in the region is the main stem Missouri River reservoirs. Lakes Fort Peck and Sakakawea are closest to the coal resources and, with Lake Oahe, are the obvious source of water for industrial development.

This reconnaissance level study summarizes the results of a one-year literature and field survey designed to provide an overview of baseline conditions, identify and define the various developments and their impacts, identify mitigation measures, and delineate future research needs. Study emphasis was placed on those areas where development has started or is imminent, namely the Big Dry Arm of Fort Peck Lake in Montana and Dunn and Mercer Counties bordering Lake Sakakawea in North Dakota. The limited data collected from the upper two impoundments are compared with more comprehensive data compiled over a period of several years on the lower four reservoirs to determine the extent of physical, chemical, and biological similarity between the respective systems. Limnology and water chemistry studies consisted of monthly sampling in September, October, and November in the Big Dry Arm of Fort Peck Lake and in the vicinity of Renner Bay, Lake Sakakawea. Fishery studies consisted of a spawning and nursery area survey conducted during May and June primarily in the Big Dry Arm of Fort Peck Lake and the Little Missouri embayment of Lake Sakakawea. The tissue of a few important fish species was analyzed for selected metals. The Big Dry Arm was emphasized because of proposed coal gasification and mining activities near Circle, Montana and the Little Missouri Arm and Renner Bay were selected to evaluate potential effects of similar activities in Dunn and Mercer Counties, North Dakota.

Limitations on the availability of historical limnological data on Lakes Fort Peck and Sakakawea, combined with the short duration of sampling in 1976 requires that qualifications be placed on cited baseline data as well as the comparisons between the respective reservoirs. However, based on extensive study of the lower four reservoirs, the information suggests that the quantities of phyto- and zooplankton exhibit a high degree of similarity in all six main stem reservoirs. The species composition of the phytoplankton communities may differ somewhat between the upper two and the lower four reservoirs. Blue-green algae seemed more abundant in Lakes Fort Peck and Sakakawea. If this is the case, the upper two reservoirs may be more susceptible to the deleterious effects of nutrient enrichment. Such enrichment could arise as a result of increases in population and use of fertilizers on irrigated cropland. The nitrogen-phosphorus ratio indicates that primary productivity is phosphorus limited in the upper two reservoirs as in the lower four reservoirs. Thus, the most productive areas in Missouri River reservoirs are downstream of a phosphorus source, usually a tributary river. Taxonomic studies of zooplankton and benthic invertebrates indicate that all six reservoirs are probably similar.

The results of fish spawning and nursery area studies in Lakes Fort Peck and Sakakawea were basically comparable with similar studies conducted on Lakes Oahe and Francis Case. Number of species present, and abundance of individual species, generally declined from the upper to lower reaches within an embayment and from the upper to lower reaches within a reservoir. Larval fishes were generally concentrated near the surface with few individuals being captured at depths of 3 and 6 m. The tributary streams of Missouri River reservoirs are apparently the sole spawning location of goldeye, white sucker, paddlefish, sauger, and pallid and shovelnose sturgeons, as well as a significant portion of the walleye stocks.

In Lakes Fort Peck and Sakakawea, the sport fishery is primarily for walleye, and the commercial fishery is dependent upon buffalofishes, goldeye, and carp. A reproducing population of lake trout has developed in Fort Peck Lake; stocking of this species continues in Lakes Sakakawea and Oahe in an effort to develop self-sustaining populations.

Lakes Sakakawea and Oahe are probably more comparable in their physical and biological characteristics than are any other main stem reservoirs. Lake Fort Peck appears to differ in many respects from the downstream reservoirs. Fort Peck Lake has a differently shaped basin, lower discharge rates, very slow water-exchange rates, cooler water temperatures, lower numbers of cyprinid and centrarchid species, and higher numbers of salmonids than downstream reservoirs.

The flesh of several adult fish species was analyzed for heavy metals. Mercury concentrations in walleye, channel catfish, and 1 of 3 goldeye collected in Fort Peck Lake exceeded Food and Drug Administration (FDA) standards of 0.5 ppm. Levels of selenium and cadmium were also high enough to warrant continued study. Concentrations of heavy metals in Lake Sakakawea specimens were not as high, but mean mercury levels were near, or exceeded the maximum permissable FDA standards.

The annual mean historical Missouri River flow at Sioux City, Ia. of 34.5 km^3 (28 million a/f) was estimated to be depleted 8 km^3 (6.5 million a/f) by 1970 and projected to be depleted an additional 6.1 km^3 (5 million a/f) by 2000. Addition of minimum downstream flow requirements and projected coal-development depletions would allocate the entire Missouri River flow in drought years. Irrigation was projected by 2000 as the single largest water use (40%), source of return flows (53%), and affect more land (2.3 million hectares) than any other type of development. Coal development was projected to deplete 15% of the water, return about 2%, and affect about 93,000 hectares of land.

Coal strip mining and operation of conversion plants will produce wastes that can be extremely harmful to the environment if not properly treated. Fugitive dust and surface runoff from the mining operation and large quantities of ash, evaporator residue, and sludge from raw water and sewage treatment units will contain harmful chemicals. Waste waters will also contain pollutants such as phenols, ammonia, and heavy metals whereas gaseous effluents will contain SO_2, NO_x, particulate material, and heavy metals. Upon completion of a coal gasification/liquefaction plant, a thorough monitoring program should be conducted to determine the quality and quantity of effluents produced.

With proper design and operating procedures, development of coal resources can occur without having a measurable effect on the water quality and biota of these reservoirs. However, to minimize the environmental impacts on a reservoir, the impact on the terrestrial ecology or ground water may be increased. Therefore, each individual facility and its associated activities must be examined and operational guidelines established, and strictly enforced, that will preserve the most valuable or fragile components of the ecosystem at that particular site.

Although limited, the available data delineated certain aspects of these reservoirs' ecology that are particularly vulnerable to perturbations. Increased loading of these reservoirs with heavy metals from any source must be avoided because of existing concentrations in fish flesh. Levels of mercury, selenium, and cadmium are presently high and further increases could close the commercial fishery and severely impact the sport fishery. Coal conversion plants could be designed for zero discharge with solid wastes buried in the mines and liquid wastes recovered, evaporated, or disposed of in deep wells if the quality of the aquifers are not disturbed. Except for potential toxic and/or metal contaminants, the impact of gaseous effluents will be negligible because of the large dilution factor and high buffering capacity of the water.

Installation of intake structures as close to the dams as possible and below an elevation of 657 m.msl in Fort Peck Lake and 539 m.msl in Lake Sakakawea would minimize entrainment and impingement of fish eggs and larvae. Installation of intake structures in tributary streams should be strongly discouraged since many reservoir species utilize these streams for spawning and these streams are the primary source of nutrients.

Although the impacts of individual developments should not be underestimated, the cumulative effects of water depletions and return flows, primarily from irrigation, will have a greater impact than site-specific effects on a reservoir. Water elevations in Lakes Fort Peck, Sakakawea, and Oahe, have been projected to average 10 m lower in 2000 than in 1976. Depletions of this magnitude will alter the water management regimen of the reservoirs which directly influences and controls the fishery resource. Decreased depth may prevent the establishment of a thermocline, which would not only alter the physical and chemical characteristics within a reservoir, but also the water discharged and therefore the downstream reservoirs. Water depletions would reduce tributary inflows and therefore the input of nutrients to a reservoir, and degrade the spawning habitats of some species of fish. Reduced water levels would also reduce the littoral area within the reservoir, further reducing spawning and nursery areas. It is extremely difficult to develop guidelines to minimize these impacts since they are the cumulative effect of many individual developments and the effects will be gradual and subtle, but inevitably they will degrade the aquatic environment. The potential fishery harvest was predicted to decline 545, 1000, and 725 metric tons in Lakes Fort Peck, Sakakawea, and Oahe, respectively, from 1976 to low-flow years and depletions projected for 2000.

Future studies recommended are: (1) analysis of the inorganic and organic composition and toxicity of coal mine and conversion plant effluents and the effects of their burial on the aquifers, (2) obtain adequate baseline data on the limnology and fish populations of Fort Peck Lake, (3) determine the contribution various tributary streams make as spawning and nursery areas for reservoir fish, and (4) develop a water quality-primary production model of individual reservoirs and the entire system based on chemical budgets.

CHAPTER 2

INTRODUCTION

The national need for increased energy production has focused attention on the vast deposits of surface minable coal available in the Northern Great Plains. Various uses of these coal deposits have been suggested, including mine-mouth electric generating plants, coal gasification/liquefaction plants, and coal exportation to other regions of the country via rail or slurry pipelines.

Development of the coal resources in this region will be greatly influenced by the availability of water. The Northern Great Plains has a semi-arid climate, and most of the streams and rivers in the region are fed by snow melt from the Rock Mountains. The largest and most dependable source of water for industrial development is the main stem Missouri River reservoirs. Lakes Fort Peck and Sakakawea are close to the coal resources and are frequently mentioned as sources of water for energy development. This one-year study was designed to provide an overview of the effects of energy development on the aquatic resources of Lakes Fort Peck and Sakakawea.

Specifically, the objectives of this report are to: (1) provide a summary of present baseline limnological and fisheries information available on Lakes Fort Peck and Sakakawea; (2) identify the various types of resource development and their potential impacts on these reservoirs; (3) identify areas of biological comparability between these two reservoirs and the downstream four main stem reservoirs; (4) develop interim recommendations to minimize environmental impacts of development; and (5) identify areas requiring additional research. This report will focus on those areas where development has started or is imminent, namely, the Big Dry Arm of Fort Peck Lake in Montana and Dunn and Mercer counties bordering Lake Sakakawea in North Dakota.

CHAPTER 3

MAIN STEM MISSOURI RIVER RESERVOIR SYSTEM

The Missouri River main stem reservoir system consists of six impoundments (Fig. 1) constructed and operated by the U. S. Army Corps of Engineers (CE) for flood control, irrigation, navigation, and hydroelectric power. In addition, the reservoirs provide recreation, and fish and wildlife benefits to the region.

Water in the reservoirs is accumulated from five subbasins within the Upper Missouri Basin (Fig. 1). The area (1000 km^2) and mean annual flow (km^3) contributed by each subbasin were as follows:

Subbasin	Area	Flow
Upper Missouri	35.7	8.971
Yellowstone	27.2	10.850
Western Dakota	29.8	3.000
Eastern Dakota	22.5	3.989
Platte-Niobrara	38.4	0.099

These subbasins contributed a mean annual flow at Sioux City, Ia. of about 27 km^3 (22 million a/f) at the 1970 level of water depletion.

The minimum, maximum, and mean (1898-1972) annual flow (km^3) at each main stem dam at the 1970 level of water depletion was as follows:

Dam	Minimum	Maximum	Mean
Fort Peck	2.646	13.003	8.431
Garrison	9.769	32.181	20.902
Oahe	11.098	40.084	22.841
Big Bend	11.116	40.675	22.905
Fort Randall	11.406	41.994	23.572
Gavins Point	12.254	43.621	25.146

Minimum annual flows at each dam are about one-third to one-half the mean flows, and the maximum flows are nearly double the mean flows. The Upper Missouri and Yellowstone subbasins provide about 87% of the mean annual flow at Oahe Dam and about 80% of the flow at Gavins Point Dam.

The Missouri River reservoirs system has a total water storage capacity of 92.02 km^3 at the top of exclusive flood control pool (CE)[1]. Storage

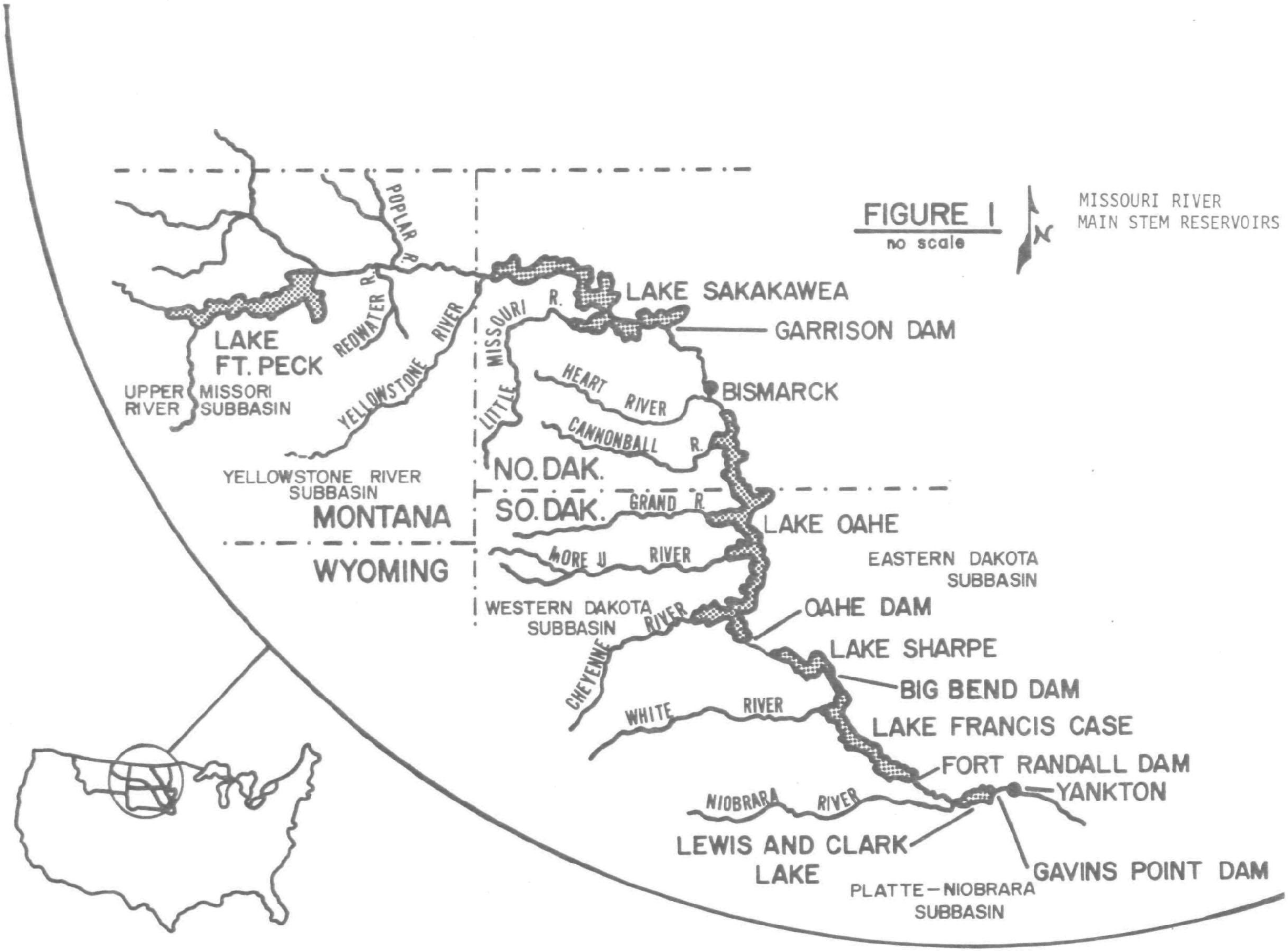


FIGURE 1
no scale

MISSOURI RIVER
MAIN STEM RESERVOIRS

volumes (km^3) of the main stem reservoirs at various elevations were as follows:

Reservoir	Base of annual flood control	Base of exclusive flood control	Top of exclusive flood control
Fort Peck	18.75	22.08	23.31
Sakakawea	22.70	28.00	29.85
Oahe	23.68	27.63	28.99
Sharpe	2.10	2.22	2.34
Francis Case	4.07	5.67	6.91
Lewis and Clark	0.49	0.62	0.62
Total	71.79	86.22	92.02

The upper three reservoirs have the largest storage volumes and are operated primarily for flood control and to supply long-term water for hydroelectric power.

Water storage, distribution, and downstream releases in the system are regulated on an annual cycle associated with seasonal inflows and the various water needs. For purposes of flood control, the reservoirs are scheduled to be near, or below, their base of annual flood control on 1 March. Most of the annual inflow occurs during the spring and summer months increasing the system's storage to a maximum. Downstream flow needs are highest during the navigation season thereby decreasing the storage during late summer and fall. Discharges decrease from the lower reservoirs during the winter and increase at Fort Peck and Garrison Dams to provide additional electric power.

Morphometric characteristics of the Missouri River main stem reservoirs have been described and reviewed by Benson and Cowell[2], and Benson[3,4] (Table 1). The upper three reservoirs have large surface areas, depths, and low water exchange rates in contrast with the lower reservoirs. Operational procedures result in mean annual water level fluctuation ranging from 0.6 m at Lake Sharpe to 6.9 m at Lake Francis Case.

TABLE 1. PHYSICAL CHARACTERISTICS OF MISSOURI RIVER MAIN STEM RESERVOIRS AT THE BASE OF ANNUAL FLOOD CONTROL

	Reservoir					
Characteristic	Fort Peck	Saka-kawea	Oahe	Sharpe	Francis Case	Lewis & Clark
Elevation* (m)	680.9	560.1	490.0	432.9	411.5	367.1
Surface area (km^2)	858	1,275	1,268	231	320	105
Average width (km)	4.0	4.4	3.4	1.8	1.9	2.6
Length (km)	216	286	372	129	172	40
Mean depth (m)	21.8	17.8	18.7	9.1	12.7	4.7
Average annual water level fluctuation (m)	3.0	3.0	3.8	0.6	6.9	1.1
Water exchange rate	2.1	1.0	1.1	0.1	0.5	0.03

* Above mean sea level.

CHAPTER 4

SAMPLING LOCATIONS

Sampling stations were established in relation to probable future industrial developments on the Big Dry Arm of Fort Peck Lake and in the vicinity of Renner Bay in Lake Sakakawea (Fig. 2). Limnology stations on the Big Dry Arm of Fort Peck Lake were located in Nelson Creek Bay, Sandy Arroyo Bay, and at a mid-reservoir site off Sandy Arroyo Bay. Larval fish were sampled in the extreme upper end of the Big Dry Arm (in the vicinity of Big Timber Creek), and in the embayments formed by Nelson, Rock, and Spring creeks. The Lake Sakakawea limnology stations were located in Renner and Beaver bays, and at a mid-reservoir site off Renner Bay. Larval fish were sampled in the upper end of the Little Missouri Arm (about 7 km downstream from Corral Creek), in Bear and Hans creek embayments, and in an un-named bay about 8 km downstream from the mouth of the Little Missouri Arm (where Highway 8 intersects the reservoir).

Larval fish were also sampled at a number of "survey" stations during June to determine if abundance at the permanent sampling sites was representative of the entire reservoir. In Fort Peck Lake, embayments formed by the Musselshell River, Swan, Sutherland, and Hell creeks were sampled. In Lake Sakakawea, the Van Hook Arm, Tobacco Garden area, and Renner and Beaver bays were surveyed; Renner Bay was also sampled at the beginning and end of the study.

The significance of tributaries as spawning and nursery areas was estimated by sampling the Missouri River in the vicinity of Wolf Point and Fort Union and the Yellowstone, Poplar, and Redwater rivers at their confluence with the Missouri River. The Little Missouri River was sampled near its confluence with Lake Sakakawea.

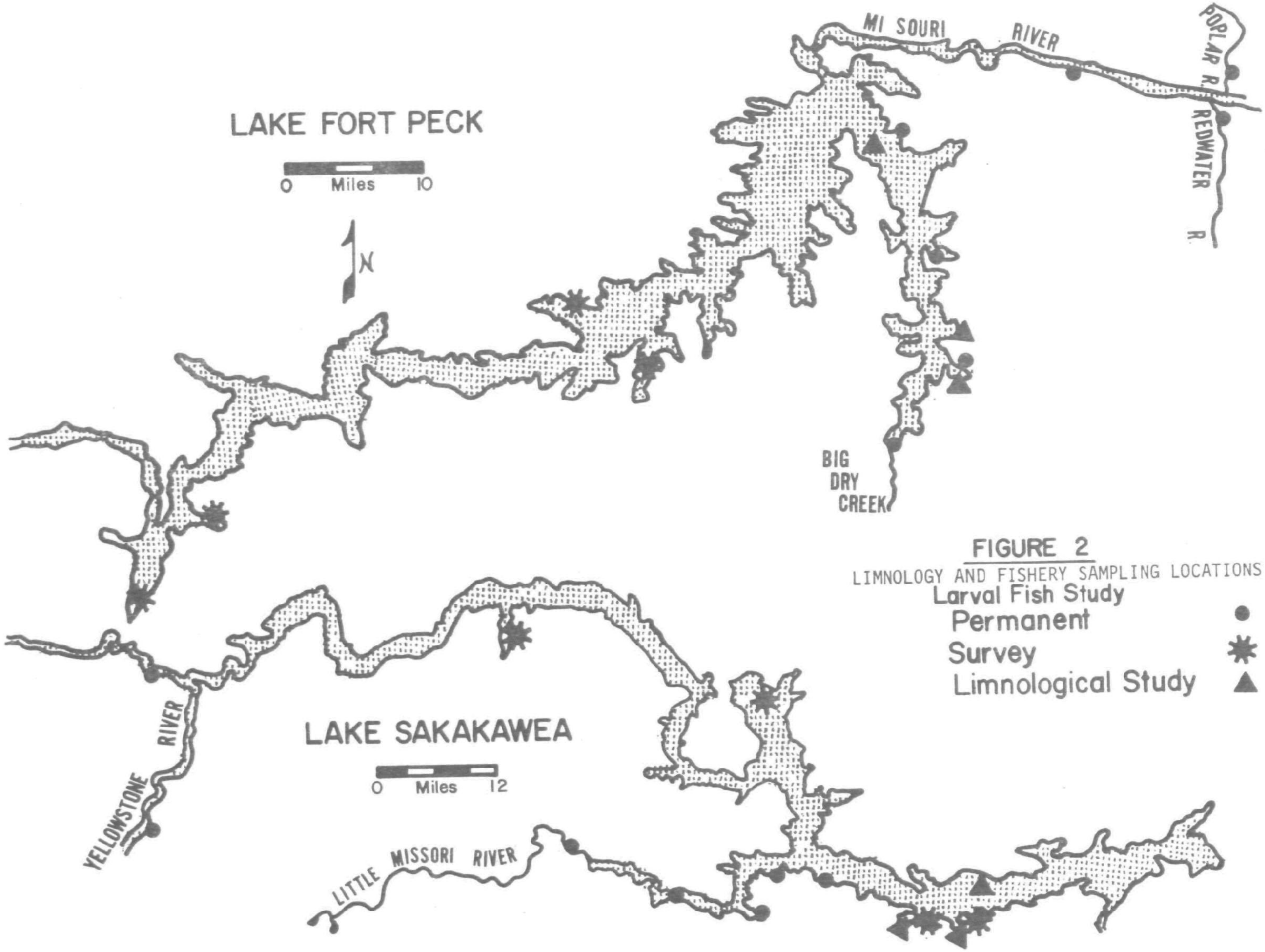


FIGURE 2
LIMNOLOGY AND FISHERY SAMPLING LOCATIONS

CHAPTER 5

SAMPLING METHODS

LIMNOLOGY

Each station was sampled once during September, October, and November, 1976. A sample of surface and bottom water was taken with a 3 l plastic Van Dorn water bottle for chemical analysis, estimation of phytoplankton standing crop, and chlorophyll analysis. Two zooplankton samples were taken with a Clarke-Bumpus sampler; one from the surface to mid-depth, and the other from mid-depth to bottom. Temperature, conductivity, and dissolved oxygen profiles were taken with a Hydrolab Model 6D in-situ water quality analyzer at 1 m intervals from surface to bottom. Samples of bottom sediment were taken in September for chemical analysis and in November for a taxonomic listing of benthic invertebrates.

All chemical analysis of water was performed in accordance with methods outlined by the U. S. Environmental Protection Agency (EPA)[5]. Chlorophyll and carotenoid pigments were analyzed by the methods of Strickland and Parsons[6]. The 430/665 ratio was used as an indicator of diversity in the phytoplankton community and to indicate the maturity of the algae community as it relates to succession (Margalef)[7]. Low values indicate less diversity and high values indicate a more diverse or mature species assemblage. The ratio indicates the optical absorbance of a 90% acetone extract of pigments from a natural phytoplankton community at the two respective wave lengths of light — 430 nm and 665 nm.

FISH

Larval fish were sampled weekly at each permanent station during May and June 1976. A 0.5-m plankton net was used at the surface and a Clarke-Bumpus plankton sampler was used at depths of 3 m and 6 m. Both samplers had #00 (760 u) mesh nets. Paired tows were made at the upper and lower end of each embayment station with the 0.5-m nets. The Clarke-Bumpus samplers were used only at the mouth of each embayment. All samples were collected by towing the nets at a constant speed for 10 minutes. Paired 10-min samples were taken at the tributary river stations with 0.5-m plankton nets. Meters were mounted in the samplers and water volumes filtered were determined for each sample. Field samples were preserved in 5% formalin with "phloxine B" stain added to aid in separating fish larvae and eggs from detritus. Adult fish were collected for heavy metals analysis in September with gill nets and were immediately frozen and sent to the Denver Co. EPA laboratory for analysis.

CHAPTER 6

FORT PECK LAKE

LIMNOLOGY

Temperature profiles taken during the 1976 larval fish sampling showed that a thermocline had developed at the mid-reservoir station in the Big Dry Arm by 7 June. Apparently high winds dissipated the thermocline by 17 June. The thermocline did not reform by 6 July (the end of the larval fish sampling) but was present when limnological sampling began in September (Fig. 3). A series of bathythermograph readings taken by North Central Reservoir Investigations personnel in August 1972 indicated thermal stratification in the vicinity of the Big Dry Arm. It seems safe to assume that the Big Dry Arm stratifies during the summer months, but that this condition may be periodically interrupted by high winds.

Dissolved oxygen concentrations were uniform from surface to bottom at all stations during the 1976 sampling (Fig. 3). The August 1972 sampling near the mouth of the Big Dry Arm indicated reduced oxygen levels (4-5 ppm) near the bottom. It seems reasonable to expect that during the height of summer stratification dissolved oxygen would be lowered in the hypolimnion; the extent of the oxygen deficit is unknown.

Results of the water chemistry analysis are summarized in Table 2, and presented in detail in Appendices A and B. All of the analyses fell within the expected range of conditions for individual parameters. Chemical conditions were similar between the three sampling areas and, because of fall overturn, no vertical differences were apparent.

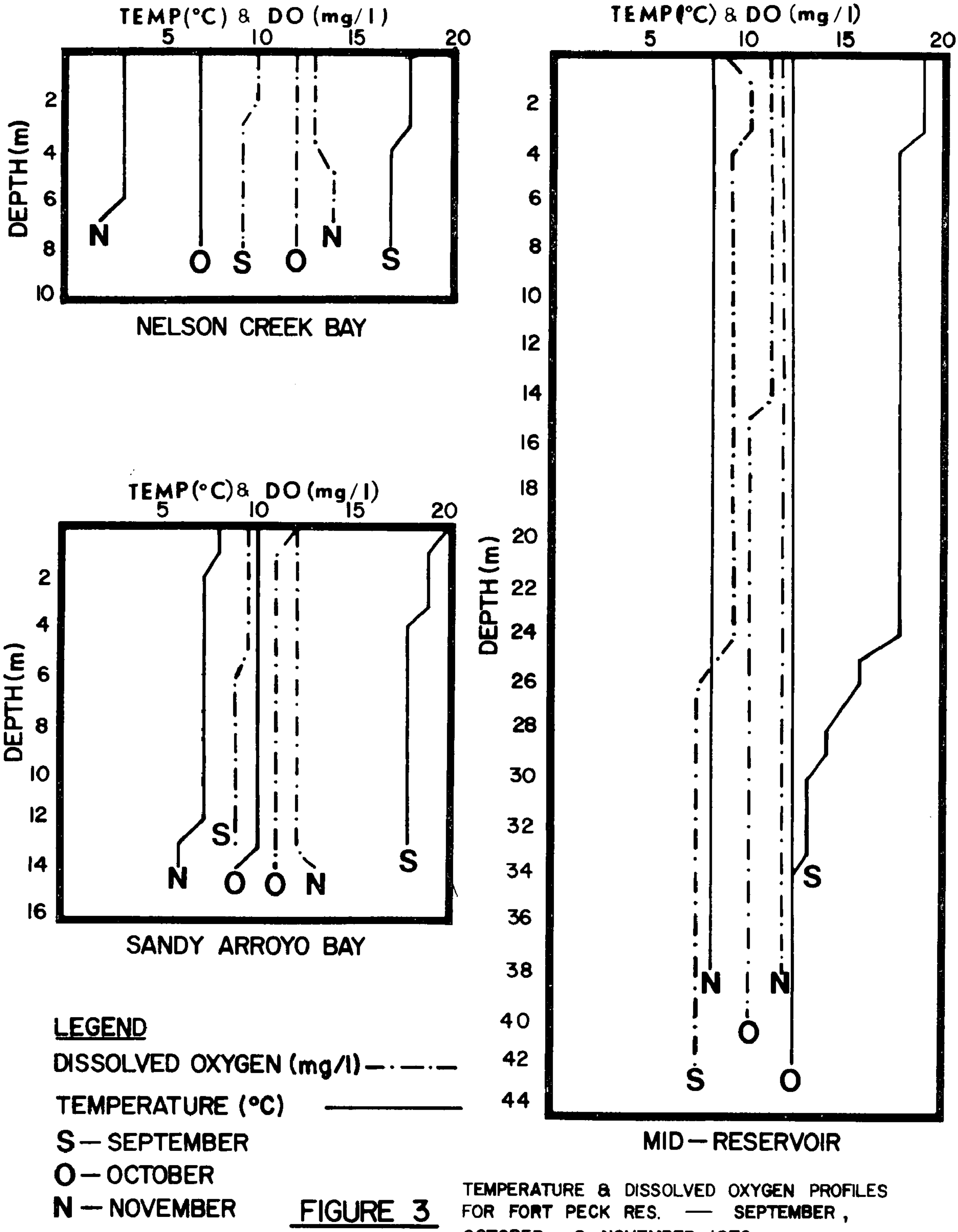


FIGURE 3 TEMPERATURE & DISSOLVED OXYGEN PROFILES FOR FORT PECK RES. — SEPTEMBER, OCTOBER, & NOVEMBER 1976.

TABLE 2. MEAN CHEMICAL CONCENTRATIONS AT THREE STATIONS IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Nelson Creek Bay	Sandy Arroyo Bay	Mid-reservoir
pH	8.1	8.2	8.0
Total alkalinity (mg/l $CaCO_3$)	159.5	153.2	152.5
Chloride (mg/l)	7.2	7.3	7.5
Sulfate (mg/l)	203.3	176.7	180.0
Silica (mg/l)	8.2	8.8	9.0
Nitrate (mg N/l)	0.09	0.07	0.10
Kjeldahl nitrogen (mg N/l)	0.36	0.32	0.32
Specific conductance (micromhos)	622.3	567.8	559.8
Total organic carbon (mg/l)	3.7	3.3	4.3
Total phosphorus (mg/m^3)	16.8	12.3	11.2
Total cations (meg/l)	7.31	6.74	6.69
Calcium (mg/l)	63.0	62.7	65.7
Magnesium (mg/l)	16.2	17.8	17.5
Sodium (mg/l)	63.0	47.5	43.7
Potassium (mg/l)	3.7	3.0	2.8
Turbidity (J.T.U.)	9.4	6.1	2.1

Chemical composition of the sediments were as follows:

Location	Replicate	Total phosphorus (ppm)	Organic matter (%)	Nitrogen (%)
Nelson Creek Bay	A	496	8.41	.07
	B	480	8.20	.07
Sandy Arroyo Bay	A	560	7.82	.07
	B	467	6.93	.07
Mid-reservoir	A	509	2.15	.03
	B	485	4.00	.06
Dam	A	775	9.04	.14
	B	736	9.04	.14
	C	687	8.82	.12

Organic matter ranged from 2 to 9% and total phosphorus ranged from 450 to 880 ppm. Nitrogen was most variable, ranging from 0.03% to 0.14%. No other data were available on sediment chemistry in Fort Peck Lake for comparisons.

Phytoplankton standing crops, as evidenced by levels of chlorophyll concentration, were rather uniformly distributed with respect to the sampling areas (Table 3 and Appendix C). A possible exception occurred in Sandy Arroyo Bay where a localized "bloom" was detected, particularly in November. Pennate diatoms were the most abundant phytoplankters; they constituted nearly two-thirds of the total cell numbers. Flagellates were the next most abundant group.

Cyclops was the most abundant zooplankter, followed by *Diaptomus* and *Daphnia* (Table 4 and Appendix C). Although zooplankton abundance appeared to be higher in Sandy Arroyo Bay than at the other stations, the data were too limited to draw definite conclusions.

LARVAL FISHES

Twelve taxa of larval fishes were captured in the Big Dry Arm of Fort Peck Lake (Table 5 and Appendices D and E). Of the larvae caught, 80% were from the upper two stations (Big Timber and Nelson creeks), or nearly four-fold more fish than at the lower two areas (Rock and Spring creeks). The abundance of all but 2 species declined from the upper to lower reaches of the Big Dry Arm.

Yellow perch and freshwater drum accounted for 95% of the total larval catch. Perch was the most abundant species caught at all sampling areas of the Big Dry Arm, ranging from 42% of the total catch at Big Timber Creek to 90% or more at the three lower stations. Drum accounted for 39% of the total catch at Big Timber Creek. Few fish were caught during the first sampling series (early May); catches generally peaked about mid-June.

TABLE 3. MEAN PHYTOPLANKTON STANDING CROPS AT THREE STATIONS IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Nelson Creek Bay	Sandy Arroyo Bay	Mid-reservoir
Chlorophyll (mg/m^3)	2.01	6.08	2.90
Carotenoids ($m.spu/m^3$)	1.46	3.93	1.71
Chlor-Carot (ratio)	1.4	1.5	1.5
430-665 (ratio)	2.5	2.5	2.0
Pennate diatoms (no/ml)	73.9	360.1	224.6
Centrate diatoms (no/ml)	19.0	48.6	30.2
Flagellate (no/ml)	33.3	117.2	67.4
Immotile (no/ml)	12.2	2.4	3.8
Blue green (no/ml)	22.6	13.2	7.4

TABLE 4. MEAN ZOOPLANKTON STANDING CROPS (no/m^3) AT THREE STATIONS IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Nelson Creek Bay	Sandy Arroyo Bay	Mid-reservoir
Cyclops	3698.8	5523.2	849.3
Diaptomus	1705.0	2912.0	774.0
Daphnia	2142.7	1714.0	473.7
Diaphanosoma	935.0	460.7	75.0
Nauplii	4987.7	3754.5	1321.5
Other	3.7	63.8	14.8

TABLE 5. LARVAL FISH ABUNDANCE (no/1000 m^3) AT PERMANENT SAMPLING STATIONS IN FORT PECK LAKE IN MAY AND JUNE, 1976

	Embayment				
Taxa	Upper Big Dry Arm	Nelson Creek	Rock Creek	Spring Creek	All areas*
Yellow perch	54.0	234.6	34.0	64.5	107.0
Freshwater drum	93.0	0.9			58.5
Ictiobus sp.	36.6		4.2		22.4
Notropis sp.	1.6	4.2	12.3		4.6
Carp	8.5	2.6	1.1		3.5
Cyprinids		3.3			3.3
Catostomids	3.4	0.5			2.1
Goldeye	1.3				1.3
Burbot			1.0		1.0
Pomoxis sp.				1.3	1.3
White sucker	0.7				0.7
Walleye		0.4			0.4
Total	199.1	246.5	52.6	65.8	206.1

* Weighted mean catch from areas where taxa present.

All larval fishes caught in the Big Dry Arm were caught at the surface except for 1 carp collected at a depth of 6 m in Rock Creek. Eighty percent of all larval fishes caught were from the upper rather than lower stations of embayments.

Yellow perch composed 88% of the catch at surveyed stations, the same as in the permanent Big Dry Arm stations (Table 6). The major difference was Lepomis sp. which were absent from Big Dry Arm catches, but which accounted for 10% of the total survey catch, and were the most abundant fishes caught at the Musselshell River and Swan Creek embayments. Perch was the most abundant species at Sutherland and Hell Creek embayments. The catch of a walleye at the Musselshell River embayment was unexpected because walleyes have only been reported as spawning in the Big Dry Arm. Also, walleye would be expected to be large enough to avoid the gear when the survey occurred on 9 June.

ADULT FISHES

Investigations of the adult fish stocks in Fort Peck Lake were initiated with a creel census in 1948 (U. S. Fish and Wildlife Service, Missouri River Basin Studies)[8] and a test netting survey in 1949 (Phenicie)[9]. The creel census, conducted from 1948 to 1950, estimated that about 17,400 fishermen annually harvested about 49,600 fish weighing 13,000 kg (28,800 lbs). Yellow perch, goldeye, and sauger constituted over 90% of the catch of 0.14 kg/ha (0.12 lb/a). Few walleyes were present in the sport fisherman's catch in 1948 and were absent the next year in gill net catches. Perch and goldeye composed about 90% of the 2,550 fish captured in 1949 in 27 experimental gill net lifts. Sauger comprised 4% of the total, with 9 species and 3 genera comprising the remaining 6%.

An important commercial fishery operates on Fort Peck Lake. In 17 years from 1957-73, Liebelt[10] reported the annual catch ranged from about 8,300 kg (18,300 lb) to 320,000 kg (704,000 lb) and averaged about 153,000 kg (337,000 lb). Therefore, the catch ranged from about 0.1 to 4.0 kg/ha and averaged about 2 kg/ha. The catches have been dominated by bigmouth and smallmouth buffalos (75%) and goldeye (21%).

Trap-netting at numerous sites throughout the Big Dry Arm from 1974 through 1976 indicated that the upper end of the Big Dry Arm was a major walleye spawning area (Liebelt)[10]. This area of the Big Dry Arm exhibits few characteristics of typical walleye spawning habitat. The waters were turbid, with thick layers of bottom sediments, and no gravel or rubble apparent.

Intensive fish stocking of warm and cold-water species has continued on Fort Peck Lake since 1938 (Appendix F). Northern pike and walleye accounted for nearly 70% of the total number of warmwater species stocked. Cold-water species introduced in earlier years were lake trout, Kokanee salmon, and brown trout and recently rainbow trout and coho salmon.

During the 1950's, about 400,000 one-inch and 7,000 three-inch lake trout were released. A significant lake trout population has developed from

TABLE 6. LARVAL FISH ABUNDANCE (no/1000 m^3) AT SURVEYED SAMPLING STATIONS IN FORT PECK LAKE, JUNE 1976

Taxa	Embayment				
	Musselshell River	Swan Creek	Sutherland Creek	Hell Creek	All areas*
Yellow perch	11.9	2.3	534.9	379.1	263.2
Freshwater drum	21.2	2.5			10.2
Walleye	3.0				3.0
Lepomis sp.	49.2	52.1		3.7	43.7
Ictiobus sp.		5.0			5.0
Catastomids	2.6				2.6
Total	87.9	61.9	534.9	382.8	327.7

* Weighted mean catch from areas where taxa present.

these introductions (personal communication, Dr. James Liebelt). During November 1976, gill nets set near Fort Peck Dam caught 46 sexually mature lake trout. The 41 males caught were ripe, 3 females were spent, and 2 females had loose eggs in the body cavity. The males ranged in weight from 0.9 - 5 kg (2.0 - 11.0 lb) and averaged 3.1 kg (6.9 lb), whereas the females ranged in weight from 2.6 - 4.3 kg (5.8 - 9.4 lb) and averaged 3.4 kg (7.4 lb).

Concentrations of heavy metals were determined from fish flesh of several major species collected from Nelson Creek (Table 7). Mercury concentrations in excess of U. S. Food and Drug Administrations (FDA) standards (0.5 ppm) were present in walleye, channel catfish, and goldeye; carp had acceptable mercury levels. Selenium concentrations and the presence of cadmium are also heavy metals of potential concern.

TABLE 7. HEAVY METALS CONCENTRATIONS (ppm) IN FISH FROM NELSON CREEK BAY, FORT PECK LAKE, SEPTEMBER 1976

	Species							
Parameter	Walleye		Channel catfish	Carp		Goldeye		
Arsenic	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cadmium	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Chromium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Copper	1.0	0.7	0.7	0.4	0.6	0.7	1.1	0.9
Lithium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Molybdenum	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nickel	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Lead	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Selenium	0.7	0.8	0.5	0.5	0.6	0.5	0.5	0.5
Vanadium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc	17.9	6.2	7.3	22.7	6.4	20.4	5.3	6.4
Mercury	1.7	1.0	0.7	0.1	0.1	0.3	1.1	0.3

CHAPTER 7

LAKE SAKAKAWEA

LIMNOLOGY

Temperature profiles obtained at Renner Bay during the larval fish sampling showed that a thermocline had formed by mid-June, but when limnological sampling began in mid-September, fall overturn was occurring (Fig. 4). Dissolved oxygen concentrations at this time were fairly uniform from surface to bottom. It seems reasonable to assume that Lake Sakakawea does stratify in the Renner Bay area and that oxygen is depleted to some extent in the hypolimnion. Additional profiles of temperature and dissolved oxygen are needed in order to determine the intensity and duration of summer stratification.

Results of Lake Sakakawea water chemistry analyses are summarized in Table 8 and presented in detail in Appendices G and H. Generally, there was little difference between Lakes Fort Peck and Sakakawea. No important spatial differences were noted among the three stations in Sakakawea and, because of the fall overturn, no real vertical differences were observed. Sediment chemistry at three locations in Lake Sakakawea were as follows;

Location	Replicate	Total phosphorus (ppm)	Organic matter (%)	Nitrogen (%)
Renner Bay	A	653	5.34	.10
	B	628	5.61	.10
Beaver Bay	A	731	6.71	.16
	B	689	6.80	.15
Mid-reservoir	A	783	7.93	.11
	B	783	7.41	.11

Concentrations of phosphorus (600-800 ppm) were less variable in the Lake Sakakawea sediment samples than those in Fort Peck Lake. Organic matter ranged from 5.3 to 8.0% and nitrogen was between 0.10 and 0.16%.

Average concentrations of chlorophyll and carotenoid pigments (Table 9) were not appreciably different from those found in Fort Peck Lake. Appendix I shows that there were no apparent differences among the three stations nor were there differences with respect to depth. In Lake Sakakawea, flagellates were the most abundant phytoplankton group followed by pennate diatoms.

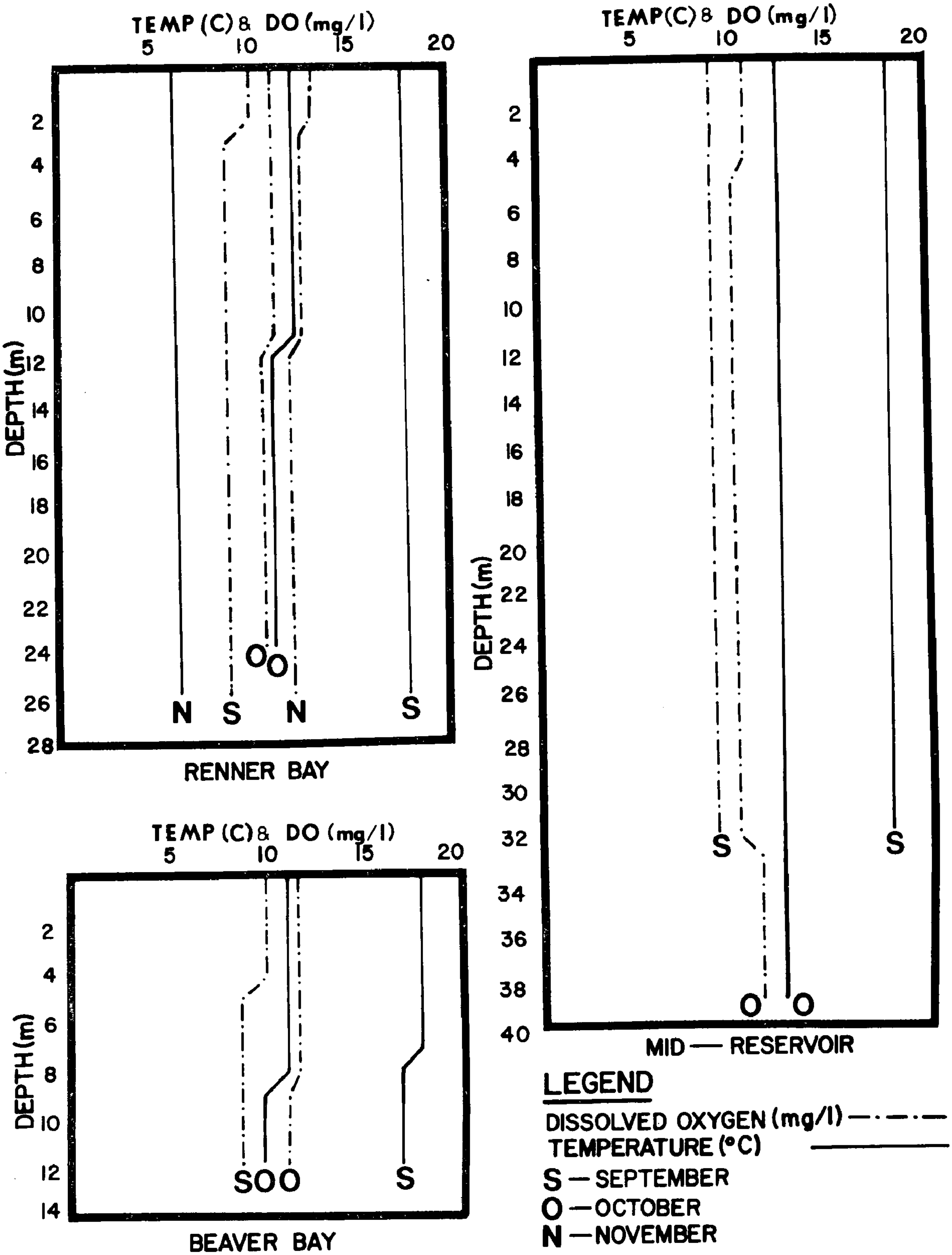


FIGURE 4 TEMPERATURE & DISSOLVED OXYGEN PROFILES FOR LAKE SAKAKAWEA — SEPTEMBER, OCTOBER, & NOVEMBER 1976.

TABLE 8. MEAN CHEMICAL CONCENTRATIONS AT THREE STATIONS IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Renner Bay	Beaver Bay	Mid-reservoir
pH	8.0	8.1	8.0
Total alkalinity (mg/l $CaCO_3$)	147.2	144.5	145.8
Chloride (mg/l)	8.2	8.2	8.5
Sulfate (mg/l)	175.0	182.5	185.0
Silica (mg/l)	8.2	8.2	8.0
Nitrate (mg/l)	0.13	0.13	0.13
Kjeldahl nitrogen (mg N/l)	0.40	0.36	0.42
Specific conductance (micromhos)	555.5	544.0	561.8
Total organic carbon (mg/l)	10.2	8.8	9.8
Total phosphorus (mg/m^3)	14.7	7.0	9.0
Total cations (meg/l)	6.51	6.24	6.46
Calcium (mg/l)	55.5	53.2	54.5
Magnesium (mg/l)	15.7	12.8	15.8
Sodium (mg/l)	54.3	56.5	54.5
Potassium (mg/l)	3.0	3.0	3.0
Turbidity (J.T.U.)	3.6	6.3	5.9

TABLE 9. MEAN PHYTOPLANKTON STANDING CROPS AT THREE STATIONS IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Renner Bay	Beaver Bay	Mid-reservoir
Chlorophyll (mg/m^3)	2.98	4.18	2.11
Carotenoids ($m.spu/m^3$)	1.82	2.83	1.08
Chlor-Carot (ratio)	1.6	1.5	2.8
430-665 ratio	2.4	2.5	2.5
Pennate diatoms (no/ml)	77.7	106.6	29.2
Centrate diatoms (no/ml)	22.9	28.8	43.0
Flagellate (no/ml)	139.2	123.1	207.3
Immotile (no/ml)	11.8	2.5	9.8
Blue green (no/ml)	30.9	31.4	18.3

Cyclops and *Diaptomus* were about equally abundant in the zooplankton samples followed by slightly fewer numbers of *Daphnia* (Table 10). Zooplankters were generally more abundant in the upper half of the water column (Appendix I).

LARVAL FISHES

Yellow perch and freshwater drum dominated the larval fish catch in the Little Missouri Arm of Lake Sakakawea, accounting for over 90% of the total catch (Table 11 and Appendix J). Abundance and number of species were highest at the upper end of the Little Missouri Arm. Larval fish abundance was lower but the number of species represented was greater at Hans Creek Bay, than at Bear Creek or Highway 8 bays.

All larval fishes caught in the Little Missouri Arm of Lake Sakakawea were taken at the surface. Nearly 75% of the total catch was from the upper rather than the mouth station of embayments. Perch was the most abundant fish at the lower three stations in the Little Missouri Arm and accounted for about 85% to 96% of the catches. At the upper end of the Little Missouri Arm, drum accounted for nearly 70% of the total catch and perch only 20%. Only 1 larva was caught during the first sampling series in early May; catches peaked during mid-June.

Yellow perch was the most abundant species at the survey stations of Lake Sakakawea (Table 12). Perch accounted for 96% of the total catch in the June survey and 76% of the total catch at the permanent stations. Drum was the second most abundant species taken in the June survey and at the permanent stations.

The largest number of species sampled was in the upper reach of Lake Sakakawea (Tobacco Garden Bay) and the fewest in the lower reservoir (Renner and Beaver Creek bays). The only larval fishes caught other than at the surface were 1 perch taken from 6 m at Renner Bay, and 5 drum from 6 m at Tobacco Garden Bay.

ADULT FISHES

Fish sampling has been conducted annually since 1956 on Lake Sakakawea by the North Dakota Department of Game and Fish. Standard gears and methods were used at seventeen test netting sites with deletion of individual sites dependent upon annual water levels. Because of the consistency of the methods used, the changes in abundance, distribution, and growth rates of the dominant species as the reservoir aged are documented. Information on the sport fish harvest is lacking, but records are available on the commercial fish harvest.

Goldeye dominated the catch of 25 species taken in experimental gill nets during the last 5 years of netting (1968, 1969, 1970, 1972, 1974). Yellow perch was the second most abundant species during the first four of these years with walleye replacing perch the fifth year (Hill[11], Ragan[12], Ragan[13], Berard[14,15]). These species, together with carp, sauger, channel

TABLE 10. MEAN ZOOPLANKTON STANDING CROPS (no/m^3) AT THREE STATIONS IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Station		
	Renner Bay	Beaver Bay	Mid-reservoir
Cyclops	1368.5	3322.8	1232.2
Diaptomus	1531.2	2739.8	1000.5
Daphnia	1114.8	1980.2	1023.8
Diaphanosoma	41.0	169.2	45.8
Nauplii	1903.2	2098.0	1277.5
Other	1.0	86.3	0.5

TABLE 11. LARVAL FISH ABUNDANCE (no/1000 m^3) AT PERMANENT SAMPLING STATIONS IN LAKE SAKAKAWEA IN MAY AND JUNE, 1976

Taxa	Embayment				
	Upper Little Missouri Arm	Hans Creek	Bear Creek	Highway 8	All areas*
Freshwater drum	347.6	5.5			174.0
Yellow perch	55.1	79.5	332.0	144.4	158.3
Goldeye	27.7				27.7
Hybognathus sp.	16.4				16.4
Etheostoma sp.	6.4	19.6	17.5	5.2	14.9
White bass	4.6				4.6
Burbot			1.9	3.6	2.9
White sucker	3.2				3.2
Notropis sp.		3.0			3.0
Carp	3.2	0.8	0.8		1.1
Rainbow smelt			0.8	2.0	1.3
Walleye	1.2	0.8		1.7	1.1
Total	465.4	109.2	353.0	156.9	408.5

* Weighted mean catch from areas where taxa present.

TABLE 12. LARVAL FISH ABUNDANCE (no/1000 m^3) AT SURVEYED SAMPLING STATIONS IN LAKE SAKAKAWEA, JUNE 1976

Taxa	Embayment				
	Tobacco Garden	Van Hook Arm	Beaver Creek	Renner Bay	All areas*
Yellow perch	8.9	23.1	257.8	207.2	182.6
Rainbow smelt			3.8	1.6	2.6
White bass	8.0				8.0
Goldeye	4.8				4.8
Freshwater drum	23.9				23.9
White sucker	5.9				5.9
Pomoxis sp.	3.0				3.0
Notropis sp.		6.8			6.8
Cyprinids	5.9				5.9
Catastomids	3.0				3.0
Total	63.4	29.9	261.6	208.8	246.5

* Weighted mean catch from areas where taxa present.

catfish, and white sucker, were the only species that averaged over 1 fish per gill net lift during any year.

In vertical distribution studies conducted during 1975, experimental gill nets were set from the surface to a depth of 45.7 m (150 ft)(Berard)[16]. Of 186 fish caught representing 7 species, 97% were caught in depths less than 15.2 m (50 ft). Goldeye dominated catches at all depths and accounted for 93% of the total.

Commercial fishing on Lake Sakakawea began in 1970 with seines, hoop nets, and gill nets. The catch has ranged from about 45,000 kg (98,600 lb) in 1973 (Berard)[17] to 333,000 kg (733,000 lb) in 1974 (Berard)[15] and averaged about 150,000 kg (330,000 lb) or 1 kg/ha. Buffalofishes dominated the catch each year; carp harvested from Lake Audubon, a sub-impoundment, were also an important species. Goldeye are not an important commercial species in Lake Sakakawea because of their small size.

Cold-water species were released in Lake Sakakawea from 1965 through 1976 (Appendix K). Adult rainbow smelt and lake whitefish were planted in 1971 and 1974, respectively, to establish a forage base for salmonid species. Both species reproduced successfully, and rainbow smelt are now present in all downstream reservoirs. Nearly 400,000 rainbow trout were stocked in 1965 and 1966 and over 700,000 coho salmon in 4 years since 1970. About 225,000 lake trout were released from 1973 through 1975. In 1976, over 37,000 chinook salmon were introduced. The success of these salmonid stockings are presently unknown.

Average mercury concentration equalled or exceeded FDA standards in the flesh of walleye, goldeye, and carp (Table 13). Other heavy metal concentrations found were similar to those of fishes in Fort Peck Lake except for high nickel concentration in 1 walleye; this was presumed to be a contaminated sample.

TABLE 13. HEAVY METALS CONCENTRATIONS (ppm) IN FISH FROM RENNER BAY, LAKE SAKAKAWEA, SEPTEMBER 1976

Parameter	Species					
	Goldeye		Walleye		Carp	
Arsenic	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cadmium	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Chromium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Copper	0.5	0.6	0.4	0.7	0.4	0.4
Lithium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Molybdenum	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nickel	<1.0	<1.0	<1.0	4.4*	<1.0	<1.0
Lead	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Selenium	<0.5	0.6	0.6	<0.5	0.7	1.0
Vanadium	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc	7.0	4.6	14.5	4.6	16.0	13.1
Mercury	0.4	2.4	0.3	0.5	1.0	0.4

* Possible contamination.

CHAPTER 8

TRIBUTARY RIVERS

The most abundant fishes in the major tributaries were the cyprinids which accounted for 88% of the total catch (Table 14 and Appendix L).

Larval fish abundance was lowest in the Yellowstone River and in the Missouri River at Wolf Point and highest in the Little Missouri River. Although the abundance of larval fishes was low in the Yellowstone River, goldeye eggs were numerous (214.4/1000 m^3) and second only to catches in the Little Missouri River (481.2/1000 m^3). It was apparent that tributaries such as the Poplar and Redwater rivers were an important source of larval fishes in the Missouri River between Wolf Point and Fort Union (Table 14).

Except for one walleye taken in the Yellowstone River on 18 May, no larval fishes were caught in the Missouri or Yellowstone rivers during the first three weeks of sampling (5, 11, and 18 May). Catches during early May in the shallower and warmer Redwater and Poplar rivers contained the largest numbers of walleye collected during the study. Since walleye eggs had hatched by 5 May in the Redwater and Poplar rivers, sampling should have been initiated earlier to ensure adequate assessment of the entire season's hatch.

TABLE 14. ABUNDANCE OF LARVAL FISHES (no/1000 m^3) IN TRIBUTARY RIVERS IN MAY AND JUNE, 1976

Taxa	Missouri *	Missouri ‡	Poplar	Redwater	Yellow-stone	Little Missouri	All areas#
Cyprinids			45.0	0.9		5285.2	1108.7
Goldeye						368.4	368.4
White sucker			81.4	8.3			47.8
Carp	3.0	196.9	29.2			10.5	44.1
Longnose dace			14.8				14.8
Catostomids			21.2	0.6		11.3	9.3
Ictiobus sp.	8.1	6.1					7.6
Burbot		6.1					6.1
Channel cat					5.5		5.5
Yellow perch			4.4				4.4
Walleye		3.0	3.7	5.3	1.4		3.9
Total	11.1	212.1	199.7	15.1	6.9	5675.4	1620.6

* Wolf Point.

‡ Fort Union.

Weighted mean catch from all areas where taxa present.

CHAPTER 9

COMPARISON OF MISSOURI RIVER RESERVOIRS

It would be impossible to accurately characterize the aquatic ecosystems of Lakes Fort Peck and Sakakawea or to compare them in detail with the four downstream reservoirs on the basis of available literature or from the results of the 1976 sampling. However, it is possible to draw some general conclusions on the similarities and differences between these two uppermost reservoirs and the more extensively studied downstream four reservoirs.

LIMNOLOGY

General thermal characteristics of all the main stem reservoirs can be ascertained from the literature. Benson[3] reviewed temperature data collected by the CE in Lakes Fort Peck, Sakakawea, and Francis Case. Distinct stratification occurs in Lakes Fort Peck, Sakakawea, and Oahe (Selgeby and Jones)[18] in the summer, while the lower three reservoirs only rarely stratify in deeper areas during extended periods of calm weather (Benson[3], Rada[19]). Summer surface water temperatures are about 5° C lower at Fort Peck Lake than at Lewis and Clark Lake. All reservoirs in the system develop ice cover in winter.

Although the Missouri River was historically known for its high turbidity, construction of the reservoirs greatly reduced turbidity in the system (Neel et al.)[20]. Turbidity is a problem in areas where shoreline erosion or tributary inputs influence fish embryo mortality (Hassler)[21].

Quantities of phytoplankton in Lakes Fort Peck and Sakakawea are similar to those in the downstream reservoirs. Past work has shown that variation within a given reservoir is often greater than the variation among reservoirs. We believe that high and low areas of phytoplankton standing crops and primary production exist in Lakes Fort Peck and Sakakawea. In general, productivity decreases from the upper to lower reaches in Missouri River reservoirs except for localized increases where tributary streams enter. The amount of chlorophyll in the surface water and calculated rates of production on an areal basis appear comparable in Lakes Fort Peck, Sakakawea, Oahe, and Francis Case.

We have shown in the downstream four reservoirs that phytoplankton standing crop and primary production are regulated by available phosphorus (Martin and Novotny[22], Martin[23]). This explains why the most productive areas are immediately downstream of a phosphorus source, usually a tributary stream. Total phosphorus concentrations averaged 13 mg/m^3 in Fort Peck Lake, and 11 mg/m^3 in Lake Sakakawea; these values are comparable to those in the downstream reservoirs. Total nitrogen averaged 416 mg/m^3 in Fort Peck Lake and 526 mg/m^3 in Lake Sakakawea. The resulting N:P ratios of 32 and 48 for Lakes Fort Peck and Sakakawea, respectively, would indicate that the phytoplankton community in these reservoirs is phosphorus limited.

The species composition of the phytoplankton community is one area where some differences among reservoirs may exist. Blue-green algae are scarce in off-shore areas in the lower reservoirs but were regularly found in Lakes Fort Peck and Sakakawea. The chlorophyll:carrotenoid ratio averaged 1.9 and 1.6 in Lakes Sakakawea and Fort Peck, respectively, whereas the average is less than 1.0 in the downstream reservoirs. The 430/665 absorbency ratio appeared lower in Lakes Sakakawea and Fort Peck than in the other four reservoirs. These characterisitcs, while difficult to interpret individually, collectively indicate a different taxonomic assemblage in Lakes Fort Peck and Sakakawea.

Zooplankton standing crops appear comparable among the six main stem reservoirs. All species encountered have been found in the lower four reservoirs with the exception of Diaptomus tyrrelli, which has not previously been reported (Table 15).

Qualitative sampling of benthic invertebrates (Table 16) indicated that the taxonomic assemblage present in Lakes Fort Peck and Sakakawea were similar to what one would expect in Lakes Oahe or Francis Case. The benthic fauna was dominated by chironomids in the near shore areas and by chironomids and oligochaetes in the deeper water.

LARVAL FISHES

The species of larval fishes collected in Lakes Sakakawea and Fort Peck in 1976 was comparable to those obtained in similar studies conducted on Lakes Oahe and Francis Case in 1974 and 1975 (Table 17). The number of taxa collected ranged from 11 in Lake Francis Case to 13 in Lakes Oahe and Sakakawea. Perch was usually the most abundant species; catches ranged from 25% of the two year total in Lake Oahe to nearly 90% in Lake Fort Peck.

Abundance of a species and the number of species present generally declined from the upper to the lower embayments and from the upper end to the mouth within an embayment. Two exceptions to this generality were perch and Notropis sp. which commonly increased in abundance from the upper to lower embayment stations. This distribution was believed related to a decrease in turbidity. Larval fish were rarely collected below the surface.

Catches of larval fishes from streams tributary to Lakes Oahe and Sakakawea were primarily Ictiobus sp., goldeye, carp, and cyprinids. These tributaries appear to be the sole spawning location for species such as goldeye and white sucker and the major location for walleye spawning. Although pallid and shovelnose sturgeons and paddlefish were not collected, the Yellowstone and Missouri Rivers provide their only potential spawning habitat.

TABLE 15. ZOOPLANKTON SPECIES IDENTIFIED IN SAMPLES COLLECTED FROM LAKES FORT PECK AND SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Taxa	Fort Peck	Sakakawea
Cyclops bicuspidatus thomasi	X	X
Mesocyclops edax	X	X
Macrocyclops albidus	X	
Paracyclops fimbriatus	X	
Diaptomus siciloides	X	X
D. forbesi	X	X
D. ashlandi		X
D. sicilis	X	X
D. tyrrelli	X	X
D. clavipes	X	X
Daphnia pulex	X	X
D. galeata mendotae	X	X
D. schodleri	X	X
D. retrocurva	S	
Diaphanosoma leuchtenbergianum	X	X
Leydigia quadrangularis	X	X
Leptodora kindtii	X	
Bosmina longirostris		X

TABLE 16. BENTHIC INVERTEBRATES IDENTIFIED IN SAMPLES COLLECTED FROM LAKES FORT PECK AND SAKAKAWEA IN NOVEMBER, 1976

Taxa	Fort Peck	Sakakawea
Chironomidae		
Chaetocladius sp.	X	
Cryptochironomus sp.	X	X
Chironomus sp.	X	X
Dicrotendipes modestus	X	X
Dicrotendipes neomodestus	X	
Harnishia sp.	X	
Procladius (Procladius) sp.	X	X
Procladius (Psilotanypus) sp.	X	X
Pseudochironomus fulviventris	X	X
Tanypus stellatus		X
Ceratopogonidae		
Bezzia complex		X
Oligochaeta		
Ilyodrilus sp.	X	X
Limnodrilus sp.	X	X
Trichoptera		
Polycentropus sp. #1	X	
Polycentropus sp. #2	X	
Corixidae		
Immature	X	
Amphipod		
Hyalella azteca	X	

TABLE 17. PERCENT COMPOSITION OF LARVAL FISH CATCHES FROM FOUR MISSOURI RIVER RESERVOIRS

	Reservoir					
	Fort Peck	Sakakawea	Oahe		Francis Case	
Taxa	1976	1976	1974	1975	1974	1975
Yellow perch	89	80	47	15	99	16
White bass		*	7	65		*
Goldeye	*	1		2		
Freshwater drum	6	14	4	*		
Pomoxis sp.	*	*	1	*		*
Burbot	*	*	*	*		
Ictiobus sp.	2		38	12	*	80
Carp	1	*	2	5	*	4
Walleye	*	*	*	*	*	*
Gizzard shad					*	*
Bluegill						*
Largemouth bass						*
Etheostoma sp.		3		*	*	*
Emerald shiner					*	
Hybognathus sp.		*	*	*		
Notropis sp.	1	*	*	*		
Rainbow smelt		*		*		
White sucker	*	*				
Catostomids	*					
Lepomis sp.	2					

* Less than 0.05%.

ADULT FISHES

Comparison of gill net catches (Table 18 and Appendix M) between Lake Sakakawea and the lower four reservoirs shows that Lakes Sakakawaa, Oahe, and Francis Case have similar fish populations. Channel catfish are most abundant in Lake Francis Case, walleye in Lake Oahe, and yellow perch and goldeye in Lake Sakakawea. However, walleye is the dominant sport species in these three reservoirs and goldeye the dominant commercial species.

No comparable netting data are available for Lake Fort Peck. However, the composition of the fish population of Lake Fort Peck appears to differ in some aspects from that of the lower five reservoirs (Appendix D). Fewer cyprinid and centrarchid species are present, and salmonid species have been more successful in Lake Fort Peck.

The distribution of species within Lakes Oahe and Sakakawea illustrates the habitat preferences of the common species (Table 19). Species adapted to higher turbidity and currents, such as river carpsucker, shorthead redhorse, sauger, and drum were most abundant in the headwaters of the two reservoirs, and their abundance decreased downstream. Northern pike and carp were also more abundant in the headwater areas, but this was attributed to more extensive spawning habitat. The higher abundance of goldeye in the middle and lower sections of Lake Sakakawea compared with Lake Oahe was apparently related to the Little Missouri Arm which provides excellent spawning and nursery habitat. Yellow perch and white sucker of Lake Sakakawea were the only species found to be most abundant in the lower section of either reservoir. Salmonid species have not yet become established, but they would be expected to inhabit the lower reaches of these reservoirs as lake trout apparently do in Fort Peck Lake.

With the information available, it appears that Lakes Sakakawea and Oahe are more comparable in their physical and biological characteristics than are any other main stem reservoirs, and information could be transferred between them. Unfortunately, the least amount of information is available on Fort Peck Lake which appears to differ in many characteristics from the other reservoirs. Fort Peck Lake has a differently shaped basin, lower discharge rate, very slow water exchange rate, cooler water temperatures, minimal number of fish species, and more abundant salmonids than in downstream impoundments.

TABLE 18. MEAN CATCH PER EXPERIMENTAL GILL NET LIFT OF THE DOMINANT SPORT AND COMMERCIAL SPECIES IN MAIN STEM MISSOURI RIVER RESERVOIRS*

Species	Reservoir				
	Lewis and Clark	Francis Case	Sharpe	Oahe	Saka-kawea
Sport					
Northern pike	‡	0.1	0.3	0.9	0.5
Channel catfish	3.4	5.9	5.0	2.6	2.5
White bass	0.5	0.7	0.1	1.7	
Yellow perch	0.3	2.7	2.7	0.9	7.8
Sauger	4.1	1.2	2.0	1.1	2.4
Walleye	1.5	9.4	18.5	13.2	4.2
Sub-total	9.8	19.8	28.5	20.5	17.4
Commercial					
Goldeye	0.6	10.5	1.1	15.8	29.0
Carp	2.2	4.1	7.2	2.4	2.9
River carpsucker	3.3	5.4	3.1	2.0	0.3
Smallmouth buffalo	0.3	0.4	0.2	0.1	0.1
Bigmouth buffalo	0.4	0.3	0.8	0.6	‡
Freshwater drum	4.9	1.2	0.5	0.6	0.7
Sub-total	11.7	21.9	13.0	21.6	33.0
Miscellaneous	3.0	3.3	7.0	3.4	2.4
Total	24.5	45.0	48.6	45.5	52.8

* For a complete species listing and data sources see Appendix M.

‡ Less than 0.05 fish per lift.

TABLE 19. MEAN CATCH PER EXPERIMENTAL GILL NET LIFT OF THE DOMINANT SPECIES IN THE LOWER, MIDDLE, AND UPPER SECTIONS OF LAKES OAHE (O) AND SAKAKAWEA (S) (percent in parentheses)

Species	Reservoir	Lower*	Middle‡	Upper#
Goldeye	O	9.8 (17)	15.2 (27)	30.4 (54)
	S	23.9 (28)	41.5 (49)	19.3 (23)
Northern pike	O	0.6 (20)	0.9 (30)	1.5 (50)
	S	0.4 (27)	0.3 (23)	0.7 (50)
Carp	O	0.6 (7)	3.4 (40)	4.6 (54)
	S	2.2 (25)	3.4 (39)	3.1 (36)
River carpsucker	O	0.6 (9)	2.3 (37)	3.3 (54)
	S	⧺ (3)	0.1 (16)	0.7 (81)
White sucker	O		0.1 (55)	0.1 (45)
	S	3.4 (68)	1.1 (23)	0.5 (10)
Shorthead redhorse	O	0.1 (1)	1.1 (27)	3.0 (72)
	S	0.3 (30)	0.2 (23)	0.5 (48)
Channel catfish	O	1.1 (14)	4.4 (61)	1.9 (25)
	S	0.9 (12)	3.0 (41)	3.5 (48)
Yellow perch	O	0.7 (22)	1.5 (50)	0.8 (28)
	S	11.5 (50)	9.9 (43)	1.6 (7)
Sauger	O	0.1 (2)	1.9 (42)	2.5 (56)
	S	1.9 (25)	1.9 (26)	3.6 (49)
Walleye	O	7.4 (17)	21.8 (51)	13.3 (31)
	S	4.2 (33)	3.8 (30)	4.7 (37)
Freshwater drum	O	0.1 (5)	0.8 (37)	1.2 (58)
	S	0.1 (5)	0.7 (34)	1.3 (61)
Total	O	22.7 (15)	58.0 (38)	71.8 (47)
	S	49.3 (32)	66.5 (43)	40.2 (26)

* Section in Lake Oahe located below Whitlocks Crossing and in Lake Sakakawea below confluence of Little Missouri Arm and main stem.

‡ Section in Lake Oahe between North and South Dakota state line and Whitlocks Crossing and in Lake Sakakawea in and between Van Hook and Little Missouri arms.

\# Section in Lake Oahe includes North Dakota portion and in Lake Sakakawea includes portion upstream of Van Hook arm.

⧺ Less than 0.05.

CHAPTER 10

WATER DEPLETIONS AND LAND-USE CHANGES

The historical mean annual discharge of the Missouri River at Sioux City, Ia. was 34.5 km^3 (28 million a/f), and total depletions by 1970 were estimated to be about 8 km^3 (6.5 million a/f)(Missouri River Basin Comprehensive Framework Study [MRBCFS])[24]. Water depletions are projected to increase considerably by 1980 and nearly double by 2000 (Table 20). Although these projections may, in time, prove in error, they are the latest published estimates, and were assumed to be accurate.

IRRIGATION

Irrigation currently is, and will continue to be, the single greatest water use and source of return water to the Missouri River (Table 20). By 2000, irrigation and water exported for irrigation is projected to account for nearly 40% of the 15.2 km^3 (12.3 million a/f) total depletion above Sioux City, Ia. An estimated 1.5 million hectares (2.7 million acres) were irrigated in 1970 (MRBCFS)[24]. Total land area under irrigation is projected to increase 311,800 hectares (767,000 acres) by 1980 and 800,000 hectares (2 million acres) by 2000.

The type of irrigation will shift from large publicly funded projects, such as the Garrison and Oahe units (included under export category in Table 20 since water will leave reservoir system) now under construction, to individual farmers and ranchers constructing their own private systems. Currently, the number of private units observed operating, and the number of permits issued by the CE varies greatly. The best estimate of the number of units operating and permits pending in 1976 was:

Location	Operating	Pending
Fort Peck Reservoir	4	3
Fort Peck to Garrison Dam	28	8
Garrison to Oahe Dam	49	27
Oahe to Big Bend Dam	17	11
Big Bend to Fort Randall Dam	36	21
Fort Randall to Gavins Point Dam	9	4
Total	143	74

The increased interest in irrigation is illustrated by the fact that the number of permits now pending is about one-half the number of units operating. Of additional importance is the amount of water requested in each permit.

TABLE 20. PROJECTED WATER WITHDRAWAL, DEPLETION, AND RETURN FLOWS (km^3) BY SERVICE CATEGORY FROM THE MISSOURI RIVER ABOVE SIOUX CITY, IOWA IN 1980 AND 2000*

Service	1980			2000		
	Withdrawal	Depletion	Return	Withdrawal	Depletion	Return
Irrigation	2.78	1.37	1.41	6.47	3.43	3.04
Exports	0.51	0.51		1.40	1.40	
Thermal power	1.09	0.04	1.05	2.32	0.13	2.18
Evaporation	0.32	0.32		0.61	0.61	
Municipal & Domestic	0.67	0.43	0.24	1.01	0.64	0.37
Wetlands, F&W	0.11	0.11		0.19	0.19	
Livestock	0.08	0.08		0.17	0.17	
Land conservation	0.05	0.05		0.16	0.16	
Coal development‡	0.16	0.16		1.13	1.05	0.08
Forest mgmt.	-0.07	-0.07		-0.23	-0.23	
Precipitation mgmt.	-0.13	-0.13		-0.43	-0.43	
Total	5.56	2.87	2.69	12.80	7.12	5.68

* Source: MRBCFS[24].

‡ Source: NGPRP[25] - Medium water use at CDP-III. Only depletions were listed for 1980 so withdrawals were assumed to equal depletion.

In the past these requests have amounted to $1.2 \times 10^6 m^3$ (1,000 a/f) or less per year but seven pending requests in 1976-77 in South Dakota exceed $12.2 \times 10^6 m^3$ (10,000 a/f).

COAL DEVELOPMENT

The development of coal resources in the northern Great Plains is difficult to predict. The factors that will determine how quickly and intensively coal is exploited are economics and governmental regulations. According to the Northern Great Plains Resources Program (NGPRP)[25], 47 million metric tons (52 million tons) of coal were mined from the region in 1975. Depending on future incentives, this will increase to between 82 and 145 million metric tons (91 and 160 million tons) by 1980 and from 131 to 886 million metric tons (144 to 977 million tons) by 2000. Projected land areas to be disturbed by coal development range from 3 to 8 thousand hectares (8 to 20 thousand acres) in 1980 and from 42 to 161 thousand hectares (103 to 397 thousand acres) by 2000. The large range in these projections is an indication of the uncertainity associated with the rate of coal development.

The use of the coal that is to be removed from projected strip mines in the Northern Great Plains is also uncertain and subject to debate. The production of substitute natural gas (SNG) is one alternative that has received attention. With intensive coal development, 7 SNG facilities would be operating by 1980 and 41 by 2000. With minimal development, there would be no SNG plants operating by 2000.

The American Natural Gas (ANG) Company has applied for 0.02 km^3 (17,000 a/f) of water from Renner Bay, Lake Sakakawea for operating a coal-gasification plant to produce 7 million m^3/day (250 million ft^3/day) of SNG. This plant, presently scheduled for completion in 1981, is the first for which a specific site has been selected and the construction and operation described (Woodward-Clyde Consultants)[26]. Dreyer Brother, Inc. of Billings, Montana has been actively engaged in the preliminaries of obtaining a permit for siting a coal conversion facility (Circle West) in the vicinity of the Big Dry Arm on Fort Peck reservoir. Although no formal application has been filed or specific site selected, their stated intentions are for one or more of the following:

(1) The manufacture of up to 2,700 metric tons/day (3,000 tons/day) of ammonia, requiring up to 8,200 metric tons/day (9,000 tons/day) of lignite and up to 0.01 km^3/yr (9,000 a/f/yr) of water.
(2) The manufacture of up to 4,500 metric tons/day (5,000 tons/day) of methanol-methyl fuel, requiring up to 9,000 metric tons/day (10,000 tons/day) of lignite and up to 0.01 km^3/yr (8,000 a/f/yr) of water.
(3) The manufacture of up to 30,000 barrels/day of synthetic diesel fuel oil, requiring up to 15,000 metric tons/day (16,500 tons/day) of lignite and up to 0.02 km^3/yr (15,000 a/f/yr) of water.

In addition to the conversion facility these proposals also entail operation and construction of strip mines, water intake structures, and construction of roads, railroads, and pipelines.

THERMAL POWER

Water for thermal electric power production is projected to become the second largest cause of water withdrawal. The projections in Table 20 were made prior to the 1972 Federal Water Pollution Control Act and may result in a change from once through, to evaporative, cooling. Therefore, these projections may overestimate water withdrawn and underestimate water consumed. Of the 35 coal-fired electric power plants listed by the Federal Power Commission to be constructed in the four subbasins by 1990, from 8 - 12 may be expected to utilize water withdrawn directly from the main stem Missouri River, with the remainder sited on tributary rivers (MRBCFS)[24].

MUNICIPAL, RURAL, DOMESTIC, AND INDUSTRIAL USES OF WATER

Water for these purposes was estimated to be the third largest service category in 1980, but the development of coal resources would utilize more water by 2000 (Table 20). Return waters from municipal sewage and industrial plants would be the third largest source of return water. Information regarding specific locations for these withdrawals was not available, but apparently the majority of increased water use will occur from expanding existing plants rather than constructing new plants.

EVAPORATION

The largest source of water depletion through 1970 was evaporation from the main stem reservoirs. Since few sites remain for reservoir construction, future increases in water loss from this source were projected to be low. However, the projected annual loss of water from this source in 2000 would be about 3 km^3. Remaining water depletions are minor, comprising less than 7% of the total loss, and are not sources of return water.

DEPLETION LOCATION

The Yellowstone and Eastern Dakota subbasins have been projected to be the primary locations for water withdrawals (MRBCFS)[24]. Depletions from the Eastern Dakota subbasin will be extensive through the Garrison diversion unit to Canada. Projected depletions from the Western Dakota subbasin will be smaller than from the other subbasins but because availability was less, over 30% of the average annual flow available in 1970 would be depleted in 2000.

CHAPTER 11

IMPACT OF DEVELOPMENTS

The impacts of energy and agricultural development on Lakes Fort Peck and Sakakawea involve the site-specific effects of individual projects as well as the combined effects of multiple developments. Water intake structures, waste products, population increases, changes in land use, and water depletions all pose potential problems for the water quality and fisheries in main stem reservoirs.

WATER INTAKE STRUCTURES

Entrainment or impingement of eggs and larval fishes is the primary deleterious effect of water intakes. The impact of a particular intake is dependent upon its location, design and the amount of water withdrawn. Although tributary streams and the shoreline and embayment areas of a reservoir are often the most desirable sites for locating water intake structures because of ease of access and minimal installation costs, these areas are also the primary spawning and nursery grounds for a number of reservoir fishes. Water intake structures must be located in deep water areas of the reservoirs to minimize entrainment of fish eggs and larvae. Intake structures for irrigation development have the greatest potential impact because of the large number of intakes, water volume, and the common practice of placing the temporary intakes in readily accessible streams or littoral areas of the reservoir.

Intake structures located in tributary streams would have a greater impact on reservoir fisheries than those located in the reservoir. Species which spawn in the reservoir environment generally spawn at numerous locations, so the eggs and larvae are not concentrated. Reservoir species which spawn in rivers may be dependent on recruitment from very few areas. The paddlefish and sturgeon populations of Lake Fort Peck may spawn exclusively in the main stem of the Missouri River, and their Lake Sakakawea populations may spawn exclusively in the Yellowstone River. Goldeye populations may also be restricted to these rivers for spawning plus the Musselshell River in Lake Fort Peck and the Little Missouri River in Lake Sakakawea. The eggs and/or larvae of these species are usually transported by the current to the reservoir. This results in a concentration of larvae at the mouths of tributary streams. The location of an intake structure near the mouth of a tributary stream could result in excessive losses of eggs and larvae.

It is difficult to perceive any deleterious limnological effects of water intake structures. Zooplankton and benthic invertebrates will be entrained and lost from the specific area. However, if intake structures are designed and located so as to minimize damage to fish stocks, it will follow that the loss of fish food organisms would be minimized.

WASTE PRODUCTS

The construction and operation of coal strip mines and conversion plants generate solid, liquid, and gaseous effluents that can be harmful to aquatic environments. Because of changing technology and the newness of the various coal conversion processes, relatively little is known about the chemical content of the effluents that will result from coal development in the Northern Great Plains.

Solid wastes produced from coal strip mining include the overburden removed to reach the lignite seams and fugitive dust from blasting, hauling, and crushing the lignite. The conversion processes generate large quantities of ash and evaporator residue and sludge from the use of scrubbers and catalysts in the conversion process. These solids could enter aquatic environments by being carried by surface water runoff or winds. Within streams or reservoirs the deposition of these sediments could introduce toxic materials, degrade localized areas of fish spawning habitat, and increase heavy metals concentration throughout the receiving ecosystem.

Waste waters are potentially hazardous to water quality and the fisheries of Missouri River reservoirs. Rubin and McMichael[27] compiled a list of known water pollutants arising from coal conversion processes. Some of these wastes, particularly ammonia and phenols, may present problems if the effluent does not receive adequate treatment (Handler and Linder)[28]. In addition to their toxic properties, phenolic wastes affect the taste of fish at levels which do not have adverse physiological effects.

The major impact of coal strip mining on the limnology of the Tongue River reservoir in Montana was the alteration of groundwater (Garrison et al)[29]. The mine discharge water primarily originated as groundwater but the principal aquifers of the region were the top two coal seams. When the coal was mined, the normal flow of groundwater to the reservoir was interrupted, and the surrounding groundwater drained into the mine since it was lower than the reservoir and river. Eventually this water entered the reservoir after passing through a settling pond. The concentrations of nitrogen in the mine water increased greatly due to the use of ammonium-nitrate explosives in the mining operations. Other chemical changes in mine water included increases in Ca, HCO_3, Mg, Na, and SO_4; heavy metals and organic pollutant analyses were evidently not included in the study. Acid mine drainage problems were minimal because of the high buffering capacity of the receiving water and because of the low sulfur content of the coal. In spite of the measurable changes that occurred in the mine water, no effects of discharging this water into the reservoir could be ascertained because of dilution.

In a different approach to determine the effects of mine waste waters on aquatic life, Olson _et al_[30] employed a bioassay technique utilizing both algae and bacteria as test organisms. There were no cases of heavy metal toxicity nor any indication of trace element deficiency in these waters. The results only showed algae were phosphorus limited. Testing continues using microorganisms to test coal leachates for the presence of additional toxic material.

Atmospheric emissions from coal conversion plants are primarily SO_2, NO_x, and particulate materials. In some regions of Canada, United States, and northern Europe, SO_2 has been precipitated from the atmosphere by rainfall in such high concentrations that they have acidified lake water to the extent fish life cannot survive. However, the extremely large dilution factor and high buffering capacity of Lakes Fort Peck and Sakakawea make it unlikely that any measurable effects would be detected from the projected number of conversion plants.

Solid, liquid, and gaseous effluents from coal strip mining and coal conversion processes will all contain heavy metals. Analysis of fish flesh indicated that mercury levels already exceed FDA standards in fish from Lakes Fort Peck and Sakakawea; selenium and cadmium are also present at significant levels. Any increase of these heavy metals in fish flesh from developing the coal resources could cause the closure of the commercial fisheries and necessitate warning sport fishermen not to consume their catch.

POPULATION INCREASE

The population increase projected to accompany coal development in the region (NGPRP)[25] is expected to increase the quantity of municipal sewage effluents discharged in the basin. This population increase will also place additional demand on the main stem reservoirs for recreation. Steps should be taken to insure that municipal sewage treatment facilities are expanded to provide adequate waste treatment.

LAND-USE CHANGES

Energy developments and irrigation involve changes in land-use patterns which, in turn, will alter the water volume, sediment, nutrient, and chemical yields of tributary watersheds. Limnological changes in Missouri River reservoirs will result from changes in the quality and quantity of tributary inflows and the cycling of chemical constituents within the reservoirs. The change from dry land to irrigated farming will increase the quantities of fertilizer, pesticides, and herbicides applied to the land which will eventually reach the Missouri River reservoirs. Proposed strip mining and coal conversion plants may involve altering the aquifers and drainage pattern and burial of process wastes at the mine site. The ash and sludge will contain considerable quantities of heavy metals, including mercury, lead, copper, and zinc (Bureau of Reclamation)[31]. The effects of mine site disposal of these substances are difficult to ascertain, since the rates of leaching and drainage patterns are unknown. Although the effects of a single strip mine, coal conversion plant, or irrigated field will be insignificant because of the large dilution factor, the cumulative effect of all these land-use changes will eventually degrade the water quality and fisheries within all the Missouri River impoundments.

CUMULATIVE WATER DEPLETION

The effect of water depletions in the various subbasins will be additive as one progresses downstream. Projected average annual cumulative river flow depletions (km^3) at each main stem dam without coal development would be:

Dam	1980	2000
Fort Peck	0.345	0.868
Garrison	1.885	4.064
Oahe	2.465	5.610
Big Bend	2.471	5.618
Ft. Randall	2.554	5.724
Gavins Point	2.742	6.225

Application of the above depletion estimates to average annual flows available after 1970 reveals that 11% of the water available in 1970 would be depleted in 1980 and 25% by 2000. In years of minimum flows these percentages would double; about 50% of the water presently available at Sioux City, Ia., would be consumed by 2000. Municipal water supplies below Sioux City, Ia., presently require a minimum flow of 5.3 km^3 (4.3 million a/f) (CE Main Stem Reservoir Regulation Studies [MSRRS])[32]. Addition of these minimum flow requirements and projected coal depletions by 2000 to the above depletions results in nearly complete allocation of Missouri River water at Sioux City, Ia., in low-flow years. Downstream flows could be maintained in low-flow years through the use of water stored in the main stem impoundments.

Inflows to the main stem reservoir system were above average from 1965-76. The water levels, surface area, water stored, and water released in 1976 were considerably above the levels to be expected from the long term (1898-1975) average annual inflow at the 1970 level of depletion or the ultimate depletion levels projected for 2000 (MSRRS)[32]. With increased depletions, water levels, surface area, etc. all decrease (Table 21 and Fig. 5). In general, because of the shape of the basins, for any given decline in elevation, the surface area will decrease the least in Lake Fort Peck and the most in Lake Oahe.

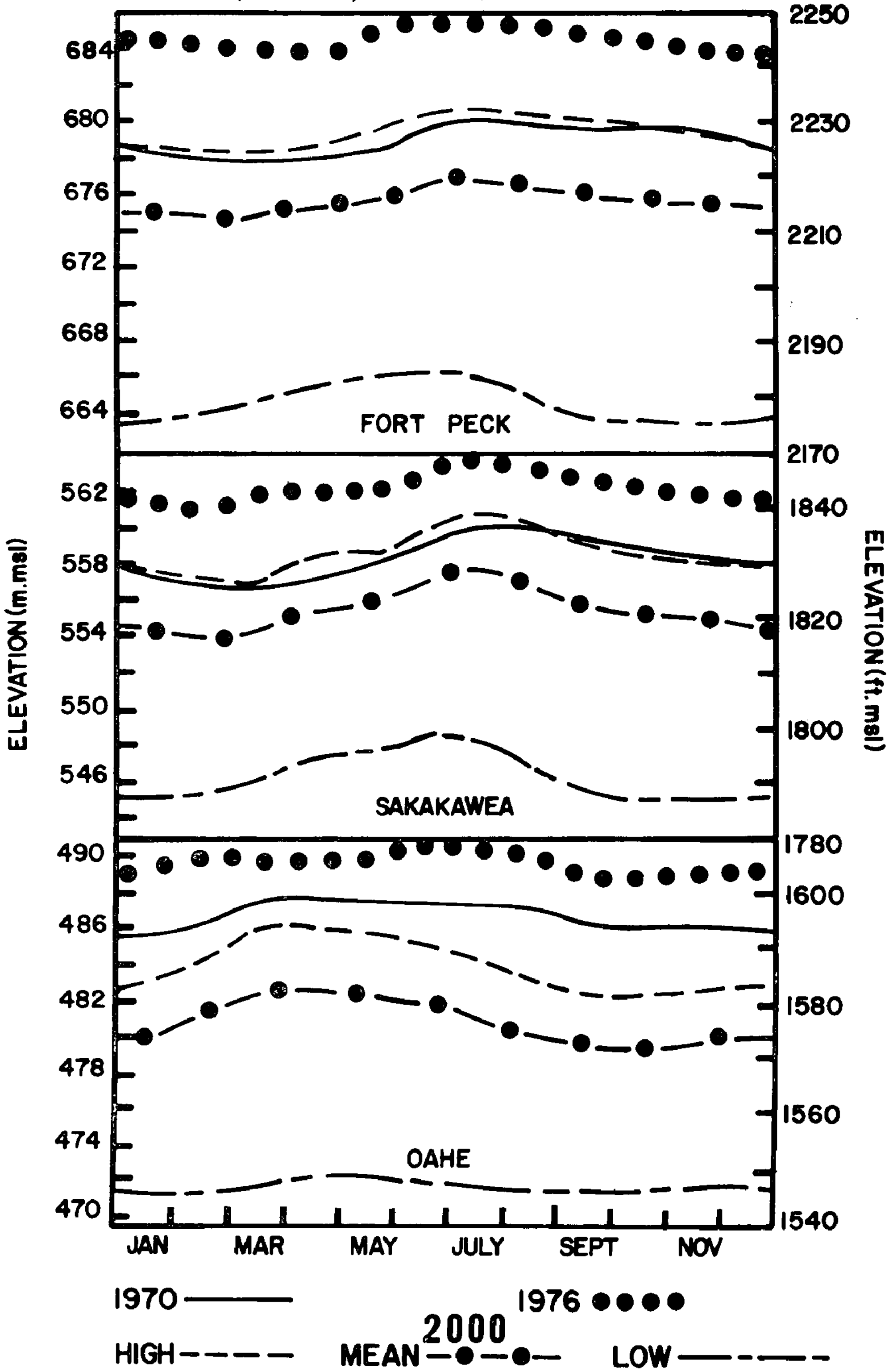
The projected increases in water depletions will have a profound effect on the reservoir ecosystems. Reduced tributary inflows will cause a decline in what is presently the major source of nutrients to the system (Martin and Novotny[22]; Martin[23]). Decreased water depth may very well prevent the establishment of thermoclines. This would not only alter the physical and chemical characteristics within a reservoir, but the tailwaters and downstream reservoirs would be altered by the change in quality of the water released.

TABLE 21. PHYSICAL CHARACTERISTICS OF LAKES FORT PECK, SAKAKAWEA, AND OAHE OBSERVED IN 1976, AT 1970 LEVELS OF DEPLETION THE 1898-1975 MEAN, AND AT ULTIMATE PROJECTED DEPLETION LEVELS IN 2000, THE MEAN (1898-1975), HIGH (1898-1930, 1944-54, 1955-75), AND LOW (1931-42) FLOW YEARS*

Characteristic	1976 Observed	1898-1975 Mean	2000 Mean	2000 High	2000 Low
			Fort Peck		
Elevation (m.msl)	684.42	678.81	675.58	679.21	664.48
Area (hectares)	95,985	79,625	71,890	80,595	48,560
Storage (km^3)	21.552	17.177	14.046	16.310	7.422
Inflows (km^3)	12.515	7.727	6.564	7.302	3.627
Releases (km^3)	12.808	7.721	6.570	7.299	3.871
Exchange rate (days)	614	812	780	816	700
			Sakakawea		
Elevation (m.msl)	562.04	558.32	555.43	558.51	546.22
Area (hectares)	138,915	118,140	105,825	118,910	67,190
Storage (km^3)	24.788	20.802	16.051	18.707	8.411
Inflows (km^3)	27.131	19.920	14.048	15.931	7.688
Releases (km^3)	26.613	19.915	14.098	15.975	7.823
Exchange rate (days)	340	381	416	427	392
			Oahe		
Elevation (m.msl)	489.60	486.77	480.70	483.96	471.71
Area (hectares)	123,930	109,595	84,200	98,335	52,810
Storage (km^3)	22.860	20.322	13.388	15.664	7.301
Inflows (km^3)	28.250	21.865	14.492	16.905	6.788
Releases (km^3)	27.496	21.857	14.529	16.829	7.038
Exchange rate (days)	303	339	336	340	379

* Source: MSRRS[32].

FIGURE 5 WATER LEVELS IN FORT PECK, SAKAKAWEA, AND OAHE RESERVOIRS OBSERVED IN 1976, AT 1970 DEPLETION LEVELS (THE 1898-1975 MEAN FLOW), AND AT ULTIMATE PROJECTED LEVELS IN 2000, THE MEAN (1898-1975), HIGH (1898-1930; 1944-54; 1965-75), AND LOW (1931-1942) FLOW YEARS.



Water depletions will also impact the reservoir fishery by altering the quantity and quality of spawning habitat. Reduced stream flows would affect species such as goldeye, sauger, paddlefish, and sturgeons by: (1) impeding migration of adults to spawning grounds; (2) retarding transport of eggs and larvae to the reservoir; (3) increasing water temperature; (4) decreasing oxygen content of water; and (5) altering the substrate by decreasing the bottom scouring action of the current and increasing silt deposition. Primary effect on reservoir habitat would be the reduction in the amount of littoral area available for spawning and alteration of the substrate since the finer sediments which have been deposited in the deeper water would become the shoreline.

CHAPTER 12

INTERIM ENVIRONMENTAL RECOMMENDATIONS

With the information presently available, general guidelines can be recommended to minimize and mitigate the environmental impacts of future developments on Lakes Fort Peck and Sakakawea. However, to minimize the environmental impacts on these reservoirs, the impacts on the terrestrial ecology and/or ground water may be increased. Therefore, each individual facility and its associated activities must be examined and operational guidelines established, and strictly enforced, to ensure that valuable or fragile components of the ecosystem are preserved.

Entrainment of egg and larval fish by improperly sited and operated water intake structures could have a significant impact on reservoir fish populations. Guidelines are already used by the FWS (Appendix N) to evaluate permits for irrigation intakes located in Missouri River impoundments. These guidelines encourage locating the intake in the main reservoir rather than in an embayment, at a minimum depth of 6 m (20 ft), and screening the intake with a mesh of 6 mm (0.25 inches); intake water velocities less than 0.15 m/s (0.5 f/s) are recommended to protect larval fishes (Atomic Energy Commission[33]; Pugh, Monan, and Smith[34]; Houde[35]). Unfortunately, data are not adequate to establish guidelines for locating irrigation intakes in tributary rivers, but they should be screened (6 mm) and have an intake velocity of less than 0.15 m/s.

The guidelines for irrigation intakes are applicable to permanent structures required by industrial and municipal users. Future predicted levels restrict locating permanent intake structures at elevations above 663 m.msl (2175 f.msl) in Lake Fort Peck and 545 m.msl (1787.5 f.msl) in Lake Sakakawea (MSRRS)[32]. Requiring permanent intake structures to be located an additional 6 m deeper would equilize requirements for all water users. Locating intake structures at the depths required for an uninterrupted water flow ensures that they will usually be constructed in the main reservoir rather than in an embayment. Screen size and water velocity at intakes should be the same as required for irrigation intakes. In general, the potential for entrainment from an intake is reduced the deeper, and the closer it is placed to the dam. When feasible, water should always be obtained from a reservoir rather than a tributary river.

Although sample size and location were restricted, the concentrations in fish flesh of mercury, selenium, and cadmium revealed high background levels. The available data indicates that increased loading of these reservoirs with heavy metals from any source must be avoided. Further increases of heavy metals in fish flesh could cause closure of the commercial fishery and severely impact the sport fishery because fish would be unsafe for human consumption.

Deleterious effects of municipal and industrial return flows will be minimized if state and federal water quality standards are met. Overloading of municipal sewage treatment facilities from population influxes associated with energy development will require prompt planning and construction of additional treatment capacity. Care should be taken to contain toxic wastes associated with coal mining and conversion processes, minimize sedimentation, and maintain the hydrologic regimen of tributary streams in the region. Pollution control and abatement facilities for the coal mines and the coal conversion plants must be designed to handle potential pollutants from three sources.

1. Solid Waste - Solid wastes include: (a) ash from gasifiers, evaporator residue, and fly ash from steam boilers, (b) inorganic sludge and silt from raw water treatment, (c) sludge from sewage treatment unit, and (d) refuse. Disposal of these wastes in the mine is the most logical solution depending upon the location of aquifers and the interchange between ground and surface water. Retention dams should be constructed on drainages being strip-mined to contain surface water runoff and sediments. Overburden piles, lignite storage piles, haul roads, etc. should be treated to minimize fugitive dust.
2. Waste Water - No waste from the coal gasification plants should be discharged into surface waters. Industrial water must be recovered for reuse within the plant, discharged as vapor, or, depending upon the aquifers, disposed of in deep wells. Effluent from sanitary waste treatment facilities should be used inside the plant for ash handling and other processes. Blowdown from the process water cooling towers should be used within the plant or evaporated. On site storage facilities should be provided for all liquid byproducts. In addition, adequate precautions such as diking around storage tanks, should be taken in order to prevent any discharge of these materials into surface waters. Heated effluents should be discharged from thermal electric plants in the form of vapor or dissipated by cooling ponds.
3. Gaseous Effluent - Except for potential toxic and/or heavy metal contaminants, the impact of gaseous effluents will be negligible because of the large dilution factor and high buffering capacity of these reservoirs. However, stringent controls may be required to protect the terrestrial ecology near industrial sites.

The proposed design and operation of the ANG conversion plant appears adequate to handle the above effluents. However, upon completion of this facility a thorough monitoring program should be conducted to ensure the plant adheres to stated operational procedures and to determine if any unforeseen deleterious environmental impacts occur.

The long-term cumulative water depletion in the system poses environmental problems which are difficult to minimize. The environmental impact statement by the Bureau of Reclamation[31] on the sale of 1.2 km^3 (1 million a/f) of water from the Missouri River reservoirs was the first attempt to examine the effects of water depletion on the entire system.

Unfortunately, only a fraction of the total projected depletions were included, and the treatment of the biological effects was incomplete. However, it is only through this type of analysis that guidelines will be established to protect the recreational and fishery resources of these reservoirs.

One method of estimating the effects of cumulative water depletions is to predict the potential standing crop and harvest of sport and commercial fishes at various water elevations. Physical, chemical, and climatic factors can be used to estimate the standing crops and harvest of fish in reservoirs (Jenkins[36], Jenkins and Morais[37]). Holding the chemical (TDS) and climatic (length of growing season) factors constant, and changing the physical factors (water level fluctuation, mean depth, water exchange rate, and surface area) in relation to projected water elevation, changes the predicted standing crop and harvest of fishes. With reduced elevations, the standing crop and harvest of sport fishes per unit area would change very little, but the standing crop and harvest of commercial species would increase substantially (Table 22). The change in total standing crop and production which would occur at various depletion levels was estimated by multiplying the biomass per unit area by the surface area of the reservoir. The relationship between water level elevation and total weight of standing crop and production was linear (Fig. 6). Solving the equations for any series of water levels gives the expected change in standing crops and production. Estimated total standing crops would decline from present levels about 6,400, 10,000 and 10,400 metric tons (14, 22, and 23 million pounds) in Lakes Fort Peck, Sakakawea, and Oahe, respectively, in low-flow years at the 2000 level of depletion. Total potential harvest would decline 545, 1000, and 725 metric tons (1.2, 212, and 1.6 million pounds) in Lakes Fort Peck, Sakakawea, and Oahe, respectively, under the above inflow conditions.

In summary, we believe that with proper design, operating procedures, and enforcement of these requirements, development of coal resources can be accomplished with minimal impact on the water quality and fishery resources of Missouri River reservoirs although the impact on terrestrial ecology or ground water could be severe. Location of coal conversion plants on tributary rivers should be discouraged since the reduced stream flows would decrease the input of nutrients into the reservoirs, reduce the quantity and quality of spawning habitat for many important reservoir fish species, and allow for less dilution of any effluents. Water intakes can be sited and operated in a reservoir with little, if any, entrainment or impingement of the egg and larval stages of fishes. Coal strip mines and conversion plants can be operated in a manner that precludes the release of liquid and solid effluents into the reservoirs. Gaseous emissions should not have a measurable effect on the reservoirs' water quality because of the large dilution factor and high buffering capacity of the water. The projected increase of irrigation, which not only depletes the most water but returns the most effluents (fertilizers, pesticides, herbicides, and sediments), will have the greatest impact on Missouri River reservoirs.

TABLE 22. PREDICTED STANDING CROPS AND POTENTIAL HARVEST (kg/h) OF SPORT AND COMMERCIAL FISH SPECIES IN FORT PECK, SAKAKAWEA AND OAHE RESERVOIRS AT PROJECTED LEVELS OF WATER DEPLETIONS

Category	1976 Observed	1898-1975 Mean	2000 Mean	2000 High	2000 Low
			Fort Peck		
Standing crop					
Sport*	78.0	78.0	77.7	77.8	76.5
Commercial	78.2	88.1	92.7	91.8	105.0
Total‡	156.3	166.0	170.4	169.6	181.5
Harvest					
Sport#	3.0	3.1	3.1	3.1	3.5
Commercial++	11.1	10.8	11.3	11.0	13.1
Total	14.1	13.9	14.5	14.1	16.6
			Sakakawea		
Standing crop					
Sport	76.3	76.3	75.0	75.2	72.8
Commercial	86.7	90.5	103.1	101.5	115.5
Total	163.0	166.8	178.1	176.7	188.2
Harvest					
Sport	2.9	3.0	3.1	3.0	3.5
Commercial	13.2	13.0	13.8	13.8	15.4
Total	16.1	16.0	16.9	16.8	18.8
			Oahe		
Standing crop					
Sport	74.8	76.8	75.6	75.7	74.2
Commercial	88.0	87.6	97.9	97.6	110.5
Total	162.8	164.3	173.4	173.3	184.7
Harvest					
Sport	4.0	4.1	4.5	4.3	4.9
Commercial	7.3	7.1	7.6	7.6	8.0
Total	11.3	11.2	12.1	11.9	12.9

* Log (sport fish standing crop) = 1.7183 + 0.3583 log (TDS/mean depth - 0.2585 [log (TDS/mean depth)]^2.

‡ Total standing crop = -108.2 + 70.32 log (growing season) + 55.48 log (flushing rate) + 20.7 log (water level fluctuation) + 77.61 log (TDS/mean depth) + 24.1 [log (TDS/mean depth)]^2.

Log (sport fish harvest) = -0.8104 - 0.2266 log (area) + 0.209 log (TDS) + 1.1432 log (growing season) - 0.2713 log (reservoir age).

++ Log (commercial fish harvest) = 6.4819 - 0.492 (mean depth) - 0.231 log (water level fluctuation) - 0.204 log (flushing rate) -2.453 log (growing season) + 0.482 log (reservoir age).

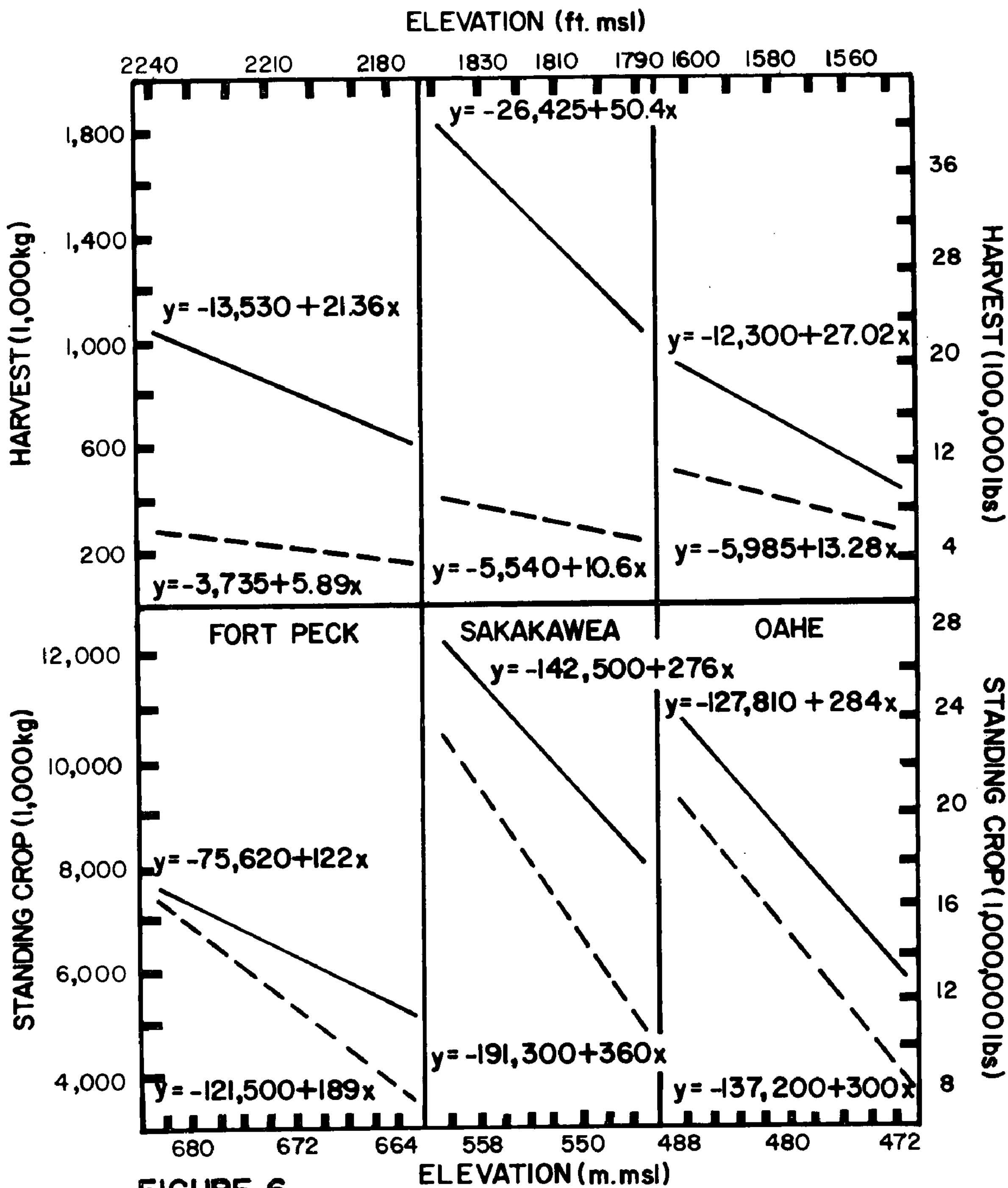


FIGURE 6

ESTIMATED TOTAL STANDING CROP AND HARVEST OF SPORT (broken line) AND COMMERCIAL (solid line) FISHES OVER THE PROJECTED RANGE OF WATER LEVELS IN FORT PECK, SAKAKAWEA, AND OAHE RESERVOIRS.

CHAPTER 13

FUTURE RESEARCH NEEDS

Data gathered in 1976 provides a cursory descriptive background of current biological conditions in Lakes Fort Peck and Sakakawea and the industrial and agricultural developments which may impact these reservoirs. The most critical data gaps encountered were concerned with the chemical constituents of effluents from coal conversion plants and baseline data on Fort Peck Lake and the use of tributary streams for spawning by reservoir fishes. The feasibility of developing a water quality-primary production model for the entire Missouri River reservoir system to evaluate increased nutrient inflow from increased population, agricultural, and energy development is also described.

The chemical constituents in solid, liquid, and gaseous effluents from coal-gasification plants and the fate of mine-site disposal of solid and liquid wastes must be known to establish guidelines for the management of heavy metals and toxic chemicals in tributary streams and the reservoir system. Additional information on the possible introduction of organic and inorganic pollutants into the aquatic ecosystems via surface or ground water discharge is needed. Future management of environmental contaminants will be balanced between the required levels of waste treatment at each site and the total number of energy conversion facilities built in an area. This problem could remain unresolved until coal-gasification plants are operating in the area and their effluents analyzed and volumes determined.

Before the impacts of future developments on Fort Peck Lake can be accurately evaluated, more extensive baseline data are required. The limnological characteristics of the entire reservoir should be described with the emphasis placed on physical and chemical parameters. The abundance, distribution, and growth rates of the dominant fish species and their spawning and nursery areas should be described. Special emphasis should be placed on describing the life history of lake trout since this species is particularly vulnerable to alteration in the existing habitat. Analysis of fish flesh for mercury, selenium, and cadmium should be expanded to better describe the background levels in economically important species such as walleye and goldeye.

Future water depletions from tributary streams will severely impact reservoir species that spawn in the tributaries. Studies should be designed to determine the relative contribution individual tributary streams make as spawning and nursery areas for reservoir fishes and the flow requirement of individual species. This project should be concentrated on the Yellowstone and Missouri Rivers above Lake Sakakawea and the Musselshell and Missouri Rivers above Fort Peck Lake. The extent of larval fish entrainment from presently operating intakes located in both streams and reservoirs should be assessed and engineering designs developed to establish installation requirements, particularly in the tributary streams.

Increases in population projected to accompany energy development of the upper Missouri River Basin will increase the quantities of phosphorus discharged into the main stem reservoirs. Limnological studies should concentrate on sampling chlorophyll, total phosphorus, and water clarity in main stem reservoirs. Combining this information with water chemistry data monitored on tributary inflows could lead to development of a water quality-primary production model for the entire Missouri River reservoir system. We believe such a model could be operational within three years. The model would be based upon watershed inputs and would be invaluable for predicting and assessing the effects of a given input on the water quality and primary productivity of an individual reservoir as well as downstream reservoirs.

CHAPTER 14

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CHAPTER 15

APPENDICES

APPENDIX A. WATER CHEMISTRY FOR LOCATIONS SAMPLED AT THE SURFACE (S) AND BOTTOM (B) IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Depth	Nelson Creek Bay			Sandy Arroyo Bay			Mid-reservoir		
		Sept	Oct	Nov	Sept	Oct	Nov	Sept	Oct	Nov
pH	S	8.2	8.1	8.1	8.2	8.2	8.1	8.2	7.9	8.1
	B	8.2	8.1	8.1	8.2	8.2	8.1	7.8	8.1	8.2
Total alkalinity	S	156	161	162	151	155	153	155	152	152
(mg/l $CaCO_3$)	B	157	160	161	152	155	153	149	153	154
Chloride	S	7.0	7.0	7.5	7.5	7.5	7.5	7.5	7.5	8.0
(mg/l)	B	7.0	7.0	7.5	7.0	7.5	7.0	7.0	7.5	7.5
Sulfate	S	200	200	200	180	180	160	180	180	180
(mg/l)	B	200	210	210	180	180	180	180	180	180
Silica	S	8.4	8.4	8.4	8.8	8.8	8.8	8.8	9.3	8.8
(mg/l)	B	8.1	8.1	8.1	8.8	8.8	8.8	9.3	8.8	8.8
Nitrate	S	.10	.05	.11	.06	.07	.06	.10	.08	.15
(mg N/l)	B	.11	.05	.10	.08	.06	.07	.08	.08	.10
Kjeldahl nitrogen	S	.52	.45	.22	.62	.37	.08	.64	.32	.13
(mg N/l)	B	.53	.24	.20	.41	.22	.21	.42	.25	.15
Specific conduct-	S	558	638	642	522	587	590	521	592	584
ance (micromhos)	B	601	647	648	527	588	593	485	589	588
Total organic	S	4	2	6	1	3	6	14	1	4
carbon (mg/l)	B	1	1	8	2	1	7	1	1	5
Total phosphorus	S	59	3	25	14	10	10	10	3	10
(mg/m^3)	B	10	3	1	10	2	28	26	4	14
Total cations	S	6.86	7.36	6.92	6.31	6.42	7.34	6.37	6.67	6.57
(meg/l)	B	7.14	7.45	8.12	6.32	6.43	7.61	6.32	6.81	7.41
Calcium	S	60	62	64	56	59	62	62	64	63
(mg/l)	B	56	62	74	61	61	77	61	66	78
Magnesium	S	12	20	11	17	17	21	14	18	21
(mg/l)	B	14	20	20	14	17	21	14	19	19
Sodium	S	64	58	63	47	46	56	47	44	38
(mg/l)	B	71	60	62	47	44	45	47	43	43
Potassium	S	4	4	3	3	3	3	3	3	2
(mg/l)	B	4	4	3	3	3	3	3	3	3
Turbidity	S	4.2	21.0	2.2	0.7	2.2	1.6	0.4	1.5	2.4
(J.T.U.)	B	7.2	5.6	16.0	6.9	22.0	3.4	3.0	3.2	2.1

APPENDIX B. HEAVY METALS CONCENTRATIONS (ppb) IN WATER SAMPLES COLLECTED AT THE SURFACE (S) AND BOTTOM (B) IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

		Nelson Creek Bay			Sandy Arroyo Bay			Mid-reservoir		
Parameter	Depth	Sept	Oct	Nov	Sept	Oct	Nov	Sept	Oct	Nov
Aluminum	S	300	1100	250	100	250	150	100	400	250
	B	350	450	850	375	1100	200	200	375	200
Arsenic	S	6	<5	<5	10	<5	<5	8	<5	<5
	B	8	<5	<5	8	<5	<5	10	<5	<5
Cadmium	S	<5	<5	<5	<5	<5	<5	<5	<5	<5
	B	<5	<5	<5	<10	<5	<5	<5	<5	6
Copper	S	<5	<5	<5	<5	<5	<5	<5	<5	<5
	B	<5	<5	<5	<5	<5	<5	<5	<5	<5
Iron	S	90	800	120	50	170	90	<25	170	180
	B	260	260	680	270	1200	140	120	230	80
Lead	S	<5	<5	<5	<5	<5	<5	10	<5	<5
	B	<5	<5	<5	<5	<5	<5	<5	<5	<5
Manganese	S	<5	25	5	<5	10	5	<5	10	5
	B	5	10	15	<5	25	5	<5	15	<5
Mercury	S	0.2	0.3	0.25	<0.2	0.35	<0.2	0.2	0.2	<0.2
	B	0.2	0.2	0.3	<0.2	0.9	<0.2	0.2	0.3	<0.2
Molybdenum	S	<10	<5	<5	<10	<5	<5	<10	<5	<5
	B	<10	<5	<5	<10	<5	<5	<10	<5	<5
Selenium	S	<5	<5	<5	<5	<5	<5	<5	<5	<5
	B	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	S	<5	20	15	5	15	25	5	50	25
	B	45	15	15	<5	65	15	10	10	15

APPENDIX C. PHYTOPLANKTON AND ZOOPLANKTON STANDING CROPS FOR LOCATIONS SAMPLED AT THE SURFACE (S) AND BOTTOM (B) IN FORT PECK LAKE IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Depth	Nelson Creek Bay			Sandy Arroyo Bay			Mid-reservoir		
		Sept	Oct	Nov	Sept	Oct	Nov	Sept	Oct	Nov
Chlorophyll	S	2.89	2.18	1.13	3.67	6.15	10.34	4.00	2.44	3.74
(mg/m^3)	B	2.87	1.62	1.36	2.42	4.59	9.33	0.46	2.87	3.87
Carotenoids	S	2.13	1.44	.99	3.19	4.26	5.72	3.19	1.14	2.36
($m\text{-}spu/m^3$)	B	2.32	.76	1.14	1.60	3.34	5.49		1.22	2.36
Chlor-Carot	S	1.4	1.5	1.1	1.2	1.4	1.8	1.3	2.1	1.6
(ratio)	B	1.2	2.1	1.2	1.5	1.4	1.7		2.4	1.6
430-665	S	2.6	2.2	2.4	2.8	2.4	2.4	2.5	2.3	2.6
(ratio)	B	3.1	2.2	2.7	2.6	2.5	2.5		2.0	2.5
Pennate diatoms	S		24.3	117.6	210.0	262.6	599.8	97.8	320.7	235.2
(no/ml)	B	173.0	36.1	92.6	14.7	109.3	599.8		276.6	417.2
Centrate diatoms	S	14.5	21.6	2.0	18.4	49.6	105.7		19.4	83.4
(no/ml)	B	20.6	47.1	8.1	18.4	29.0	70.5	6.1	38.8	33.7
Flagellate	S	3.9	45.2	144.5	3.9	58.6	271.8	1.0	101.0	123.2
(no/ml)	B		6.1		2.9	59.7	306.6		142.3	36.8
Immotile	S		16.5	6.1					16.5	
(no/ml)	B		43.5	7.1			14.5		6.1	
Blue green	S			35.1	27.5		15.5	2.0	27.8	
(no/ml)	B	85.9		14.5	36.1				14.5	
Cyclops	S	8,866	2,727	1,932	9,599	3,235	12,808	1,008	777	1,020
(no/m^3)	B	2,452	4,022	2,194	1,922	1,612	3,963	184	1,288	819
Diaptomus	S	1,471	2,000	2,170	1,974	4,470	5,932	770	834	1,026
(no/m^3)	B	134	2,284	2,171	240	1,664	3,192	58	946	1,010

(continued)

APPENDIX C (continued)

Parameter	Depth	Nelson Creek Bay			Sandy Arroyo Bay			Mid-reservoir		
		Sept	Oct	Nov	Sept	Oct	Nov	Sept	Oct	Nov
Daphnia (no/m^3)	S	4,250	1,841	2,136	2,292	2,430	2,154	1,102	675	276
	B	231	2,830	1,568	208	1,212	1,988	48	477	264
Diaphanosoma (no/m^3)	S	3,038	1,136	23	1,130	664	370	116	86	68
	B	106	1,284	23	94	382	124	2	102	76
Nauplii (no/m^3)	S	5,682	4,795	5,954	1,244	6,453	4,938	456	2,130	1,898
	B	4,346	3,955	5,194	1,115	5,129	3,648	34	2,029	1,382
Other (no/m^3)	S	10			10	6		2		
	B		12		202	165			4	83

APPENDIX D. SPECIES COMPOSITION AND RELATIVE ABUNDANCE OF FISHES IN MISSOURI RIVER RESERVOIRS IN THE EARLY 1970's (A = abundant; C = common; R = rare)

Common name	Scientific name	Lewis and Clark Lake	Lake Francis Case	Lake Sharpe	Lake Oahe	Lake Saka-kawea	Lake Fort Peck
Pallid sturgeon	Scaphirhynchus albus	R	R	R	R	R	R
Shovelnose sturgeon	S. platorynchus	C	C	A	C	R	C
Paddlefish	Polyodon spathula	C	C	R	R	C	C
Shortnose gar	Lepisosteus platostomus	C	C	R	R	R	R
Gizzard shad	Dorosoma cepedianum	C	C	C	-	-	-
Goldeye	Hiodon alosoides	C	A	C	A	A	A
Lake whitefish	Coregonus clupeaformis*	-	-	-	-	C	-
Coho salmon	Oncorhynchus kisutch* ‡ #	-	-	R	R	R	R
Kokanee salmon	O. nerka‡ #	-	-	R	R	-	R
Chinook salmon	O. tshawytscha*	-	-	-	-	R	-
Bonneville cisco	Prosopium gemmiferum‡	-	-	R	-	-	-
Rainbow trout	Salmo gairdneri* ‡ #	-	R	C	R	R	C
Brown trout	S. trutta* ‡ #	-	-	R	-	R	R
Lake trout	Salvelinus namaycush* ‡ #	-	-	-	-	R	C
Rainbow smelt	Osmerus mordax*	-	-	R	R	A	-
Northern pike	Esox lucius	R	R	R	R	C	C
Carp	Cyprinus carpio	A	C	A	A	A	A
Brassy minnow	Hybognathus hankinsoni	-	-	R	R	R	R
Silvery minnow	H. nuchalis	R	R	C	C	C	C
Plains minnow	H. placitus	-	-	R	R	R	C
Flathead chub	Hybopsis gracilis	-	R	R	R	R	C
Silver chub	H. storeriana	C	-	-	-	-	-
Golden shiner	Notemigonus crysoleucas	-	-	R	R	R	-
Emerald shiner	Notropis atherinoides	A	A	A	A	C	A
Spottail shiner	N. hudsonius‡ ++	R	-	-	C	-	-
Red shiner	N. lutrensis	C	C	C	-	-	-
Sand shiner	N. stramineus	-	R	-	-	-	-
Topeka shiner	N. topeka	-	-	R	R	-	-
Northern redbelly dace	Phoxinus eos	-	-	-	-	-	R
Bluntnose minnow	Pimephales notatus	-	-	R	R	-	-
Fathead minnow	P. promelas	R	R	C	C	C	C
Blacknose dace	Rhinichthys atratulus	-	-	R	R	-	-

(continued)

APPENDIX D (continued)

Common name	Scientific name	Lewis and Clark Lake	Lake Francis Case	Lake Sharpe	Lake Oahe	Lake Saka-kawea	Lake Fort Peck
Longnose dace	R. cataractae	-	-	-	-	-	R
Creek chub	Semotilus atromaculatus	-	R	R	R	R	-
River carpsucker	Carpiodes carpio	A	A	A	A	A	A
White sucker	Catostomus commersoni	R	R	C	C	C	C
Blue sucker	Cycleptus elongatus	R	R	R	R	R	R
Smallmouth buffalo	Ictiobus bubalus	C	C	C	A	C	C
Bigmouth buffalo	I. cyprinellus	A	C	A	A	C	A
Shorthead redhorse	Moxostoma macrolepidotum	C	R	C	C	C	C
Blue catfish	Ictalurus furcatus	R	R	R	-	-	-
Black bullhead	I. melas	R	R	R	R	R	C
Channel catfish	I. punctatus	A	A	A	A	A	C
Stonecat	Noturus flavus	R	R	R	R	R	R
Flathead catfish	Pylodictis olivaris	C	R	R	R	-	-
Burbot	Lota lota	R	R	R	R	C	A
Brook stickleback	Culaea inconstans	-	-	R	R	R	R
White bass	Morone chrysops++	A	C	C	C	C	-
Green sunfish	Lepomis cyanellus	R	R	R	R	-	-
Orangespotted sunfish	L. humilis	R	R	R	R	R	-
Bluegill	L. macrochirus	R	R	R	R	R	-
Smallmouth bass	Micropterus dolomieui*	-	-	-	-	R	-
Largemouth bass	M. salmoides	R	R	R	R	-	-
White crappie	Pomoxis annularis	C	C	C	C	C	C
Black crappie	P. nigromaculatus	C	C	C	C	C	C
Iowa darter	Etheostoma exile	-	-	R	R	R	R
Johnny darter	E. nigrum	R	R	-	R	R	-
Yellow perch	Perca flavescens	C	A	A	A	A	A
Sauger	Stizostedion canadense	A	C	C	C	C	A
Walleye	S. vitreum vitreum	C	A	A	A	A	A
Freshwater drum	Aplodinotus grunniens	A	C	C	C	A	A

* Introduced in Lake Sakakawea.
‡ Introduced in Lake Oahe.
# Introduced in Fort Peck reservoir.
++ Introduced in Lewis and Clark Lake.

APPENDIX E. TOTAL SAMPLING EFFORT (1000 m^3), TOTAL CATCH, AND CATCH OF INDIVIDUAL TAXA AT EACH SAMPLING STATION IN FORT PECK LAKE IN MAY AND JUNE, 1976 (SAMPLING EFFORT EXPENDED AFTER INITIAL CATCH OF EACH TAXA IN PARENTHESES)

	Embayment								
Depth	Upper Big Dry Arm	Nelson Creek	Rock Creek	Spring Creek	Mussel-shell River	Swan Creek	Hell Creek	Suther-land Creek	Total
				Total effort (tows in parentheses)					
Surface									
Upper	3.484 (9)	3.887 (10)	3.866 (10)	3.736 (10)	0.388 (1)	0.400 (1)	0.270 (1)	0.321 (1)	16.532 (43)
Mouth		3.948 (10)	3.912 (10)	3.797 (10)	0.283 (1)	0.444 (1)	0.437 (1)	0.426 (1)	13,247 (34)
3 m		0.123 (10)	0.131 (9)	0.114 (9)			0.027 (1)	0.026 (1)	0.421 (30)
6 m		0.134 (10)	0.121 (9)	0.127 (8)			0.025 (1)	0.027 (1)	0.434 (29)
Total	3.484 (9)	8.092 (40)	8.030 (38)	7.774 (37)	0.671 (2)	0.844 (2)	0.759 (4)	0.800 (4)	30.454 (136)
					Total catch				
Surface									
Upper	451	1324	71	196	11	22	216	329	2620
Mouth		261	166	120	39	26	53	70	735
6 m			1						1
Total	451	1585	238	316	50	48	269	399	3356
					Yellow perch				
Surface									
Upper	188 (3.484)	1312 (3.505)	49 (3.492)	196 (2.606)	5 (0.388)		215 (0.270)	329 (0.321)	2294 (14.066)
Mouth		257 (3.184)	165 (2.802)	120 (2.294)	3 (0.283)	1 (0.444)	53 (0.437)	70 (0.426)	669 (9.870)
Total	188 (3.484)	1569 (6.689)	214 (6.294)	316 (4.900)	8 (0.671)	1 (0.444)	268 (0.707)	399 (0.747)	2963 (23.936)

(continued)

APPENDIX E (continued)

Depth	Upper Big Dry Arm	Nelson Creek	Rock Creek	Spring Creek	Mussel-shell River	Swan Creek	Hell Creek	Suther-land Creek	Total
	Embayment								
					Freshwater drum				
Surface									
Upper	178 (1.914)	1 (1.146)				1 (0.400)			180 (3.460)
Mouth					6 (0.283)				6 (0.283)
Total	178 (1.914)	1 (1.146)			6 (0.283)	1 (0.400)			186 (3.743)
					***Notropis* sp.**				
Surface									
Upper	3 (1.914)	2 (0.772)	10 (0.813)						15 (3.499)
Mouth		3 (0.406)							3 (0.406)
Total	3 (1.914)	5 (1.178)	10 (0.813)						18 (3.905)
					White sucker				
Surface									
Upper	1 (1.528)								1 (1.528)
					Carp				
Surface									
Upper	13 (1.528)	3 (1.146)	2 (0.813)						18 (3.487)
Mouth			1 (1.958)						1 (1.958)
6 m			1 (0.051)						1 (0.051)
Total	13 (1.528)	3 (1.146)	4 (2.822)						20 (5.496)

(continued)

APPENDIX E (continued)

Depth	Embayment: Upper Big Dry Arm	Nelson Creek	Rock Creek	Spring Creek	Mussel-shell River	Swan Creek	Hell Creek	Suther-land Creek	Total
					***Ictiobus* sp.**				
Surface Upper	56 (1.528)	(1.192)	5			2 (0.400)			63 (3.120)
					Catostomids				
Surface Upper	8 (2.365)				1 (0.388)				9 (2.753)
Mouth		1 (1.959)							1 (1.959)
Total	8 (2.365)	1 (1.959)			1 (0.388)				10 (4.712)
					Cyprinids				
Surface Upper		5 (1.520)							5 (1.520)
					Goldeye				
Surface Upper	1 (0.757)								1 (0.757)
					***Pomoxis* sp.**				
Surface Mouth				1 (0.755)					1 (0.755)
					Walleye				
Surface Upper		1 (2.731)			1 (0.388)				2 (3.119)
Mouth					1 (0.283)				1 (0.283)
Total		1 (2.731)			2 (0.671)				3 (3.402)

(continued)

APPENDIX E (continued)

Depth	Upper Big Dry Arm	Nelson Creek	Rock Creek	Spring Creek	Mussel-shell River	Swan Creek	Hell Creek	Suther-land Creek	Total
					Embayment				
					Burbot				
Surface									
Upper			4 (3.866)						4 (3.866)
					Lepomis sp.				
Surface									
Upper					4 (0.388)	19 (0.400)	1 (0.270)		24 (1.058)
Mouth					29 (0.283)	25 (0.444)			54 (0.727)
Total					33 (0.671)	44 (0.844)	1 (0.270)		78 (1.785)

APPENDIX F. COLD-WATER FISHES INTRODUCED INTO FORT PECK LAKE

Year	Coho salmon	Kokanee salmon	Rainbow trout	Brown trout	Lake trout
1942			635,000		
1943			105,000		
1945				40,000	
1946		55,000	4,200	6,240	
1947		52,400			
1948		52,000			
1949		56,000	8,400	1,682	
1950		57,000			
1951		52,000			
1952		63,360	5,440		
1953					24,000
1954					137,287
1955					7,000
1956					153,318
1957					94,000
1969	141,240				
1970	178,000				
1972	174,132		228,311		
1973	71,400				
Total	564,772	387,760	986,351	47,922	415,605

APPENDIX G. WATER CHEMISTRY ANALYSIS FOR LOCATIONS SAMPLED AT THE SURFACE (S) AND BOTTOM (B) IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

Parameter	Depth	Renner Bay			Beaver Bay		Mid-reservoir	
		Sept	Oct	Nov	Sept	Oct	Sept	Oct
pH	S	8.0	8.1	8.0	8.1	8.1	8.0	8.0
	B	8.1	8.1	7.8	8.1	8.1	8.0	7.9
Total alkalinity ($Mg/l\ CaCO_3$)	S	147	148	152	149	145	146	146
	B	147	146	143	140	144	146	145
Chloride (mg/l)	S	8.5	7.5	8.0	8.5	8.0	8.5	8.5
	B	9.0	8.0	8.0	8.5	8.0	9.0	8.0
Sulfate (mg/l)	S	180	180	170	180	180	180	190
	B	180	180	160	180	190	180	190
Silica (mg/l)	S	7.8	8.1	8.8	8.1	8.4	7.5	8.1
	B	7.5	8.1	8.8	7.8	8.4	7.8	8.4
Nitrate (mg N/l)	S	.13	.11	.16	.16	.12	.15	.10
	B	.12	.12	.15	.12	.12	.16	.12
Kjeldahl nitrogen (mg N/l)	S	.51	.44	.29	.59	.23	.62	.29
	B	.49	.46	.20	.44	.19	.55	.22
Specific conductance (micromhos	S	5.9	596	569	498	581	536	588
	B	522	586	541	513	584	536	587
Total organic carbon (mg/l)	S	34	1	13	5	2	1	1
	B	4	3	6	26	2	36	1
Total phosphorus (mg/m^3)	S	10	4	14	10	3	10	5
	B	24	9	27	10	5	10	11
Total cations (meg/l)	S	6.39	6.49	6.95	6.28	6.24	6.64	6.50
	B	6.33	6.32	6.56	6.34	6.12	6.31	6.41
Calcium (mg/l)	S	56	55	60	49	58	53	57
	B	54	55	53	51	55	52	56
Magnesium (mg/l)	S	13	16	19	15	10	17	16
	B	13	15	18	15	11	14	16
Sodium (mg/l)	S	56	54	53	58	56	58	52
	B	57	52	54	57	55	57	51
Potassium (mg/l)	S	3	3	3	3	3	3	3
	B	3	3	3	3	3	3	3
Turbidity (J.T.U.)	S	1.6	3.5	3.2	1.9	5.6	1.6	4.0
	B	2.5	6.5	4.1	7.9	9.7	7.1	11.0

APPENDIX H. HEAVY METALS CONCENTRATION (ppb) IN WATER SAMPLES COLLECTED AT THE SURFACE (S) AND BOTTOM (B) IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

		Renner Bay			Beaver Bay		Mid-reservoir	
Parameter	Depth	Sept	Oct	Nov	Sept	Oct	Sept	Oct
Aluminum	S	150	200	200	100	250	<100	100
	B	100	325	150	550	450	300	375
Arsenic	S	6	<5	<5	6	<5	10	<5
	B	14	<5	<5	6	<5	6	<5
Cadmium	S	<5	<5	<5	<5	8	<5	6
	B	<5	6	<5	<5	8	<5	8
Copper	S	<5	<5	<5	<5	<5	<5	<5
	B	<5	<5	<5	<5	<5	<5	<5
Iron	S	40	120	120	70	200	50	120
	B	120	290	60	520	490	340	420
Lead	S	<5	<5	<5	<5	<5	5	<5
	B	<5	<5	<5	<5	<5	<5	<5
Manganese	S	<5	10	10	<5	5	<5	5
	B	5	10	10	10	15	10	15
Mercury	S	<0.2	<0.2	<0.2	<0.2	0.3	<0.2	<0.2
	B	<0.2	<0.2	0.25	<0.2	0.2	0.2	<0.2
Molybdenum	S	<10	<5	<5	<10	<5	10	<5
	B	<10	<5	<5	<10	<5	<10	<5
Selenium	S	<5	<5	<5	<5	<5	<5	<5
	B	<5	<5	<5	<5	<5	<5	<5
Zinc	S	5	20	25	5	15	10	15
	B	<5	20	35	<5	60	10	20

APPENDIX I. PHYTOPLANKTON AND ZOOPLANKTON STANDING CROPS FOR LOCATIONS SAMPLED AT THE SURFACE (S) AND BOTTOM (B) IN LAKE SAKAKAWEA IN SEPTEMBER, OCTOBER, AND NOVEMBER, 1976

		Renner Bay			Beaver Bay		Mid-reservoir	
Parameter	Depth	Sept	Oct	Nov	Sept	Oct	Sept	Oct
Chlorophyll (mg/m^3)	S	2.32	3.51	3.26	3.36	5.01	1.86	2.55
	B	2.16	3.24	3.38	3.02	5.35	2.41	1.62
Carotenoids ($m\text{-}spu/m^3$)	S	1.75	2.13	1.90	2.43	3.34	1.29	0.84
	B	1.06	2.13	1.98	2.20	3.34	1.90	0.30
Chlor-Carot (ratio)	S	1.3	1.6	1.7	1.4	1.5	1.4	3.0
	B	2.0	1.5	1.7	1.4	1.6	1.3	5.4
430-665 (ratio)	S	2.8	2.3	2.2	2.9	2.4	2.9	2.0
	B	2.3	2.8	2.2	2.6	2.2	2.9	2.1
Pennate diatoms (no/ml)	S	14.5	7.1	83.6	128.8	34.9	68.0	6.1
	B	64.2	161.1	135.5	228.7	33.9	--	42.9
Centrate diatoms (no/ml)	S	14.5	48.4	63.9	35.1	36.8	26.8	34.9
	B	--	5.9	4.9	16.5	36.8	12.3	98.1
Flagellate (no/ml)	S	58.1	213.2	282.3	107.7	101.0	346.9	273.9
	B	1.0	84.6	196.3	--	283.7	92.0	116.5
Immotile (no/ml)	S	--	--	21.6	1.0		14.5	12.3
	B	32.9	--	16.5	2.9	6.1	--	12.3
Blue green (no/ml)	S	65.8	63.6	--	69.9	14.5	31.9	14.5
	B	26.8	14.5	14.5	20.6	20.7	6.1	20.6
Cyclops (no/m^3)	S	1,931	1,188	1,862	1,656	6,210	1,900	948
	B	559	910	1,761	1,419	4,006	1,557	524
Diaptomus (no/m^3)	S	3,955	1,170	1,283	1,628	5,094	1,912	722
	B	778	932	1,069	919	3,318	1,044	324
Daphnia (no/m^3)	S	3,424	876	616	3,264	2,352	2,408	797
	B	757	500	516	703	1,602	792	98
Diaphanosoma (no/m^3)	S	139	19	26	176	257	98	46
	B	28	12	22	102	142	33	6
Nauplii (no/m^3)	S	1,472	1,918	3,330	1,446	2,872	1,253	1,967
	B	875	1,770	2,054	986	3,088	922	968
Other (no/m^3)	S	--	--	--	14	--	--	--
	B	--	--	6	94	237	2	--

APPENDIX J. TOTAL SAMPLING EFFORT (1,000 m^3), TOTAL CATCH, AND CATCH OF INDIVIDUAL TAXA AT EACH SAMPLING STATION IN LAKE SAKAKAWEA IN MAY AND JUNE, 1976 (SAMPLING EFFORT EXPENDED AFTER INITIAL CATCH OF EACH TAXA IN PARENTHESES)

	Embayment								
Depth	Upper Little Missouri	Hans Creek	Bear Creek	Highway 8	Renner Bay	Van Hook Arm	Tobacco Garden	Beaver Creek	Total
				Total effort (paired tows in parentheses)					
Surface									
Upper	3.758 (10)	3.189 (10)	3.216 (10)	2.542 (8)	0.980 (3)	0.295 (1)	0.338 (1)	1.227 (4)	15.545 (47)
Mouth		3.113 (10)	3.174 (10)	2.508 (8)	0.931 (3)	0.355 (1)	0.289 (1)	0.526 (2)	10.896 (35)
3 m		0.122 (7)	0.109 (7)	0.108 (7)	0.047 (2)	0.026 (1)	0.024 (1)	0.047 (2)	0.483 (27)
6 m		0.100 (6)	0.100 (7)	0.121 (7)	0.046 (2)	0.022 (1)	0.024 (1)	0.047 (2)	0.460 (26)
Total	3.758 (10)	6.524 (33)	6.599 (34)	5.279 (30)	2.004 (10)	0.698 (4)	0.675 (4)	1.847 (10)	27.384 (135)
					Total catch				
Surface									
Upper	801	226	1,072	339	178	15	18	407	3,056
Mouth		260	431	146	72	2	14	47	972
3 m									0
6 m					1		5		6
Total	801	486	1,503	485	251	17	37	454	4,034
					Yellow perch				
Surface									
Upper	158 (2.869)	184 (2.830)	1,033 (2.209)	319 (1.609)	177 (0.625)	13 (0.295)	3 (0.338)	407 (1.227)	2,294 (12.002)
Mouth		233 (2.418)	409 (2.135)	139 (1.562)	72 (0.577)	2 (0.355)		45 (0.526)	900 (7.573)
6 m					1 (0.023)				1 (0.023)
Total	158 (2.869)	417 (5.248)	1,442 (4.344)	458 (3.171)	250 (1.225)	15 (0.650)	3 (0.338)	452 (1.753)	3,195 (19.598)

(continued)

APPENDIX J (continued)

Depth	Upper Little Missouri	Hans Creek	Bear Creek	Highway 8	Renner Bay	Van Hook Arm	Tobacco Garden	Beaver Creek	Total
					Embayment				
					Freshwater drum				
Surface									
Upper	522	4					3		559
	(1.588)	(0.978)					(0.338)		(2.904)
Mouth		5					12		17
		(0.658)					(0.289)		(0.947)
6 m							5		5
							(0.024)		(0.024)
Total	522	9					20		581
	(1.588)	(1.636)					(0.651)		(3.875)
					White bass				
Surface									
Upper	3						4		7
	(0.651)						(0.338)		(0.989)
Mouth							1		1
							(0.289)		(0.289)
Total	3						5		8
	(0.651)						(0.627)		(1.278)
					Etheostoma sp.				
Surface									
Upper	2	36	38	7					83
	(0.312)	(1.582)	(1.603)	(0.982)					(4.479)
Mouth		20	17	3					40
		(1.278)	(1.536)	(0.958)					(3.772)
Total	2	56	55	10					123
	(0.312)	(2.860)	(3.139)	(1.940)					(8.251)
					Goldeye				
Surface									
Upper	27						2		29
	(0.973)						(0.338)		(1.311)
Mouth							1		1
							(0.289)		(0.289)

(continued)

APPENDIX J (continued)

Depth	Embayment: Upper Little Missouri	Hans Creek	Bear Creek	Highway 8	Renner Bay	Van Hook Arm	Tobacco Garden	Beaver Creek	Total
Total	27 (0.973)						3 (0.627)		30 (1.600)
Surface					Carp				
Upper	1 (0.312)								1 (0.312)
Mouth		1 (1.278)	1 (1.266)						2 (2.544)
Total	1 (0.312)	1 (1.278)	1 (1.266)						3 (2.856)
Surface					Walleye				
Upper	3 (2.524)	2 (2.509)							5 (5.033)
Mouth				1 (0.596)					1 (0.596)
Total	3 (2.524)	2 (2.509)		1 (0.596)					6 (5.629)
Surface					Rainbow smelt				
Upper				2 (0.982)	1 (0.625)				3 (1.607)
Mouth			1 (1.266)					2 (0.526)	3 (1.792)
Total			1 (1.266)	2 (0.982)	1 (0.625)			2 (0.526)	6 (3.399)
Surface					White sucker				
Upper	1 (0.312)						2 (0.338)		3 (0.650)

(continued)

APPENDIX J (continued)

Depth	Embayment								
	Upper Little Missouri	Hans Creek	Bear Creek	Highway 8	Renner Bay	Van Hook Arm	Tobacco Garden	Beaver Creek	Total
					Notropis sp.				
Surface									
Upper						2 (0.295)			2 (0.295)
Mouth		1 (0.329)							1 (0.329)
Total		1 (0.329)				2 (0.295)			3 (0.624)
					Hybognathus sp.				
Surface									
Upper	16 (0.973)								16 (0.973)
					Burbot				
Surface									
Upper			3 (1.614)	7 (1.249)					10 (2.863)
Mouth				2 (1.261)					2 (1.261)
Total			3 (1.614)	9 (2.510)					12 (4.124)
					Pomoxis sp.				
Surface									
Upper							1 (0.338)		1 (0.338)
					Cyprinids				
Surface									
Upper							2 (0.338)		2 (0.338)
					Catastomids				
Surface									
Upper							1 (0.338		1 (0.338)

APPENDIX K. COLD WATER FISHES INTRODUCED INTO LAKE SAKAKAWEA

Year	Lake whitefish	Coho salmon	Chinook salmon	Rainbow trout	Lake trout	Rainbow smelt
1965				180,135		
1966				209,442		
1970		100,125				
1971		228,742				4,800
1973					76,119	
1974	500	203,515			63,000	
1975		188,387			86,750	
1976			37,306			
Total	500	720,769	37,306	389,577	225,869	4,800

APPENDIX L. TOTAL SAMPLING EFFORT (1000 m^3) AND NUMBER OF LARVAL FISH CAUGHT IN THE MAJOR TRIBUTARY RIVERS IN MAY AND JUNE, 1976

Taxa	Missouri River		Poplar River	Redwater River	Yellowstone River	Little Missouri River	Total
	Wolf Point	Ft. Union					
Yellow perch			5(1.134)				5(1.134)
Goldeye						105(0.285)	105(0.285)
Carp	3(0.991)	89(0.452)	37(1.265)			3(0.285)	132(2.993)
Walleye		1(0.329)	8(2.138)	10(1.880)	1(0.715)		20(5.070)
Channel catfish					1(0.181)		1(0.181)
White sucker			103(1.265)	9(1.079)			112(2.344)
Burbot		2(0.329)					2(0.329)
Longnose dace			4(0.270)				4(0.270)
Cyprinids			51(1.134)	1(1.079)		3039(0.575)	3091(2.788)
Catostomids			24(1.134)	1(1.645)		4(0.355)	29(3.134)
Ictiobus sp.	8(0.991)	2(0.329)					10(1.320)
Total catch	11	94	232	22	2	3157	3518*
Total effort‡	1.370(9)	0.836(10)	2.138(10)	1.880(10)	0.894(10)	0.533(10)	7.651(59)

* Seven larval fish were unidentified and are not included in the species summary.
‡ Number of paired tows in parentheses of 1000 m^3.

APPENDIX M. CATCH OF ADULT FISHES PER EXPERIMENTAL GILL NET LIFT IN LAKES LEWIS AND CLARK, FRANCIS CASE, SHARPE, OAHE, AND SAKAKAWEA

Species	Lewis and Clark Lake *	Lake Francis Case ‡	Lake Sharpe ‡	Lake Oahe #	Lake Saka-kawea ⧺
Pallid sturgeon	**	**	0.1	**	**
Shovelnose sturgeon	**	2.3	4.0	1.7	**
Paddlefish	**	**	**	**	**
Shortnose gar	0.2	0.4	**	**	
Gizzard shad	1.9	**	0.4		
Goldeye	0.6	10.5	1.1	15.8	29.0
Bonneville cisco			**		
Rainbow trout			**	**	**
Kokanee salmon			**	**	**
Coho salmon			**	**	**
Rainbow smelt					**
Northern pike	**	0.1	0.3	0.9	0.5
Carp	2.2	4.1	7.2	2.4	2.9
Golden shiner				0.3	**
Blue sucker	**	**	0.4	**	**
Bigmouth buffalo	0.4	0.3	0.8	0.6	**
Smallmouth buffalo	0.3	0.4	0.2	0.1	0.1
River carpsucker	3.3	5.4	3.1	2.0	0.3
Shorthead redhorse	0.7	**	1.4	1.3	0.4
White sucker			0.1	0.1	1.6
Black bullhead		0.1	0.3	**	0.2
Channel catfish	3.4	5.9	5.0	2.6	2.5
Blue catfish		**			
Stonecat			**	**	**
Flathead catfish	**	**	**	**	
Burbot			**	**	**
White bass	0.5	0.7	0.1	1.7	
Bluegill		**	**	**	
White crappie	0.6	0.1	0.1	0.2	0.1 ≠
Black crappie	**	**	**	0.1	
Yellow perch	0.3	2.7	2.7	0.9	7.8
Sauger	4.1	1.2	2.0	1.1	2.4
Walleye	1.5	9.4	18.5	13.3	4.2
Freshwater drum	4.9	1.2	0.5	0.6	0.7
Total	24.5	45.0	48.6	45.5	52.8
Effort (lifts)	452	356	386	242	452

* Walburg, 1976.
‡ Unpublished data, NCRI.
# Unpublished data, NCRI and S. D. Game, Fish and Parks Dept.
⧺ Hill 1969, Ragen 1970 and 1972, Berard 1973 and 1975.
** Less than 0.05 fish per lift.
≠ Black and white crappies combined.

APPENDIX N. CRITERIA ADOPTED BY THE U. S. FISH AND WILDLIFE SERVICE FOR REVIEWING APPLICATION TO CONSTRUCT IRRIGATION WATER INTAKES IN THE MISSOURI RIVER

1. The Service's primary concern in irrigation intake structures is the resultant biological damage from pumping water in shallow embayments and backwaters. Therefore, siting the intakes in or near the main body of the reservoirs or free-flowing channels generally will be encouraged except areas which provide fish spawning, rearing, and feeding habitats, and areas important to waterfowl and other wildlife including endangered or threatened species of fish and wildlife.

2. In instances where sites in embayments of storage reservoirs are selected, the following criteria should be considered. Each spring when the intakes are installed, they should be placed at least 20 feet below the water level existing at that time. Installation at this depth usually would be sufficient to minimize fish losses during periods of spring and summer short-term drawdowns. Intake sitings in embayments where the above criteria cannot be met will be discouraged.

3. Intake sitings in backwaters of flow-through reservoirs and free-flowing channels also will be discouraged.

4. In shallow embayment areas, innovative devices that prevent the removal of young fish and their food supply will be considered as an alternative to pumping long distances to deeper water.

5. All water intakes should be screened. Screens with openings not to exceed 0.25 inches generally should be used. Special cases may require louvres, microscreens, bypasses, or other devices. A screen with opening of 0.25 inches at the recommended depth of the intakes will serve as a warning device, thus preventing most small fish from being drawn into the intakes.

6. Intakes should be designed so that the intake approach velocity cannot exceed 0.5 feet per second immediately in front of the screens. In some cases involving clupeid and cyprinid fishes, a lower intake velocity should be required.

7. Whenever diesel or gasoling-powered pump engines are used, a berm should be constructed around the fuel tank. The volume of the enclosure should exceed that of the fuel tank.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The North Central Reservoir Investigations (NCRI) group reviewed pertinent literature and conducted a one-year reconnaissance level aquatic study of potential energy impact areas of Fort Peck Reservoir in Montana and Lake Sakakawea in North Dakota.

Effects of energy development on the ecological conditions in the area can be projected from this ecological overview. Evaluated in this study were limnology, water chemistry and fisheries of the two Missouri River impoundments.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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