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river
dam
water flow
water level control
flooding
silt
turbidity
sedimentation
tailwater

A Study of the Effects of Spencer
Hydro Flushing on Water Quality,
Fishes, and Insect Fauna in the
Niobrara River

water action point tool
water

chemical characteristics
physical properties

Hesse, LW; Newcomb, BA

fish
in fish channel - life history

macroinvertebrates

mayflies

caddisflies

stoneflies

dobsonflies

beetles

phytoplankton

outside park

bibkey: 549721

State of Nebraska
Game and Parks Commission
Fisheries Division
Research

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CHAPTER 1

Niobrara River water quality as related to the flushing of Spencer Hydroelectric Dam with special reference to periodic fish kills

Introduction

The Niobrara River meanders across northern Nebraska for 484 km from headwaters to confluence with the Missouri River. Average annual discharge into the Missouri River is $45 \text{ m}^3/\text{sec}$. There are eight major tributaries to the Niobrara, the last being the Keya Paha River, 93 km upstream from the Missouri River - Niobrara River confluence. Nebraska Public Power District (NPPD) operates a hydroelectric power station (Spencer Hydro) 63.3 km upstream from the confluence. This facility has posed a complete barrier to fish migration since construction in the 1930's. A great amount of sand, silt, and organic debris is routinely carried down the Niobrara River and soon after Spencer Hydro was constructed the pond began filling with sediment. Within a few short years, this encroaching bed of material threatened to move into the vicinity of the turbine intakes and as a result a program of flushings developed. Records are unavailable for most of Spencer's history but in recent years flushings have occurred as needed or quarterly. The flushing procedure involves the raising of flood gates and a specially constructed sluice gate to permit the full flow of the Niobrara to erode the pond bottom and banks and carry this material downriver.

The first indication of a flushing related problem came in 1975 when a local landowner reported a fish kill associated with a flushing. Since that time several more fish kills resulting from the operation of Spencer Hydro have occurred.

The Nebraska Game and Parks Commission and the Nebraska Department of Environmental Control have engaged in routine water quality monitoring since 1975 in an attempt to identify the immediate cause of flush related fish kills and to determine whether a violation of State Water Quality standards occurred during flushings. This chapter will summarize these findings.

In addition, the Nebraska Game and Parks Commission investigated the dynamics of Niobrara River aquatic insect communities (Chapter 2) and the spawning chronology of channel catfish, the major sport fish in the Niobrara River (Chapter 3).

Previous investigation into the fish community structure of the Niobrara River was reported in Hesse et. al. (1979). 

During the course of public hearings held in 1978 to discuss a request for a Variance by NPPD to continue normal operation, it became evident that some factions were not aware of the impact of silt on aquatic environments.

Hollis et al. (1964) prepared a literature review of the effects of turbidity and siltation on aquatic life. We feel that this review is very important to the better understanding of the current research reported here and so a portion of this report is reprinted in Appendix I. A more recent literature review of this topic was completed by Muncy et. al. (1979). Recent research has demonstrated that fish eggs and larvae as well as plankton and macroinvertebrates have been impacted by suspended solids and sediment introductions.

Methods and Materials

The Nebraska Department of Environmental Control (DEC) was instrumental in gathering water quality data. Field personnel travelled to the site and obtained pre-flush data, followed by hourly samples after flushing began. Temperature (C), dissolved oxygen (DO in mg/l), and pH were measured in the field; conductivity, turbidity, total dissolved solids and suspended solids (SS in mg/l), and hydrogen sulfide (H_2S in mg/l) measurements were made in the laboratory in Lincoln, Nebraska. Two stations were established: Station A was 0.8 km below the Spencer Hydro Dam, Station was 3.2 km downstream of the dam. A portion of the data presented in Table 1.2 is published with the approval of Mike Swiggart, Head, Surveillance and Monitoring Section, Water Pollution Control Division, Department of Environmental Control.

The Nebraska Game and Parks Commission gathered information on various water quality parameters including settleable solids. In addition, research personnel sampled aquatic insect communities and channel catfish.

Results and Discussion

Spencer Hydro was flushed 22 times between January, 1975 and December, 1979. On 12 of these occasions, water quality data were gathered (Table 1.1) and on four occasions significant fish kills occurred (Table 1.2). Nearly all observed flushings resulted in the appearance of stressed fish throughout the area within a kilometer of the plant.

Rule 6 of the Nebraska Water Quality Standards for Surface Waters effective June 30, 1976 established the following numeric criteria to protect fish and wildlife and agricultural needs: dissolved oxygen level cannot be less than 6.4 mg/l, conductivity level cannot exceed 450 micromhos, total dissolved solids cannot exceed 400 mg/l. Under Rule 2(3) general numeric criteria for wastewater discharges or activities of man are given. Rule 2(3) states: "Turbidity caused by wastewater shall not import more than a 10 percent increase in turbidity, as measured in Jackson Turbidity Units, to the receiving water." Under Rule 2(2) "All surface waters shall meet general standards and shall be capable of supporting the assigned beneficial use (Rule 2 (1)). These waters shall be free of substances attributed to wastewater discharges or the activities of man that will form objectionable deposits, floating debris, oil scum and other matter producing objectionable color, odor, taste or turbidity." Specifically listed in Rule 2(2) is a standard for suspended, colloidal or settleable solids which

Table 1.1. Water quality in Niobrara River during the flushing of Spencer Hydroelectric 1975-1979.

Date	STATION A										STATION B									
	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l		
Oct. 18, 77	1145	11.0	9.5	7.4	300	2,450*	271	12,270	0.03	1145	9.5	11.4	7.6	270	525*	200	1,784	0.00		
	1215	11.0	9.9	7.4	285	2,200*	223	12,010	0.00	1215	10.5	10.0	7.4	310	2,075*	190	7,180	0.00		
	1245	11.5	11.1	7.5	290	1,575*	387	2,880	0.04	1245	11.5	9.8	7.3	300	2,050*	216	6,240	0.106		
	1315	12.5	11.1	7.6	295	1,400*	258	4,930	0.00	1315	11.5	10.0	7.3	310	1,850*	216	9,400	0.00		
	1345	12.0	11.4	7.6	260	1,025*	231	4,860	0.00	1345	12.0	10.8	7.4	300	1,600*	217	7,250	0.00		
	1415	13.5	10.3	7.5	285	1,425*	217	5,050	0.109	1415	13.0	11.6	7.4	290	1,300*	208	5,450	0.08		
										1445	14.5	11.4	7.5	285	1,050*	202	4,430	0.00		
Sept. 12, 78	1810	24.0	8.1	8.1	210	33	210	108	<0.1											
	0730	16.0	8.4	7.4	240	1,025*	253	6,320	<0.1											
	0800	16.2	8.2	7.4	240	1,050*	221	7,460	<0.1											
	0830	18.2	6.9	7.4	265	1,825*	193	13,880	<0.1											
	0900	19.0	7.0	7.3	265	1,425*	200	10,660	<0.1											
	0930	19.1	7.2	7.3	255	1,200*	196	12,040	<0.1	0930	20.0	8.3	7.4	205	140*	184	500	-		
	1000	18.0	7.2	7.3	250	1,025*	213	7,200	<0.1	1000	20.5	7.9	7.4	220	195*	185	700	-		
	1030	20.0	7.5	7.3	250	1,075*	236	8,440	<0.1	1030	20.5	7.7	7.3	220	360*	171	1,300	-		
	1100	20.0	7.2	7.3	250	1,250*	219	8,360	<0.1	1100	21.0	7.5	7.5	225	475*	270	1,820	-		
	1130	20.0	8.2	7.2	235	850*	218	5,940	<0.1	1130	21.0	7.2	7.5	225	650*	190	2,320	-		
	1200	24.0	8.0	7.2	250	950*	207	8,200	<0.1	1200	22.5	7.0	7.7	225	700*	193	2,340	-		
	1230	22.4	8.4	7.2	235	700*	190	5,010	<0.1	1230	23.0	6.9	7.6	230	700*	202	2,510	-		
	1300	24.0	8.4	7.2	225	675*	265	5,980	<0.1	1300	23.5	6.8	7.7	240	775*	188	2,620	-		
	1330	24.0	7.2	7.2	230	700*	184	5,750	<0.1	1330	24.5	7.0	7.9	230	650*	190	2,150	-		
	1400	26.5	7.0	7.2	230	675*	244	4,710	<0.1	1400	25.5	7.0	8.2	230	625*	192	2,110	-		
	1625	10.0	10.7	7.9	485	56	234	270	0.01											
	1720	9.0	11.0	7.9	260	43	210	178	-											
Nov. 7, 78																				

*Denotes a value exceeding legal limits

Table 1.1. Water quality in Niobrara River during the flushing of Spencer Hydroelectric 1975-1979.

Date	STATION A										STATION B									
	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l		
Nov. 8, 78	0730	5.0	4.1*	7.2	270	1,925*	220	13,035	0.19											
	0800	5.0	4.0*	7.3	290	1,325*	268	16,104	0.51											
	0830	5.5	4.6*	7.4	285	1,350*	236	7,420	0.51	0830	5.0	7.1	-	270	1,325*	210	7,320	0.12		
	0900	5.5	5.1*	7.4	260	1,075*	212	7,220	0.19	0900	5.0	7.1	-	270	1,100*	314	6,780	0.26		
	0930	5.5	4.5*	7.3	270	1,125*	272	10,220	0.51	0930	5.5	6.9	-	265	1,150*	322	6,400	0.08		
	1000	6.0	4.5*	7.3	260	950*	260	8,040	0.58	1000	6.0	7.1	-	260	1,100*	256	5,260	0.01		
	1030	6.0	4.7*	7.2	260	1,275*	218	8,440	0.40	1030	6.0	6.8	-	270	1,188*	266	6,020	0.08		
	1100	6.4	5.6*	7.2	250	900*	230	7,320	0.22	1100	6.0	7.1	-	260	800*	226	3,720	0.05		
	1130	7.0	5.1*	7.2	260	1,450*	324	9,780	0.30	1130	7.0	7.1	-	255	900*	242	5,240	0.05		
	1200	7.5	4.7*	7.0	270	1,725*	298	9,460	0.54	1200	8.0	6.9	-	240	950*	182	4,360	0.05		
	1230	8.5	4.8*	7.0	270	1,550*	210	7,880	0.65	1230	9.0	6.4*	-	270	1,175*	216	5,620	0.08		
	1300	8.8	5.1*	7.1	260	1,050*	264	8,140	0.30	1300	10.0	6.4*	-	260	850*	438	6,260	0.19		
	1330	9.0	5.0*	7.0	265	1,700*	236	8,000	0.58											
Apr. 10, 79	0735	4.0	11.6	8.4	260	64	243	196	0.36											
	0800	4.0	11.8	8.5	255	63	234	190	0.36											
	0830	4.0	11.5	8.6	255	98	240	420	0.28	0800	5.5	11.1	6.7	250	70	235	1,160	0.38		
	0900	4.0	11.6	8.5	260	465*	250	3,950	0.36	0830	5.5	11.3	7.0	260	82	240	552	0.32		
	0930	5.0	11.6	8.3	270	1,275*	229	6,540	0.38	0900	5.5	11.5	7.1	260	180*	227	728	0.39		
	1000	5.0	11.6	8.3	260	465*	272	3,700	0.34	0930	6.0	11.0	6.9	260	220*	233	1,300	0.41		
	1030	5.0	11.6	8.3	255	370*	228	2,840	0.60	1000	6.5	11.0	7.0	265	1,150*	228	6,090	0.34		
	1100	6.0	12.0	8.3	260	725*	244	3,720	0.40	1030	7.0	11.1	7.0	265	925*	223	5,020	0.39		
	1130	7.0	12.5	8.2	260	700*	245	4,870	0.04	1100	7.3	10.8	6.9	260	2,225*	207	2,940	0.39		
	1200	7.5	12.6	8.1	255	575*	207	3,510	0.34	1130	8.0	10.8	7.1	255	390*	223	2,230	0.39		
	1230	8.5	12.4	8.3	250	575*	230	2,120	0.33	1200	8.5	10.6	7.1	255	295*	234	1,360	0.40		
	1300	8.2	11.8	8.2	250	600*	238	3,030	0.28	1230	9.0	10.5	7.1	255	280*	233	1,470	0.38		
	1330	7.0	10.5	8.2	250	600*	231	3,820	0.38	1300	9.0	10.1	7.1	260	265*	221	1,350	0.32		
1400	7.0	10.9	8.3	255	575*	228	3,050	0.34	1330	9.0	10.0	7.1	250	285*	250	1,560	0.34			
										1400	8.5	10.5	7.1	260	270*	222	1,760	0.34		

*Denotes a value exceeding legal limits

Table 1.1. Water quality in Niobrara River during the flushing of Spencer Hydroelectric 1975-1979.

Date	STATION A							STATION B										
	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l
Oct. 28, 75	1215	11.5	13.2	7.8	255	29	120	100	—									
	1315	8.5	12.4	7.5	245	56*	132	236	—									
	1415	9.0	11.7	7.1	245	75*	20	3636	—									
	1515	10.0	10.4	7.3	265	975*	54	5620	—									
	1715	10.0	10.8	7.2	245	1075*	65	5690	—									
Oct. 29, 75	1115	5.0	15.2	7.2	260	200*	196	950	—	1115	6.2	12.4	7.1	260	200	96	656	—
Oct. 11, 76	0955	12.1	10.2	8.2	230	12	197	50	0.6	0930	12.0	10.2	8.1	210	14	180	61	0.2
	1045	12.0	10.8	8.2	205	23*	202	94	0.1	1045	12.0	8.2	7.2	220	21*	201	87	0.1
	1115	12.0	10.8	8.3	215	44*	189	207	0.1	1115	12.0	9.3	8.3	212	26*	187	110	0.2
	1145	14.0	11.6	8.4	210	41*	174	217	0.2	1145	14.0	9.5	8.5	215	25*	170	96	0.1
	1215	16.0	10.0	8.0	225	220*	187	1,014	4.0	1215	14.0	8.0	8.7	210	43*	182	188	0.2
	1245	17.0	3.5	7.4	315	3,750*	210	21,875	12.4	1245	14.0	9.2	8.9	220	62*	186	220	0.1
	1315	17.0	7.8	7.8	275	1,675*	183	17,883	2.2	1315	15.0	9.0	8.4	230	175*	172	886	0.8
	1345	17.0	8.2	7.9	275	1,575*	308	2,729	1.4	1345	19.0	5.0*	7.5	310	2,300*	250	14,700	2.3
	1415	17.0	8.0	7.9	270	850*	205	6,508	0.6	1415	20.0	5.2*	7.6	310	1,850*	249	12,271	0.4
	1445	17.0	7.8	7.7	295	738*	217	5,063	1.2	1445	19.0	6.5	7.8	280	1,400*	250	5,958	1.8
	1515	17.0	8.0	7.7	285	662*	171	6,943	0.7	1515	19.0	7.8	7.9	290	1,100*	227	6,500	0.2
Apr. 25, 77	1045	15.0	9.3	8.0	300	64	226	198	0.01	1055	11.5	10.0	7.8	300	73	274	262	0.00
	1115	10.0	8.7	7.9	300	79	160	724	0.07	1115	11.5	9.4	7.7	300	74	244	236	0.00
	1145	10.0	8.7	8.1	300	84*	268	500	0.03	1145	12.0	9.4	7.8	300	93*	286	442	0.13
	1215	13.5	8.6	8.0	300	225*	292	1,628	0.08	1215	12.5	9.0	8.1	305	85	256	348	0.03
	1245	14.0	8.7	8.1	310	512*	250	4,800	0.09	1245	13.0	9.0	8.2	300	125*	236	494	0.00
	1315	15.0	7.8	7.7	330	1,225*	410*	11,400	0.01	1315	13.5	8.8	7.8	300	238*	214	752	0.09
	1345	16.0	7.8	7.7	300	1,000*	300	8,810	.09	1348	14.5	8.4	8.0	300	275*	130	1,480	0.00
	1415	16.5	7.6	7.7	320	1,175*	270	5,030	0.00	1420	15.0	7.4	7.8	315	575	230	3,550	0.00

*Denotes a value exceeding legal limits

Table 1.1. Water quality in Niobrara River during the flushing of Spencer Hydroelectric 1975-1979.

Date	STATION A										STATION B									
	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l		
Apr. 25, 77	1445	17.5	7.7	7.8	315	487*	250	5,470	0.11	1445	15.5	7.5	7.7	315	425 *	0	2,610	0.00		
	1515	17.0	7.7	7.8	320	762*	660 *	5,700	0.06	1515	16.5	7.7	7.7	310	450*	90	2,470	0.00		
	1545	17.5	7.4	7.6	325	738*	610 *	5,720	0.00	1545	16.5	7.8	7.9	310	350*	70	2,100	0.09		
	1615	19.0	7.6	7.6	330	862*	360	7,710	0.40	1615	17.0	7.6	7.9	310	300*	0	2,180	0.06		
	1645	19.5	7.6	7.7	320	850*	570 *	6,150	0.17											
	1715	20.0	7.7	7.8	320	550*	610 *	4,200	0.07											
June 25, 77	1115	22.2	9.1	7.7	285	163*	206	360	0.05	1145	21.5	8.0	8.0	285	160	296	548	0.00		
	1145	24.0	9.2	8.0	280	155	250	530	0.00	1215	21.5	9.6	8.1	280	140	352	496	0.00		
	1215	24.9	9.4	8.1	280	155	260	604	0.00	1245	21.5	7.9	8.0	290	155	296	548	0.0004		
	1245	23.8	8.7	8.0	291	420*	192	2,348	0.0004	1315	22.0	8.0	8.0	290	195	244	680	0.00		
	1315	25.1	7.4	7.8	325	1,475*	180	11,560	0.00	1345	22.5	7.7	7.8	310	600*	190	2,610	0.0006		
	1345	26.5	7.7	7.7	330	775*	30	7,190	0.00	1415	23.0	7.3	7.9	310	700*	310	2,940	0.00		
	1415	25.2	7.4	7.7	315	1,200*	30	6,360	0.00	1450	23.0	7.6	7.9	300	525*	470*	2,195	0.00		
	1445	20.0	7.8	7.8	320	575*	90	6,310	0.00	1515	23.5	7.6	7.9	205	450*	120	1,860	0.0002		
	1515	28.0	7.9	7.7	315	375*	180	5,450	0.00	1545	23.5	7.4	7.9	310	400*	70	1,770	0.00		
	1545	25.4	6.7	7.6	325	1,000*	145	12,845	0.00	1620	23.5	6.8	7.8	310	550*	100	2,910	0.0004		
	1615	27.0	8.1	7.8	310	600*	130	4,590	0.00	1645	23.0	7.3	7.8	310	725*	90	2,850	0.00		
	1645	26.2	8.3	8.0	310	475*	620*	4,460	0.00											
	1715	28.5	8.4	7.9	310	450*	670*	4,100	0.00											
	Oct. 18, 77	0815	7.5	11.5	8.0	250	52	272	190	0.03	0845	8.0	12.2	7.9	250	54	200	282	0.00	
0845		7.5	11.1	8.4	240	57	286	208	0.00	0915	8.0	11.8	7.9	250	56	228	190	0.03		
0915		7.5	11.1	8.3	250	61	292	166	0.096	0945	8.0	11.6	7.9	255	54	202	188	0.09		
0945		7.5	11.5	8.3	250	83*	214	368	0.096	1015	8.5	12.0	8.0	255	58	182	166	0.106		
1015		8.0	11.5	7.9	250	200*	240	670	0.00	1045	8.0	12.4	7.9	240	74*	202	262	0.15		
1045		9.5	10.4	7.7	310	2,625*	501*	8,450	0.00	1115	9.0	11.6	7.8	255	162*	422*	318	0.00		

*Denotes a value exceeding legal limits

Table 1.2. Spencer Hydro flushing schedule, 1975-1979, showing dates when water quality was monitored and when fish kills were observed.

<u>Date of Flushing</u>	<u>Water Quality</u>	<u>Fish Kill</u>
March 1975		
April 1975		
July 1975		X
October 1975	X	
February 1976		
April 1976		
June 1976		X
October 1976	X	X
March 1977		
April 1977	X	
May 1977		
June 1977	X	
July 1977		X
October 1977	X	
March 1978		
May 1978	X	
September 1978	X	
November 1978	X	
April 1979	X	
May 1979	X	
September 1979	X	
November 1979	X	

states: "None from wastewater sources which will permit objectionable deposition or be deleterious for the assigned beneficial uses."

Exceedance of these standards occurred during the flushing operations of Spencer Hydro. At its lowest level dissolved oxygen was found to be 3.5 mg/l on October 11, 1976. Low levels of DO also occurred during the November, 1978 flushing. Acceptable levels for total dissolved solids, turbidity, suspended solids and settleable solids were surpassed in nearly every instance of flushing.

During 1979, water quality was monitored from the dam downriver to the mouth of the Niobrara under flushing and non-flushing circumstances (Table 1.3). The entire Niobrara system was shown to be affected by flushings. Mean turbidity 60 km below Spencer Hydro for June, July and September under non-flushing conditions was 56 JTU. Turbidity at this location after flushing began in September was recorded at 240 JTU, an increase of more than 400%. Settleable solids increased 15 fold over ambient at this same location (60 km below the source). Suspended solids increased four fold and dissolved solids more than doubled.

Few species of fish escaped the effects of flushing (Table 1.4). These numbers (22,471) are considered a conservative estimate of the total number of fish killed. During a flushing operation, fish stranded behind rocks and in depressions were quickly buried by a half meter or more of new sediment, and we saw only those near the end of the initial water level rise and decline. Other fish in extreme stress were observed to be carried downriver, beyond the limits of our survey area. Young-of-the-year and yearlings of most species were highly affected as demonstrated by length-frequency analysis of those fish killed during several flushings (Bliss, 1975; Wallace, 1976; Hesse, 1976 and 1977).

The actual cause of death was difficult to establish. A combination of events appears to have led to the fish kills. First, fish must be present in the immediate vicinity of the tailwaters. The largest populations are probably there in the summer and fall months and the fish kills which occurred took place in summer and fall. Fish are present at all times but in lesser numbers in the spring and early winter (Hesse et. al. 1979). It was evident in most flushings that the extreme increase in water level, water velocity and sediment load along with declining DO and the buffeting by large debris caused fish to become disoriented and very stressed. The presence of fish in large numbers near the shores and their willingness to remain there even when prodded indicated their stressed condition.

The presence of a great deal of cobble and boulder substrate in the vicinity of the tailwater provided places where stressed fish could find safe harbour from the intense river velocities. Once in these protected spots their escape was quickly cutoff by sediment deposition. These pockets eventually filled with sediment which buried the occupants or dried up causing the fish to be stranded; in any event, death was inevitable. The consequences of a kill quickly disappeared. Large water birds preyed upon trapped fish soon after the first fish appeared, and because flushing went on for three or four days, bars were periodically inundated and eroded away carrying dead fish downstream.

Table 1.1. Water quality in Niobrara River during the flushing of Spencer Hydroelectric 1975-1979.

Date	STATION A										STATION B									
	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l	Time	Temp. oc	DO mg/l	pH	Cond. umho/ccm	Turb. JTU	TDS mg/l	SS mg/l	H ₂ S mg/l		
May 15, 79	0650	11.0	9.6	7.9	270	31	233	77	0.12											
	0700	11.0	9.8	7.9	265	49	234	238	0.15											
	0730	11.0	9.8	8.1	270	58*	226	288	0.12	0730	12.8	15.0	7.8	270	33	214	164	0.15		
	0800	11.5	9.2	8.2	270	165*	244	1,008	0.13	0800	13.0	14.4	7.8	280	67*	264	282	0.18		
	0830	12.0	8.9	8.0	280	365*	239	2,770	0.16	0830	14.0	15.2	7.7	275	61*	232	268	0.21		
	0900	12.5	8.6	8.0	290	370*	234	3,320	0.12	0900	14.0	16.2	7.7	270	140*	212	570	0.18		
	0930	13.5	7.2	7.8	310	2,075*	241	9,600	0.10	0930	15.0	16.1	7.5	280	235*	232	1,060	0.21		
	1000	14.5	8.1	8.1	290	1,350*	225	8,520	0.16	1000	15.0	16.0	7.4	290	335*	261	1,472	0.18		
	1030	15.0	8.2	8.1	280	1,550*	232	9,460	0.09	1030	15.8	11.5	7.2	320	1,625*	234	5,860	0.18		
	1100	17.0	8.9	8.1	280	1,225*	223	8,050	0.13	1100	16.4	13.2	7.3	300	825*	242	4,440	0.15		
	1130	17.0	8.9	8.1	290	1,150*	245	8,800	0.13	1130	16.8	12.8	7.3	295	1,050*	228	5,350	0.22		
	1200	18.0	8.9	8.1	290	1,100*	218	7,580	0.16	1200	17.0	13.0	7.3	290	750*	233	3,940	0.19		
	1230	17.5	8.5	8.1	275	470	228	3,250	0.16	1230	17.8	13.0	7.3	290	650*	235	4,340	0.22		
	1300	—	—	—	275	800	219	4,300	0.19	1300	18.8	13.2	7.4	290	625*	230	3,220	0.16		
										1330	18.9	13.0	7.4	280	575	229	3,090	0.18		

*Denotes a value exceeding legal limits

Table 1.3. Water quality in Niobrara River in 1979 under non-flushing and flushing conditions of Spencer Hydroelectric Dam.

Date	Time	DO	Temp	pH	Turbidity	Settleable Solids (S.)	Suspended S.	Dissolved S.	Conductivity
Station 1: Highway 12 bridge--60km below Spencer Dam, 1.6km upstream of mouth.									
June 18 (Control)	9:00 AM	10.2	17.0	7.7	43	0.10	134	214	240
July 30 (Control)	8:35 AM	8.8	24.4	7.9	65	0.09	186	197	230
Sept. 17 (Control)	4:22 AM	—	17.0	7.9	59	0.10	140	197	250
Sept. 17 (Flushing)	5:20 PM	—	—	—	—	0.20	—	—	—
Sept. 18 (Flushing)	5:05 PM	8.4	23.5	8.0	240*	1.81	620	491*	245
Sept. 19 (Flushing)	12:50 PM	—	—	7.9	155*	0.60	348	208	245
Station 2: Pischelville bridge--39km below Spencer.									
Sept. 17 (Control)	5:30 AM	—	—	7.8	51	—	114	207	245
Sept. 17 (Flushing)	7:00 PM	—	—	—	—	2.25	—	—	—
Sept. 18 (Flushing)	3:46 PM	—	—	7.8	43	1.75	428	240	250
Sept. 19 (Flushing)	—	—	—	7.9	150*	—	388	219	240
Station 3: Redbird bridge--18km below Spencer.									
June 18 (Control)	12:25 PM	12.2	16.4	7.7	5.4	0.14	180	211	240
July 30 (Control)	11:01 AM	8.6	25.8	8.2	66	0.11	254	188	230
Sept. 17 (Control)	6:10 AM	—	—	7.7	70	0.28	216	217	230
Sept. 17 (Flushing)	2:45 PM	—	—	—	—	15.60	—	—	—
Sept. 18 (Flushing)	3:30 PM	8.2	22.0	7.7	240*	1.63	1100	213	250
Sept. 19 (Flushing)	—	—	—	7.7	170*	1.25	576	217	250
Station 4: Tailwaters of Spencer Dam.									
June 18 (Control)	2:45 PM	9.6	16.5	—	—	0.05	—	—	—
July 30 (Control)	1:30 PM	8.6	26.5	8.1	47	0.05	106	215	230
Sept. 17 (Flushing)	8:15 AM	6.1*	17.1	7.1	2075*	46.50	14540	237	315
Sept. 17 (Flushing)	11:20 AM	—	—	—	—	18.00	—	—	—
Sept. 18 (Flushing)	—	8.5	20.4	8.0	110*	0.50	464	234	235
Sept. 19 (Flushing)	9:50 AM	—	—	7.8	190*	1.87	156	207	240
Station 5: Highway 11 bridge--22km above Spencer, 15km below mouth of Keya Paha River.									
July 30 (Control)	2:30 PM	8.2	29.5	8.4	54	0.14	196	232	235
Sept. 17 (Control)	9:30 AM	—	—	—	34	—	100	227	225
Sept. 18 (Control)	9:45 AM	9.6	17.5	8.1	31	0.10	101	211	235
Sept. 19 (Control)	9:10 AM	—	—	8.1	32	0.05	109	202	220
Station 6: Grand Rapids bridge--47km above Spencer, 10km above mouth of Keya Paha River.									
June 18 (Control)	5:01 PM	9.0	17.2	7.9	38	0.09	130	181	210
July 30 (Control)	4:40 PM	8.2	29.6	8.4	62	0.11	186	193	205
Sept. 17 (Control)	10:30 AM	—	—	8.1	40	—	128	189	215
Sept. 18 (Control)	8:30 AM	9.6	16.0	8.1	35	0.10	192	217	240
Sept. 19 (Control)	7:30 AM	—	14.0	7.9	38	0.05	126	180	220

*Denotes a value exceeding legal limits

Table 1.4 Fish found dead in the Niobrara River following the flushing of Spencer Dam, 1975-1979.

Species	Number
Channel catfish	954
Walleye	9
\Sauger	94
Green sunfish	31
\Bullhead	10
Madtom	4
\Bluegill	29
\Gizzard shad	2
\Largemouth bass	78
\Drum	158
Crappie	41
\Carp	560
Shorthead redhorse	763
River carpsucker	819
Stonecat	58
Goldeye	2
Northern pike	5
Brown trout	4
Smallmouth bass	2
White sucker	2
Minnow species	18846
TOTAL COUNTED	22471

One consequence of flushing that has had little study is the effect of dewatering on the Niobrara after flushing has ended. Flow was reduced for a short time in order to refill the reservoir. This effectively dewatered the Niobrara for a short period only. But the consequences of this dewatering can be significant if it occurs during a period when fish eggs are abundant in the river.

During 1977 and 1978, age-0 channel catfish were sampled from the Niobrara with an explosive (Primacord) according to the method of Hesse et. al. (1979). From these samples, the mean monthly length of age-0 fish was determined and an estimate of population numbers was made.

Whether siltation or dewatering was the cause, a reduced spawning season for channel catfish occurred in 1977, when flushings occurred in March, April, May, June and July. Channel catfish began to spawn in the Niobrara during the last half of May, 1977 (Hesse et. al. 1979). Water flow in the Niobrara River is relatively stable with minimal fluctuations in stage (Niobrara River Basin Water Quality Management Plan 1976; Hesse, personal observation). Because the river is shallow and quite braided water temperature from year to year is consistent especially during the summer. These factors should have very little influence on catfish reproductive behavior. Several papers reviewed by Hollis et. al. (1964) stated that siltation can reduce egg and prolarval survival through reduced oxygen transfer across the silt laden chorion and because of physical abrasion, causing gill membrane inflammation. Flushing occurred on May 19, 1978 and not again until September, 1978. In 1978, the mean length of age-0 catfish in each month was lower than in 1977 (Table 1.5). Smaller fish were present in the river later in the year in 1978. We concluded that in 1978 greater survival of egg and larval catfish occurred over an extended successful spawning season because of the absence of flushings. Apparently heavy mortality occurred during August and September, 1977. The CPE increased from June to July as expected and then rapidly decreased (Table 1-5). In 1978, when flushing was not a factor throughout the breeding season, CPE continued to rise throughout the entire spawning period.

A flushing occurred July 25, 1977 at which time a major fish kill occurred. Channel catfish was the most heavily affected game species as demonstrated by the number of dead fish tabulated. Flushing commenced at 12:00 noon; stressed fish were evident at 3:00 p.m. below the dam.

The population estimate of young-of-the-year catfish was obtained from explosive samples acquired the previous day, July 24, 1977. The evidence is still circumstantial since we cannot say without question that the heavy mortality experienced between July and August, 1977 was plant induced. But the evidence suggests that the flushing is suspect.

The upper Niobrara (upstream of Spencer Hydro) was found to have only a small population of juvenile and adult channel catfish as demonstrated by hoop-net CPE in 1977 (Hesse et. al. 1979). This portion of the Niobrara is entirely isolated from the lower river by Spencer Hydro. Mean monthly lengths from 1978 Primacord samples above the dam were higher than below (Table 1.5). This may indicate that growth above the dam is better because of better food supply and a lack of competition, since a limited population of older fish apparently exists above Spencer Dam as shown from hoopnetting CPE (Hesse et al 1979).

Table 1.5. Mean length, catch per unit effort and population estimates for young-of-the-year channel catfish in the Niobrara River, 1977-78.

Year and River Section	Month	Location	Length		$\bar{X}$	CPE*	Std. Dev.	Population** Estimate	95% C.I.	Minimum Length Fish (mm)
			$\bar{X}$	Std. Dev.						
1977 Lower Niobrara	June	Bank	25.57	3.89	174.8	169.2	13,355	+ 21,208		20
	July	Bank	47.07	12.88	787.2	851.49	60,142	+ 106,685		23
	Aug.	Bank	61.77	8.56	259.1	232.2	19,795	+ 29,098		39
	Sept.	Bank	63.40	17.09	61.5	57.4	4,699	+ 7,189		44
1978 Lower Niobrara	June	Bank	27.47	4.50	98.9	139.8	7,556	+ 17,520		17
		Midbar	27.47	4.50	98.9	139.8	380,747	+ 333,889		
	July	Bank	36.76	8.85	189.0	89.1	14,440	+ 11,163		20
		Midbar	36.76	8.85	189.0	89.1	727,800	+ 212,778		
	Aug.	Bank	47.97	9.53	252.0	69.3	19,253	+ 8,682		25
		Midbar	47.97	9.53	252.0	69.3	970,400	+ 162,528		
	Sept.	Bank	58.44	10.17	378.0	--	28,879	--		29
		Midbar	58.44	10.17	378.0	--	1,455,600	--		
1978 Upper Niobrara	July	Bank	44.36	8.52	56.4	101.1	8,884	+ 31,437		23
		Midbar	42.30	8.07	277.8	523.9	1,006,045	+ 3,111,719		
	Aug.	Bank	55.23	5.79	91.2	141.6	14,359	+ 44,024		53
		Midbar	67.02	5.56	291.7	810.7	1,056,358	+ 4,815,357		
	Sept.	Bank	70.06	6.80	133.5	305.0	21,023	+ 94,801		54
		Midbar	67.65	6.49	270.0	726.4	977,886	+ 4,314,885		
	Oct.	Bank	72.20	3.35	9.12	18.8	1,436	+ 5,856		69

*CPE = Channel catfish/KM for bank and channel catfish/hectare for midbar.

**Based on estimated bankline habitat of 76.4 KM for Lower Niobrara, 190.1 KM for Upper Niobrara and estimated midbar habitat of 1455.6 ha for Lower Niobrara, 3621.8 ha for Upper Niobrara.

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CHAPTER 2

The influence of Spencer Hydroelectric Dam on the aquatic insect communities of the Niobrara River

Introduction

Environmental disturbances may cause temporary and/or long-term alterations in aquatic invertebrate faunas of lotic habitats (Lehmkuhl 1979). Fluctuating water level ecosystems can be productive provided the communities can adapt to the frequency and magnitude of the fluctuations, but this degree of adaptation requires time measurable on the evolutionary time scale (Fisher and LaVoy 1972). Fluctuating water levels such as occur at Spencer Hydro during and after flushing can produce what Fisher and LaVoy (1972) term a freshwater "intertidal zone". A similar situation was documented by Radford and Hartland-Rowe (1972) and Grimas (1965).

Periodic flushing of Spencer Hydroelectric Dam on the Niobrara River has caused large fluctuations in the water level below the dam (Hesse, 1976, 1978; Wallace, 1976). Heavy loads of sediment have been released upon the lower Niobrara River and as Hollis et. al. (1964) has reported there are potential significant consequences. Mayfly populations have been affected by these flushings and there has been concern as to the effects on the entire lower Niobrara insect fauna (Wallace, 1976). This project was an attempt to monitor the short-term effects of Spencer Dam flushings on the aquatic insect fauna of the Niobrara River and to provide insight into the long-term consequences.

Methods and Materials

Between April and October, 1979, Spencer Hydro carried out routine flushing operations only in September. During this flushing, aquatic insect samples were taken from stations located above and below the power station (Figure 2.1). Control samples were acquired in June and July from these same locations.

Aquatic insects were collected from the drift and from artificial substrate samplers at each station (Figure 2.1). Station 2 was inaccessible because of road construction. Multiple plate artificial substrate samplers were constructed according to Parsons and Tatum (1974) and six were placed at each station for a minimum of 54 days before retrieval, an adequate time for colonization (Crossman and Cairns, 1974). Samplers were retrieved and the entire multiple plate preserved in 70% ethanol and returned to the lab for insect enumeration and identification. Drift samplers were rectangular shaped nylon nets of #0 Nitex mesh (0.571 mm apertures), 1.37 m long with a 0.114m² mouth surface area. Each drift net carried a calibrated flowmeter suspended in the mouth. Samples were obtained by holding the net stationary in the current for 2-10 minutes. Samples were preserved in 10% formalin and returned to the laboratory and stained with Rose Bengal.

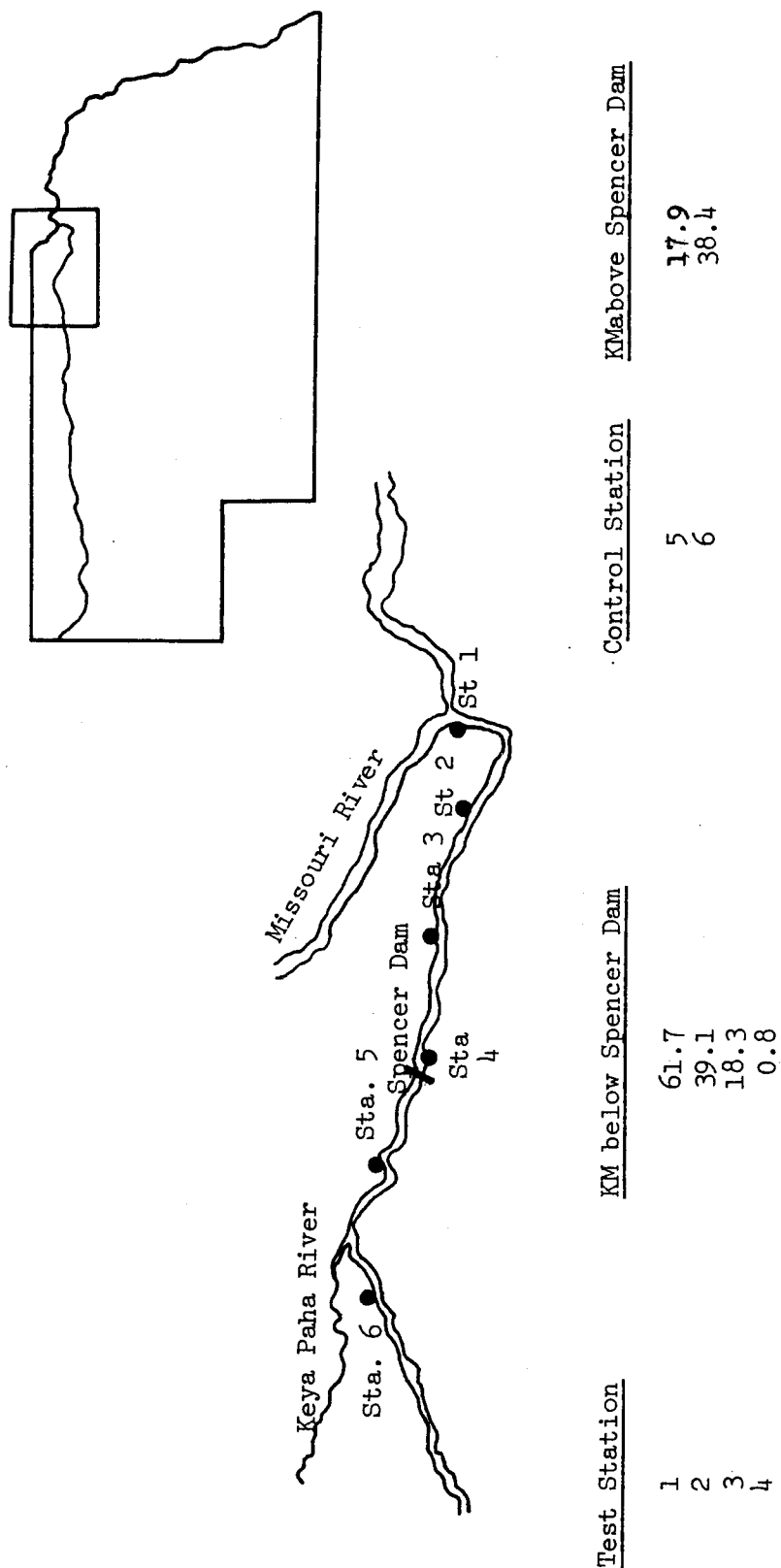


Figure 2.1 Niobrara River insect sampling stations, 1979

In the laboratory, easily observed insects from multiple plate samples were picked from white pans. Insects in drift samples were separated from debris by the water floatation method of Koosman and Newburg (1977). The remaining portion of the samples, which contained very small organisms, was subsampled with a Hensen-Stempel pipet. The subsample normally amounted to 10% of the sample. The subsampling procedure was tested statistically by comparing two groups of five replicate subsamples from one multiple plate sample in a Student's-t. There was no significant difference in the mean number of each of the eight species encountered ($P > 0.01$). All insect identification and enumeration was done with a stereoscopic microscope and was aided by keys from Borrow et. al. (1976), Edmunds et. al. (1976), Johannsen (1969), Merritt and Cummins (1978), Needham and Needham (1972), Pennak (1978), Usinger (1956), and Wiggins (1977).

Beals' Prominence Index (c) (Beals 1960) was used to compare similar sample stations along the Niobrara River to detect the influence of a pollutant entering the system. A "prominence" value for each insect group (Genera) at a sample station was obtained by multiplying the density at that station by the square root of the frequency of that group at all stations. Thus to compare two stations the following equation was used:

$$C = 2(P_1)/P_i + P_j$$

where P_i is the sum of the prominence values of all groups at station i, P_j is the sum at station j, the value of P_1 is the sum of the lowest prominence values for each insect group common to both stations. The value of C can vary from 0 to 1 with 1 indicating an identical comparison between the two stations. The prominence indices are useful only to compare two stations at a time. To derive the comparison of all stations as a unit, cluster analysis was performed. A matrix of prominence indices was formed for each sampling period. These matrices were then clustered using the unweighted pair-group method (UPGMA) of Sokal and Sneath (1963) from which dendograms were subsequently prepared for graphic representation of the clustered matrices.

Results and Discussion

Drift samples exhibited large variability between stations and sampling dates (Table 2.1); therefore, no statistical analysis was attempted on this data. However, one organism (Isonychia sp) appeared much more abundantly in the drift below the plant during the September flushing operations, while previous sample dates showed large numbers attached but not in the drift. This indicates a migratory response to flushing. In general, Isonychia sp were most abundant in the drift during flushing, while Caenis sp, Heptagenia sp and Diptera larvae were most abundant in the drift during non-flushing periods.

A reduction in gross numbers of many species occurred below the plant after flushing operations began (Table 2.1). In all sampling periods, Brachycercus sp, Ephoron sp, Hexagenia sp, Brachycentrus sp, Mayatrichia sp, Ceraclea sp, and all Odonata species were found to inhabit multiple plate samplers only above the influence of Spencer Hydro, a clear indication that long term influence has resulted from flushing operations. One organism,

Tricorythodes sp, was not collected below the plant after flushing began, but was evident in control stations. This same organism was collected below the plant in the previous non-flushing periods.

Similarity (Prominence) matrices and dendograms for multiple plate samples are reported in Table 2.2. Similarity coefficients indicate a fairly even level of similarity between all stations in the June and July sampling periods. Comparisons between stations 4 and 5 showed the lowest similarity in June and July, with 33% and 14% similarity, respectively. Since station 4 was expected to be most affected by flushing operations, the mean similarity coefficient of station 4 comparisons was tested against the mean similarity coefficient of all station comparisons, with station 4 excluded in June and July. No significant difference was demonstrated in June or July ($P > 0.01$). However, following flushing which began September 17, the values were found to be significantly different in a Student's-t ($P < 0.01$). The mean station 4 value was $13\% \pm 1.3\%$ (SE) and the mean value for all other stations comparisons was $71\% \pm 16\%$ (SE). The mean value for station 4 comparisons, ($13\% \pm 1.3\%$ SE), closely approximates the level (10%) reported for aquatic environments immediately below an effluent discharging raw sewage (Burlington 1962).

The dendograms resulting from cluster analysis diagrammatically represent the data and give clear evidence of very low similarity between station 4 and the aggregation of all other stations in September (Table 2.2). In July, the aggregation of stations 3 and 4 had low similarity with the aggregation of the other three stations. This information provides evidence of intense short-term effects in September during the flushing and indicates a possible long-term alteration based on July data.

Table 2.1. Summary of insect collections from multiple plate samples (/m²) and, in parenthesis, drift samples (# /m³) from the Niobrara River, 1979.

	JUNE 18						JULY 30						SEPT. 18					
	STATION			STATION			STATION			STATION			STATION			STATION		
	TEST	AREA		TEST	AREA		TEST	AREA		TEST	AREA		TEST	AREA		TEST	AREA	
	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4
Ephemeroptera																		
Heptagenia sp.	44	500(144)	244	78(1)	2256(1)	790	367	111	89	189	178	244	67	144	378			
Caenis sp.	3133(156)	511(2)	322	9689	2256(2)	8444(8)	156(5)	132(11)	14400(70)	2633(4)	78(3)	144	78	1633	122			
Brachycerus sp.				78					22					33				
Baetis sp.	1589(55)	56(2)	989(1)	33(5)	11(14)	711(2)	144(1)	311(11)	44(7)	67(1)	(17)	22(7)		1289(1)	89			
Pseudocleon sp.		(2)	(2)	(1)	(6)													
Isonychia sp.	11(2)	1056	278	1856(1)	200(2)	244(1)	333(2)	22	222	78(1)	(3)	44(728)		56	56			
Tricorythodes sp.	11	22		56	22	(2)	11	78	122	89			56	78	156			
Paraleptophlebia sp.															67			
Ephoron sp.				22(1)	(1)													
Hexagenia							(1)			11					22			
Plecoptera																		
Perlida sp.	33	44	11	89	11						22				11			
Acronuria sp.											22							
Pteronarcy's sp.	11	11		22	11	33	33											
Trichoptera																		
Hydropsyche sp.		33				878(1)	367	56(1)	211(1)		2889(3)	2344(14)	267(3)	833(1)	1100			
Brachycentrus sp.							11								11			
Cynellus sp.	11																	
Mayatrichia sp.																		
Ochnotrichia sp.																		
Nectopsyche sp.				11	(1)	33	22	44(2)	22(3)					33	33			
Ceraclea sp.				1067														
Diptera																		
Hemerodromia sp.																		
Bezzia sp.	(1)										67	11			11			
Chironomidae	3100(1)	4711(2)	8733	1978(133)	20311(66)	5178(4)	1489(1)	2489(4)	222(4)	1344(45)	10634(3)	4367(7)	89	2878(1)	10667(1)			
Simuliidae	56	811(287)	22(2)	311(1)	1244(6)	11(1)	(2)	22(3)	611(72)	(2)		11	(3)	545	11			
Odonata																		
Gomphus sp.						(1)		(1)			(3)			11	11			
Ornithogomphus sp.																		
Argia sp.																		
Coleoptera																		
Stenelmis sp.		11	11															
TOTALS	7999(215)	8077(439)	10610(5)	14223(143)	27411(159)	6322(20)	2933(12)	3266(23)	15954(157)	4433(53)	13890(32)	7187(756)	557(6)	7533(3)	2889(1)			

Table 2.2 Similarity matrices and dendograms for 1979 Niobrara River Insect collections.

June 18			July 30			September 18		
Prominence Value (Similarity)	Dendograms (UPGMA Cluster Analysis)		Prominence Value (Similarity)	Dendograms (UPGMA Cluster Analysis)		Prominence Value (Similarity)	Dendograms (UPGMA Cluster Analysis)	
Station 1 3 4 5 6 1 X 3 .49 X 4 .61 .77 X 5 .61 .47 .33 X 6 .57 .71 .63 .47 X			Station 1 3 4 5 6 1 X 3 .32 X 4 .21 .65 X 5 .80 .21 .14 X 6 .56 .51 .46 .58 X			Station 1 3 4 5 6 1 X 3 .91 X 4 .11 .13 X 5 .52 .57 .13 X 6 .84 .84 .14 .60 X		
Station 1 3 4 5 6 1 X 3 .61 X 4 .61 .77 X 5 .61 .61 .61 X 6 .61 .71 .71 .61 X			Station 1 3 4 5 6 1 X 3 .39 X 4 .39 .65 X 5 .80 .39 .39 X 6 .60 .39 .39 .60 X			Station 1 3 4 5 6 1 X 3 .91 X 4 .14 .14 X 5 .59 .59 .14 X 6 .86 .86 .14 .59 X		

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CHAPTER 3

The reproductive life history of channel catfish from the Niobrara River

Introduction

Channel catfish is the major sport fish in the Niobrara River. Many landowners adjacent to the river fish for this species with bank lines set overnight and at certain times during the year are very successful. Public access to the Niobrara is limited primarily to the bridges where country roads intersect the river. In the spring, catfish are caught by rod and reel from these bridges. Past sampling has revealed that the channel catfish is an underutilized resource in the Niobrara (Hesse et. al. 1979). This results from poor access, large distance from population center, and the repopulating potential of the Missouri River.

Spencer Hydroelectric Dam, as previously stated in this report, poses a barrier to fish migration beyond 63 km upstream from the confluence of the Missouri and Niobrara Rivers. Routine flushing operations of Spencer Hydro could seriously deplete annual recruitment in the Niobrara through siltation effects, namely reduced hatchability of eggs and limited survival of larvae. These effects could occasionally manifest a change in the Missouri River population, since a sympatric relationship with respect to channel catfish likely exists between the two rivers (Hesse et. al. 1979).

We have undertaken this research to quantify the breeding biology of the Niobrara channel catfish for future reference and to establish the value of this fishery.

Methods and Materials

Channel catfish were captured during 1979 with cheese baited hoopnets, and those fish expected to be nearing sexual maturity were preserved, returned to the laboratory and dissected. Gonads of both males and females were removed and preserved for future processing. Gonadal-somatic indices were computed according to Jerald and Brown (1971) and fecundity was estimated by the sphere volume method (Kucera and Kennedy 1977).

Results and Discussion

Gonads were removed from a random subsample of channel catfish between 250 mm TL and 275 mm TL, and from all channel catfish greater than 275 mm TL. The total sample of 154 channel catfish examined was 45% females and 54% males. April and May sex ratios were 2:1 (Female to male) and 2.5:1 (female to male) respectively.

Female catfish were classified mature when ova development indicated spawning would occur in the current season. They reached sexual maturity between 275 mm and 704 mm. Seventy-one percent of females examined from the Little Nemaha River, Nebraska, were found to reach maturity from 319-364 mm (Hesse et. al. 1979). Only 22% of Niobrara River females 319-364 mm TL were sexually mature.

Male catfish were considered mature when testis appeared swollen and well developed. Males reached maturity at a larger size than females. Fifty percent of the males examined were found to be mature by 411 mm TL. No males less than 275 mm TL were found mature. Male catfish from the Little Nemaha began to mature at 266 mm TL and 94% were found mature by 411 mm TL (Hesse et. al. 1979).

Gonadal-Somatic Indices (GSI) were computed for all catfish with a gonad weight greater than 0.1 g between April and October, 1979. Mean monthly GSI values for immature female catfish ranged from 0.3% to 0.4% (Figure 3.1). The mean GSI for mature females ranged from 3.4% to 15.4% from April to July 7. Thereafter, GSI declined to 0.9% on July 11 and to 0.6% on August 1 (Figure 3.1). The mature female GSI peak (15.4%) occurred July 3 when water temperatures averaged 25°C (Hesse et. al. 1979).

Immature male mean monthly GSI values were less than 0.5% from April to July and peaked in August at 0.7%. Mean GSI values for mature males ranged from 0.3% in May to 0.8% in July and 1.1% in August.

Spawning time was determined by mature female GSI values and the presence of spent females in the sample. Mean GSI values for mature female catfish showed a steady increase from 3.4% on April 22, to 15.4% on July 3. The first spent female was observed July 11 when water temperature was 29°C. All mature females subsequently sampled were spent. Spawning, therefore, occurred between July 1 and July 15. On July 11, 1979, a 12 lb. male was captured which was guarding a nest of eggs. The spawn were sampled for aging according to Clemens and Sneed (1957) and were less than two days old.

In October, mean mature female GSI values increased from the 0.6% value in August to 1.65% (10°C). Ova appeared much the same in color as the April sample, and two modes were distinguishable (Hesse et. al. 1979).

Mature ova diameters ranged from 1.78 mm (April 22) to 2.68 mm (July 3). Maximum ova diameter for a single female was 2.82 mm (June 6) when water temperature was 23°C.

Fecundity was estimated for nine females from 265 mm TL to 600 mm TL (428 ± 135 , mean $\pm$ SD). Estimates were made using the sphere volume technique (Kucera and Kennedy, 1977). Ova counts ranged from 2,655 to 25,156 ($10,885 \pm 9,306$, mean $\pm$ SD).

The relationship of absolute fecundity to body weight and total length was found to be best represented by an exponential equation. The relationship between fecundity and body weight was described by $\text{Log } F = 1.588 + 0.82114 \text{ Log } W$ ($r = 0.98$), where F = absolute fecundity and W = total weight (grams). Fecundity was related to total length by the equation $\text{Log } F = 3.287 + 2.747 \text{ Log } L$ ($r = 0.98$) where F = absolute fecundity and L = total length (mm).

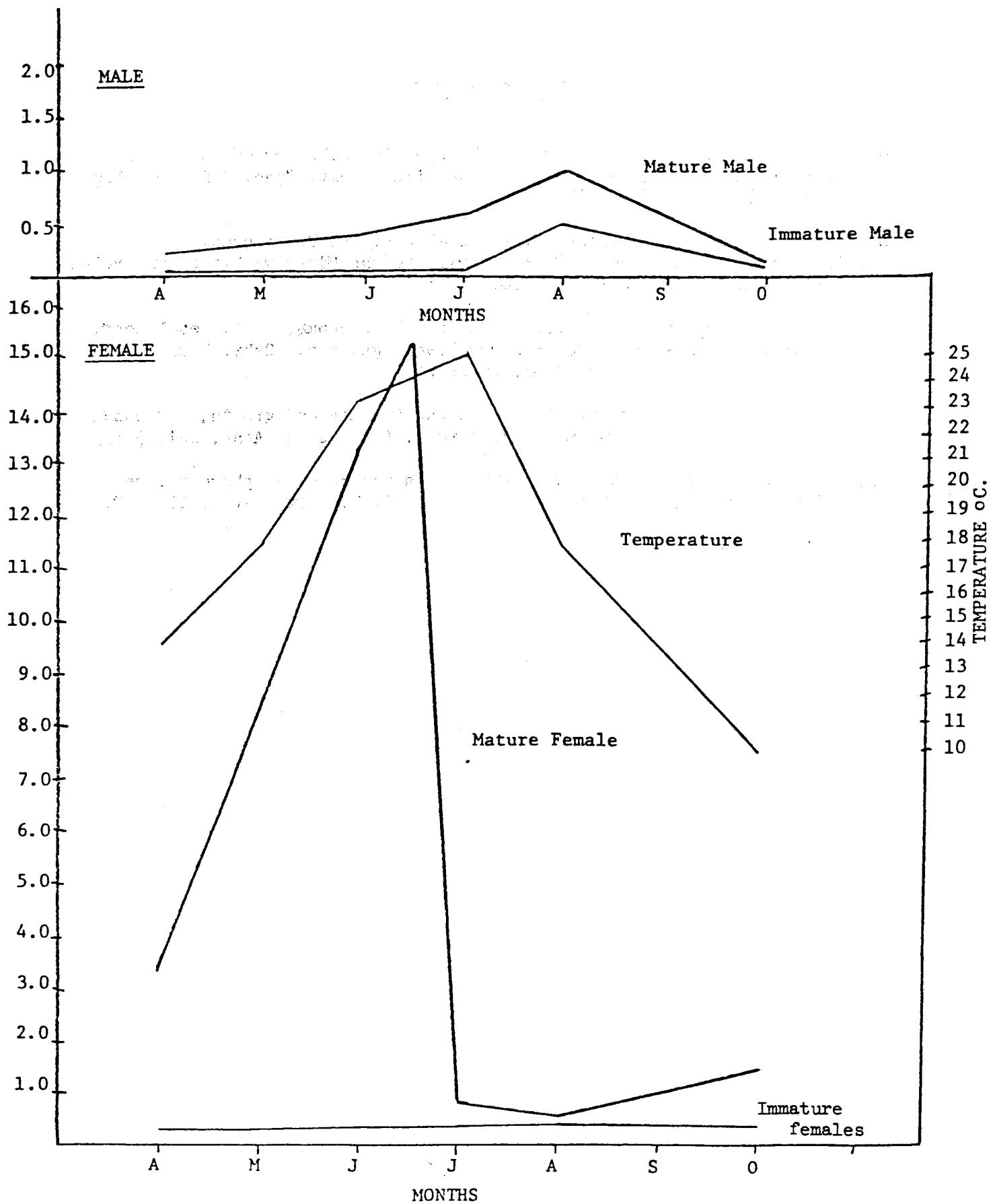


Figure 3.1 Gonadal-Somatic Index (GSI) of channel catfish from the Niobrara River, April-October, 1979.

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CHAPTER 4

The Niobrara River and Spencer Hydroelectric Dam: Conclusions and Recommendations

Conclusions:

1. Nebraska Water Quality Standards were exceeded in nearly every instance of flushing. The parameters most affected include turbidity, total dissolved solids, suspended solids, settleable solids and dissolved oxygen.
2. Fish kills occurred during four of the 15 observed flushings, resulting in the death of more than 22,000 fish. This figure represents only those lying on the surface or trapped in shallow pools. Many more fish were noted to have been buried or carried downstream beyond the limits of our study area.
3. Dewatering of the Niobrara downstream from the Hydro occurs after each flushing as the flow is constricted in order to refill the reservoir. This flow reduction compounds the problem of insect recolonization and will effectively eliminate fish eggs and immobilizes fish larvae at the time. Dewatering will play a special role in future management plans for the Niobrara as well. Planned stockings of sauger, walleye, and northern pike fry and fingerlings into the Niobrara will be less successful, possibly even fail, if flushing followed by dewatering occurs after a stocking. This situation occurred in 1980. A million northern and walleye fry were stocked into the Niobrara prior to the April, 1980 flushing.
4. Between July and August, 1977, a large reduction in age-0 channel catfish was demonstrated. Within this time frame a flushing occurred that resulted in the largest documented fish kill. 852 channel catfish were present in the kill. During 1978 flushings did not occur between May and September. Age-0 catfish density increased throughout this period.
5. Aquatic insects were the primary food of all size ranges of channel catfish in the Niobrara as demonstrated in a 1976-1977 study.
6. Our data suggests that six genera and all species of the Odonata have been eliminated below Spencer Hydro.
7. The prominence index, a measure of aquatic insect diversity, revealed that during and after a flushing operation diversity significantly decreased below the Hydro.
8. The mature female channel catfish Gonadal-Somatic-Index peaked at 15.4% in July in 1979. Channel catfish spawning was placed at between July 1 and July 15.
9. With the large number of species present in the river, spawning of other species can be expected to take place over an extended period from April 1 to late summer. Young, vulnerable members of some species are present in the river until at least September 15 each year.

APPENDIX I

Partial reprint of "A literature review of the effects of turbidity and siltation on aquatic life"

by Edgar H. Hollis

" Turbidity Levels in Natural Waters"

In the Powder River, Oregon, silt concentrations of 3-4 grams per liter (3,000-4,000 mg/l) seldom occurs in nature except during heavy floods and channel dredging (Lossanoff and Tommers 1948).

Interaction of Inorganic and Organic Suspensoids and Sediments

Siltation traps organic matter on the bottom and creates an oxygen demand which may result in gas ebullition and objectional anaerobic conditions (Ellis 1940) and (Bartsch 1954). Turbidity delays self-purification of water and allows distant transport of organic wastes (Tarzwell and Gauvin 1953). Silt flocculates planktonic algae and carries it to the bottom to die (Jackson 1963). Absorption of particulate matter increases the settling rate of bacteria (Weiss 1951).

Effects of Turbidity and Siltation on Fish Production

Buck (1956) investigated the effects of turbidity on fish production in 39 farm ponds stocked with largemouth bass and sunfish. At the end of the second growing season the pounds of fish per acre were as follows:

Clear Ponds	Turbidity less than 25 ppm	161.5 lbs/acre
Intermediate Ponds	Turbidity 25 ppm to 100 ppm	94 lbs/acre
Muddy Ponds	Turbidity 100 ppm to 185 ppm	29.3 lbs/acre

Average total fish weight was 5.5 times greater in clear ponds than muddy ponds. This difference was due to faster growth and better reproduction in clear ponds. At the end of two growing seasons largemouth bass in clear ponds increased 6.9 inches in length and 14 times in weight while bass from muddy ponds increased 2.4 inches in length and 2.5 times in weight. At the end of the first summer young of year largemouth bass were found in 7 of 12 clear ponds, 4 of 12 intermediate ponds, and 0 of 9 muddy ponds. The most turbid pond from which young bass were recovered averaged 84 ppm of turbidity. Redear sunfish spawned successfully in 8 of 9 clear ponds, 9 of 9 intermediate ponds, and 1 of 7 muddy ponds. Based on this, the critical turbidity levels for largemouth bass, redear sunfish, and bluegills appeared to be between 75 and 100 ppm, with 100 ppm as the approximate level above which spawning was severely restricted or nonexistent. Fishes in Whitewood Creek, S. D., were completely driven out where mine wastes had raised the residual turbidity (1 hour settling time) above 720 APHA (Amer. Pub. Health Assoc. Units) (Ellis 1948). Silt from gravel washings eliminated trout food and cover in Wynooche River, Washington, even though turbidities were low - 91 to 102 ppm. (Wagner 1959). Siltation destroyed the whitefish population of the Detroit River and the Maumee

Bay (Troutman 1957). Trout were less abundant in streams with 6,000 mg/l (6,000 ppm) of turbidity than in clear streams. (Anon. 1961). Six miles of Bear Butte Creek was rendered unfit for fish and fish food organisms by shifting sand and silt from mines. (Ellis 1945).

Effects of Turbidity and Siltation on Fish Reproduction

The most critical period in the life cycle of a fish species generally occurs during the egg and larvae stages. At this time, survival requirements are most exacting and any severe changes from optimum conditions is usually lethal. We would expect, therefore, that the direct effects of turbidity and siltation would be most pronounced during early development and the literature supports this assumption.

Direct Effects of Turbidity and Siltation on Fish Eggs

Stuart (1953) conducted laboratory experiments concerning the effects of silt on development of loch trout (brown trout) ova. Trout eggs showing various developmental stages were placed in trays of water charged with natural stream sediments. Particle size ranged from suspended material to fine sands. Tray sediments were stirred at frequent intervals to maintain turbidity. Control trays contained water in which sediments had been introduced and then filtered out.

Trout ova held in clean water have a smooth glassy chorion with a pearly lustre. Upon introduction into the turbid water the chorion began attracting the suspended silt particles and soon became covered with a dark coat of sediment. This coating was so tenacious that vigorous agitation of the water was required to dislodge it. All early development ova held in the trays of turbid water died without hatching. Some of the late development ova, which were subjected to silt conditions for 48 hours or less, hatched into healthy larvae.

Wilson (1960) stated that silt often destroys eggs in spawning gravel by reducing water seepage and hence, oxygen, and by interference with gaseous exchange through the chorion. Jackson (1963) writes that silt suffocates fish eggs either by coating the egg which excludes oxygen or by reducing the flow of water-containing oxygen past the eggs.

Direct Effects of Turbidity and Siltation on Fish Larvae

Laboratory experiments by Stuart (1953) showed that turbidity and siltation produced high mortalities in loch trout (brown trout) larvae if more than a 1 mm depth of natural stream silt was placed in the holding trays. Inhalation of the silt particles resulted in gill membrane inflammation and death. When less than 1 mm of silt was present, trout larvae succeeded in keeping their gills clean by dislodging silt particles with mucus and expelling the material from the gill openings. In time all the silt in the tray was bound in strings of mucus laying on the bottom and the water was clean. Intermittent additions of fresh silt was tolerated if the amounts were small and intervals sufficiently separated. However, continuous additions of fresh silt could not be tolerated and the trout larvae died from gill inflammation. Older larvae were slightly more resistant to continuous applications of silt. In addition to the elimination of the mucus coated particles through the gills, a "coughing" reflex developed which expelled small accumulations through the mouth.

Spawning and Fish Egg Survival at Various Turbidities.

Cambell (1954) found that all trout eggs placed below a gold dredging operation in the Powder River where turbidities ranged from 1,000 ppm to 2,500 ppm died within six days, while eggs placed in a clear tributary suffered only 6 percent mortality after 20 days. Shapovalov and Berrian (1940) showed a one percent survival. Shaw and Maga (1943) received a fry yield of 1.16 percent from trout and salmon eggs held in silt laden water while eggs held in normal hatchery water gave a 16.2 percent survival. Wickett (1959) stated that the hatching rate of salmon eggs deposited in Williams Creek rose from 7.5 percent to 17 percent after silt was flushed out. Buck (1956) determined that at turbidities above 100 ppm., spawning of largemouth bass, redear sunfish, and bluegills was severely restricted or non-existent.

Spawning Losses from Siltation

Siltation produced catastrophies among fish eggs at hatcheries located in Spear-Fish Creek, S.D. (Ellis 1945). Erosion silt in some streams suffocated fish eggs by covering nests and spawning grounds (Ward 1938). Silt and turbidity from placer mines caused losses of trout spawn in some Colorado Rivers (Jordan 1889). Placer mining silt will smother salmon eggs and trout eggs (Ellis 1937). Silting can be detrimental to the survival of the steelhead eggs in gravel (Shapovalov 1937). Irwin (1960) showed that increasing turbidity and siltation in new reservoirs eventually prevented reproduction of bass, shad, and flathead catfish. When fish larvae were produced the death of zooplankton from siltation limited survival. Swingle (1949), states that largemouth bass failed to reproduce when heavy loads of suspended silts were present. Hamilton (1959) reported that fish didn't spawn in areas where sediment from a sand washing operation covered the bottom. Bartsch (1957) believes that no sediment waste should be added to a rubble or gravel bottom stream as the deposition will seriously limit spawning of most nest building fishes. Langlois (1941) suggested that walleye year class failures may be due to the heavy silt loads during the spawning season. Cisco depletion in Lake Erie may be due to siltation of the eggs which lay on the bottom approximately 115 days before hatching (Langlois 1954). Butler (1936) reported serious losses of walleye eggs at the Swan Creek Hatchery when gale winds stirred up mud and raised water temperatures.

Destruction of Spawning Grounds by Siltation

Siltation in the Nechako River, a tributary of the Fraser River, destroyed a spawning area formerly accomodating from 5,000 to 7,500 salmon (Wickett 1959). Smith (1940) reported that salmon spawning in the muddy Yuba River, California, was largely restricted to a clear streak of water below a clear tributary. Heavy siltation in the Wynooch River, Washington, covered salmon spawning gravel, while light siltation filled interstitial spaces retarding seepage and oxygen (Ziebell 1960). Troutman (1957) stated that siltation destroyed whitefish spawning areas in Maumee Bay. Ellis (1931) believes that game fish were scarce in Lake Keokuk because suitable spawning bottom was limited to a narrow wave washed zone around the edge of the lake. Large areas of spawning grounds in various estuaries have been destroyed or shifted downstream by sedimentation (Mansueti 1961).

Direct Effects of Turbidity on Fingerling and Adult Fish

Rainbow trout were subjected to turbidities of 30, 90, and 270 mg/l of china clay and diatomaceous earth for 5 months. No adverse effects were noted at 30 mg/l, (30 ppm), some fish died at 90 mg/l (90 ppm) and over 50 percent died at 270 mg/l (270) of turbidity. Examination of fish gills revealed a thickening of epithelial cells and fusion of adjacent lamellae. Trout from turbid streams exhibited a gill pathology similar to the laboratory fish (Anon. 1961). Pautzke (1937) found that steelhead trout placed in a trout stream polluted with coal washings died within 2.5 hours. Dead fish were heavily coated with mucus and coal and slate particles. Controls placed in silt free mine water suffered no mortality. Klein (1962) determined that kaolin and diatomaceous earth turbidities caused significant mortalities among rainbow trout. At 270 ppm diatomaceous earth produced a median period of survival of 11 days. Death resulted from gill irritation. Mullet, carp and fundulus exposed to high concentrations of suspended mud were killed by mechanical injury to gills. These fish also exhibited an avoidance reaction to silt (Ingle 1955). Wallen (1951) investigated the direct effects of turbidity on adult warmwater fishes and concluded that concentrations below 70,000 ppm were not harmful.

Field Observations

Kemp (1949) believed that suspended silt will clog and cut the gills of fish and mollusks and considers turbidities of 3,000 ppm dangerous if maintained for ten days. He attributed a large fish kill in the Potomac River during 1936 to a flood which produced turbidity levels of 6,000 ppm for 15 days. Ellis (1935) states that silt particles too large to pass through a 1,000 mesh per inch screen will cut and injure the gills of fish and mollusks. Van Oosten (1945) wrote that fish live and thrive in turbidities that range above 400 ppm.

Effects of Turbidity and Siltation on Fish Species Composition.

There is general agreement in the literature that turbidity and siltation alter the aquatic environment producing conditions unfavorable to many of the game and commercial fishes. If a species has a low tolerance for environmental changes its numbers may be drastically decreased or even eliminated by turbidity and siltation.

Turbidity caused by inorganic particulate matter suspended in the water mass may drive fish from the polluted area by irritating the gills, concealing forage fish, and destroying vegetational cover essential for the survival of young fish and the spawning of those species that need plants for egg attachment. Deposition of silt on the bottom may physically alter the habitat by filling in holes, smothering demersal eggs, and decreasing bottom organisms to the extent that fish must search elsewhere for food. It is not always clear which of these deleterious factors result in population decrease. In many cases the decline is the result of the combined effect of two or more of these factors.

Game fishes are usually not very tolerant of turbidity and of siltation. Troutman (1957) states that in the Ohio region habitat changes primarily due to siltation have, 'considerably modified the fish fauna, changing it from a species complex dominated by fishes requiring clear and/or vegetated waters to one dominated by those

species tolerant of much turbidity of water and of bottoms composed of clay silts. There has been a shift from large fishes of great food value to smaller species unfit as human food, or large fishes of inferior quality as human food! Before siltation filled in the narrow, deep streams covering the clean sands, gravels, boulders and bedrock, the fish population consisted of pikes, walleye, catfishes, buffalo fishes, suckers, drum and sturgeons. Environmental changes in Ohio's lakes caused by soil erosion changed the fish populations in these lakes from that of a largemouth bass - bluegill - pumpkinseed - yellow bullhead association to that of a white crappie - brown and black bullhead - channel catfish association. (Troutman 1957).

Fish populations may be completely driven out of a body of water if silt pollution is great enough. Whitewood Creek in the Black Hills of South Dakota was so heavily polluted with rock powder from a mine (22 percent by volume of settleable solids) that all fishes were driven out of the polluted area. Not until pollution was greatly reduced (3 percent by volume of settleable solids) did the fish populations reappear (Ellis 1948). If all fishes are not driven out those requiring turbid quiet water and/or silted bottoms are benefited. Some of them such as carp now dominate silt polluted rivers (Troutman 1957). Investigations in the Powder River, Oregon, below a gold mining operation disclosed 1,700 ppm turbidity in a section of stream below the dredge. A fish survey revealed only rough fishes in this area, while in the clear water (5 ppm) above the dredge, the stream was inhabited by trout and whitefish (Wilson 1956).

The elimination of fish habitats by siltation results in the numerical decrease of the number of fish species. Two Ohio streams having both dredge and undredged sections were investigated by Troutman (1939). Survey records dating from 1886 and 1938 show little change in numerical abundance of the fish species in the undredged sections, while in the dredged sections, there has been a drastic decrease in abundance of fish species requiring clear water, constant flow, pools, or aquatic vegetation. In another example (Troutman 1957) the elimination of fish habitats by silt in Middle Harbor, Ohio, resulted in the disappearance or reduction in numbers of 51 fish species. When the remaining fishes were killed with rotenone, more than 90 percent of the fish population consisted of carp, goldfish, their hybrids, and dwarfed bullheads.

The manner in which silt affects a species of fish is not always known. A species may survive in large number only if it is tolerant of changes brought about by siltation in all phases of its life cycle. Other sections of this report have covered much of this material.

Langlois (1941) attributed the decline of the Cisco and Whitefishes in Lake Erie to siltation of their spawning areas. The spawning grounds of these species were limited to the clean, hard bottoms surrounding islands in western Lake Erie. Water currents of the south shore tributaries carried silt onto these grounds resulting in silt deposits several feet deep. Other species limited in abundance by Lake Erie siltation are yellow perch, walleye and chain pickerel. Yellow perch spawn in and over water plants along the south shore. The death of aquatic plants caused by siltation may be the most important factor limiting this species. Langlois also believes that the failure of walleye production is caused by heavy silt loads carried by the Maumee River during their spring spawning run. Less desirable, turbid tolerant species such as sauger, sheepshead, catfish, and carp have greatly increased in abundance in Lake Erie.

Buck (1956) compared the effect of turbidity on largemouth bass, redear sunfish, and bluegill sunfish stocked in twelve farm ponds equally divided (four of each) between clear, intermediate and muddy waters. Based on average turbidities compiled over a two year period, the critical level for spawning appeared to be from 75 to 100 ppm for all three species with 100 ppm as the approximate level above which spawning was severely restricted or non-existent. Bluegills and redears were found to be more tolerant of turbidity than bass. Almost no young-of-the-year bass were produced in muddy ponds. Buck also compared a turbid reservoir, having a surface turbidity ranging from 300 to 50 ppm and a summer average of 131 ppm with a clear reservoir. The number of species, as well as individuals, of all scaled fishes was low in the turbid reservoir, apparently due to a lack of successful reproduction and also to a competition from the better adapted catfishes. Forage fishes were extremely scarce, and this limited growth of carnivorous species such as bass and crappie. The clear reservoir contained more desirable species resulting in much greater angling effort.

Upper Mississippi Lake fish fauna was investigated by Ellis (1931) who concluded that the reason for the increase in rough fishes is that the narrow silt free edges of the lakes were too small to provide sufficient spawning and nursery areas for game species.

That a trout population can recover after improvement of stream environment was demonstrated by McDonald and Shepard (1955), who noted that fry production was more than doubled after much of the sediment was flushed from a silt polluted stream.

Effects of Turbidity on Fishing Success

Creel census data from Fork Lake in Illinois shows striking correlation between water transparency and numbers of largemouth bass and bluegills caught (Bennett, Thompson, and Parr 1940).

Transparency - Feet

Fish Caught per Man Hour

0.5 - 2.0	2.04
2.0 - 3.5	2.86
3.5 - 4.5	6.53

Buck (1956) compared turbid Heyburn reservoir with clear Upper Spavinow Reservoir and found that the clear reservoir attracted more anglers, yielded more fish per unit effort as well as more desirable species, and was immeasurably more appealing in the aesthetic sense. A study of the Meramar River watershed in Missouri showed that recreational attendance, mostly fishermen, dropped 1/3 when the water was muddy. Based on 25 muddy water days per year, this amounted to a revenue loss of \$49,000 annually to people in the area (Brown 1945). Gunter (1938) noted that trawl fishing was very effective in turbid water, presumably because reduced visibility lowered avoidance.

Effects of Turbidity and Siltation on Bottom Organisms

Our literature search has uncovered at least 27 papers which record adverse effects of turbidity and siltation on bottom organisms. According to most of these authors, the unstable silts and shirting sands form a false bottom that will not usually support benthic animals.

Tarzwel (1937) rated streams according to population density of animal organisms on different types of bottoms: sand - 1; silt - 10.5; rubble - 30; coarse gravel - 32; plant beds - 452.

Bartsch (1953) described the effects of effluents from sand-glass crushing operation on bottom organisms. Warm Spring Run, carrying the particulate washing wastes, discharges into the right side of the Potomac River three miles from the sand plant. Bottom samples from the gravel, stream bed of the Potomac River, 0.1 miles above this tributary contained organisms in the following volumes: 2.6 cc/sq. ft. near right bank and 2.9 cc/sq. ft. near left bank. At the tributary mouth, turbidity measured 5,000 ppm, and bottom fauna were absent. Downstream from the tributary (1.0 mile) the right side of the main stream showed a death of bottom fauna, while the left side was unaffected. At 0.4 mile increased turbidities were measured over two-thirds the width of the river, while volumes of bottom animals decreased on the left and recovery on the right had started. Between 1.4 and 2.4 miles, current mixing caused deposition of sediments across the whole river. Bottom fauna yield was 1 cc/sq. ft. on each side. Volumes of bottom animals for the right side did not equal the amount sampled above the Warm Spring Run confluence until the study proceeded 13.1 miles downstream. Irwin (1951) considered turbidities 25 ppm as subject to measuring error and, therefore, used the standard of 25 ppm as his starting point.

The action of rock powder is similar to that of sand sediments in that such particles blanket the stream bed and smother bottom life. Ellis (1945) observed six miles of Bear Butte Creek rendered unfit for fish and food organisms through silting from mines. Ellis (1943) claims that clay precipitates in streams, covers the bottom, and excludes life except for low oxygen tolerant fauna.

With the elimination or decimation of benthic populations the food chain can be broken, and some fish will starve when a particular bottom food is scarce. For example, the winter flounder as a young fish (1 to 4.5 in TL) feeds mostly (39) on worms. As these fish grow older, they increase their molluscan diet. The adult is limited by its small mouth to a diet of the smaller invertebrates, including annelids and mollusks. (Bigelow 1953).

Jackson (1953) summarized that reductions in benthic populations may approach 75 - 90 percent or greater for distances up to 10-50 miles below sources of silt pollution. Wagner (1959) supported this point of view when he observed pollution from gravel removing operations; bottom insects were reduced 75 - 85 percent where turbidity measured 91 - 102 ppm.

Effects of Turbidity and Siltation by Phytoplankton and Plant Production

Algae is the basis of the aquatic food chain, and the effects of turbidity and siltation upon it are of critical importance to the fish population. Silt destroys planktonic algae by absorbing light needed for photosynthesis, and by flocculating and precipitating algae cells. Encrusting algae are smothered by a silt coating (Cordone and Kelley 1961). The abrasive action of inorganic particles may damage algae cells. Aquatic plants, which are essential to many fishes for egg attachment, and cover may be destroyed by silt through elimination of light, and interference with gas exchange through the leaves (Phinney 1959).

It is stated by Reid (1961) that, 'The major effects of high turbidity in estuaries are (1) the quenching of light penetration; thereby inhibiting photosynthesis and the production of plants, and (2) the building up of deep zones of mud, silt, and other sediments and detritus.'

Inorganic particulate matter suspended in water decreases light penetration (Anderson 1956, Reid 1961, Chandler 1942, and Tarzwell 1953). The greater the concentration of silt the greater the exclusion of light. In studies of western Lake Erie, Chandler (1942) found turbidities, resulting from materials derived from bottom sediments, to vary from 5 to 230 ppm. One percent of the light penetrated 9.7 m when the turbidity was 5 ppm, 0.8 m when the turbidity was 115 ppm. The greatest loss of light occurred within the first 10 cm., and varied from 13 to 49 percent of the surface light. In many estuaries when tributary flow is voluminous, light is reduced to one percent of the surface radiation at less than 3 m (Reid 1961). By contrast, in certain regions of the open sea, the yellow-green components are not diminished to one percent until a depth of nearly 100 m is reached.

The growth of algae is limited by light. Turbidity is the major factor in the poor phytoplankton productivity of Lake Erie (Verdium 1954). Chandler and Weeks (1945) believe that high turbidity in Lake Erie during 1942 caused an observed 19 percent reduction of the plankton crop below the 1941 level. In one pond productivity study (Claffey 1955) the plankton volume in clear ponds during a single growing season was eight times that produced in ponds of intermediate turbidity and 12.8 times that produced in muddy ponds. A similar study of two adjacent Oregon Lakes (Wickett 1959) disclosed that plankton production in the clear lake was five times that produced in the turbid one. As turbidity decreased from 800 to 12 ppm in a Missouri impoundment (Bartsch 1959) phytoplankton production increased from 10 to 100 ppm.

Ellis (1935) suggested that a minimum turbidity standard for aquatic life should not reduce the millionth intensity level (0.0001 percent of incident light) to less than five meters.

Phytoplankton may be flocculated by the adherence of silt particles to the algae cells which carried them to the bottom to die. (Bartsch 1960).

A few studies on the effects of siltation on the higher aquatic plants and attached algae have been conducted. A survey of aquatic plants in western Lake Erie from 1899 to 1949 disclosed a significant reduction in the amount of aquatic vegetation (Langlois 1954). Elimination of most of the beds of water vegetation occurred in the bays and at mouths of rivers flowing into Lake Erie where sedimentation was heavy. Bartsch (1953) conducted a significant study of a silt polluted area on a stretch of the Potomac River below a gravel crushing industry. One side of the river was turbid, the other clear and not affected by silt. No vegetation was present at the site when turbidity was 5,000 ppm, but Vallisneria, Zannichellia, and the algae Cladophora were growing along the clear opposite side. At 4.9 miles below the site of pollution turbidity had decreased to less than 25 ppm, but vegetation did not reappear until 9.4 miles below. Some silt was still being deposited 13.1 miles downstream from the gravel operation.

A deposit of sediment on the leaves of higher plants is believed to act as a physical barrier preventing the free exchange of gases (Phinney 1959). Siltation may smother attached algae as occurred in the Truckee River, California, where an abundant population of algae pads of the genus Nostoc was destroyed by sediment (Cordone and Pennoyer 1960).

Most of the research on the effects of turbidity and siltation on aquatic algae and plants have resulted in general conclusions. The determination of the effects of turbidity is a complex research problem, and care is needed to control and measure all the factors of the photosynthetic process (Cordone and Kelley 1961."

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