Effects of renovation on the Sacajawea Park Lagoon system in Livingston, Montana
by Thomas Patrick Clancey

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:
The water chemistry, morphology, and trout populations in sections of Fleshman Creek and the water quality and quantity in the Sacajawea Park lagoon were studied from July 1980 to July 1982 to determine the effects of renovation on the lagoon system. Prior to renovation (June 1, 1981), water from Fleshman Creek flowed through all three study sections and the sediment filled Sacajawea Park Lagoon basin. After renovation, the two downstream study sections and the lagoon contained water from the Yellowstone River. Average dissolved oxygen concentrations , temperatures and pH levels increased and turbidities, conductivities, alkalinities and hardnesses in the affected areas decreased following renovation. Physical alteration of one stream section resulted in (1) a decrease in channel width, average depth and total cover, (2) increases in average velocity and sinuosity and (3) elimination of the estimated 67 (± 13) trout present. Following renovation, the beginning of recolonization by trout was documented. Before renovation, the lagoon area contained only a stream of water averaging 21 cm in depth with a peak discharge of 0.28 m^3/s and was unsuitable for recreation. After the removal of nearly 23,000 m^3 of sediments, the lagoon averaged 1.5 m in depth, contained over 23,000 m^3 of water and was attractive to boaters, fishermen, and other recreationists.

EFFECTS OF RENOVATION ON THE SACAJAWEA PARK LAGOON SYSTEM IN LIVINGSTON, MONTANA

by

Thomas Patrick Clancey

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 1983

APPROVAL

of a thesis submitted by

Thomas Patrick Clancey

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

5/18/83 — William R. Gould

Date — Chairperson, Graduate Committee

Approved for the Major Department

5/20/83 — J M Pickett

Date — Head, Major Department

Approved for the College of Graduate Studies

5-24-83 — Michael Malone

Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Pat Clancey

Date May 23, 1983

ACKNOWLEDGMENTS

The author wishes to sincerely thank those who aided him during the study. Dr. William Gould directed the study, assisted in the field and aided with the preparation of the manuscript. Drs. Harold Picton and Robert Eng critically reviewed the manuscript. Friends and other students offered suggestions and aided with field work. The Save our Lagoon Committee deserves recognition for their efforts in securing funding for the rehabilitation effort.

Special thanks to my family for their support, and especially to Chris Clancey for his technical and moral support. The City of Livingston, Park County, the Montana Department of Fish, Wildlife and Parks, the Montana Department of Natural Resources and Conservation and the Environmental Protection Agency, provided funding. The Montana Cooperative Fisheries Research Unit provided in-kind services, supplies and equipment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

ABSTRACT

The water chemistry, morphology, and trout populations in sections of Fleshman Creek and the water quality and quantity in the Sacajawea Park Lagoon were studied from July 1980 to July 1982 to determine the effects of renovation on the lagoon system. Prior to renovation (June 1, 1981), water from Fleshman Creek flowed through all three study sections and the sediment filled Sacajawea Park Lagoon basin. After renovation, the two downstream study sections and the lagoon contained water from the Yellowstone River. Average dissolved oxygen concentrations, temperatures and pH levels increased and turbidities, conductivities, alkalinities and hardnesses in the affected areas decreased following renovation. Physical alteration of one stream section resulted in (1) a decrease in channel width, average depth and total cover, (2) increases in average velocity and sinuosity and (3) elimination of the estimated 67 ($\pm$ 13) trout present. Following renovation, the beginning of recolonization by trout was documented. Before renovation, the lagoon area contained only a stream of water averaging 21 cm in depth with a peak discharge of 0.28 m^3/s and was unsuitable for recreation. After the removal of nearly 23,000 m^3 of sediments, the lagoon averaged 1.5 m in depth, contained over 23,000 m^3 of water and was attractive to boaters, fishermen, and other recreationists.

INTRODUCTION

The Sacajawea Park Lagoon System at Livingston, Montana has been severely impacted by sediments from Fleshman Creek since its formation. It was created in 1939 and by 1959 it had become too shallow to hold fish or provide a site for general recreation and required dredging to make it fully usable again. Concern for the adverse impacts of continuing deposition on the general use of the lagoon and on its suitability for the annual Children's Trout Derby caused interested state and local officials and private citizens to form the Save Our Lagoon Committee in April 1976 to determine ways to rehabilitate the lagoon.

The efforts of this committee resulted in the State of Montana entering into an agreement with the U. S. Environmental Protection Agency (E.P.A.) in July 1980 to renovate the Sacajawea Park Lagoon System under the Clean Lakes Act of 1977. This Act, in part, provided a means whereby states could enter into an agreement with the E.P.A. to receive funds for the development and implementation of restoration programs for lakes which would provide significant public benefits over a long period of time.

The plan for renovation of the Sacajawea Park Lagoon System included recommendations that the lagoon be excavated to bedrock and a source of water other than Fleshman Creek be used to reduce the rate of future sedimentation in the system. The objectives of this study were to measure changes in selected water quality parameters, channel morphology, and trout populations which resulted from the renovation of the lagoon system. Field work was conducted from July 1980 through July 1982.

DESCRIPTION OF STUDY AREA

The Sacajawea Park Lagoon System is located in southcentral Montana in Park County at the City of Livingston (Figure 1). It is formed by two side channels of the Yellowstone River which the city severed from the river with rock dikes. The 2.3 hectare (ha) lagoon was formed where the two side channels converged. With the elimination of flows from the Yellowstone River in 1939, the sole source of water for the system became Fleshman Creek.

Fleshman Creek has its headwaters on Bangtail Ridge in the Bridger Mountains west of Livingston. It flows in an easterly direction for approximately 23 kilometers (km). The drainage area is 63 km^2 consisting largely of moderately alkaline loam and clay-loam soils (Don Freeman, personal communication) used for rangeland, irrigated cropland, and some housing. The creek has an average gradient of 34 meters per kilometer (m/km) and typically contains less than 0.28 cubic meters per second (m^3/s) of water from July to April. However, during the spring, flows may increase to 1.42 m^3/s, at which time significant amounts of soil and organic materials are transported.

The Yellowstone River, which is within a few hundred feet of the Sacajawea Park Lagoon, flows north at Livingston. Its drainage area above Livingston is 9197 km^2 (U.S.G.S.) in primarily igneous and sedimentary deposits (Perry, 1962). Maximum discharge during the 1981 water

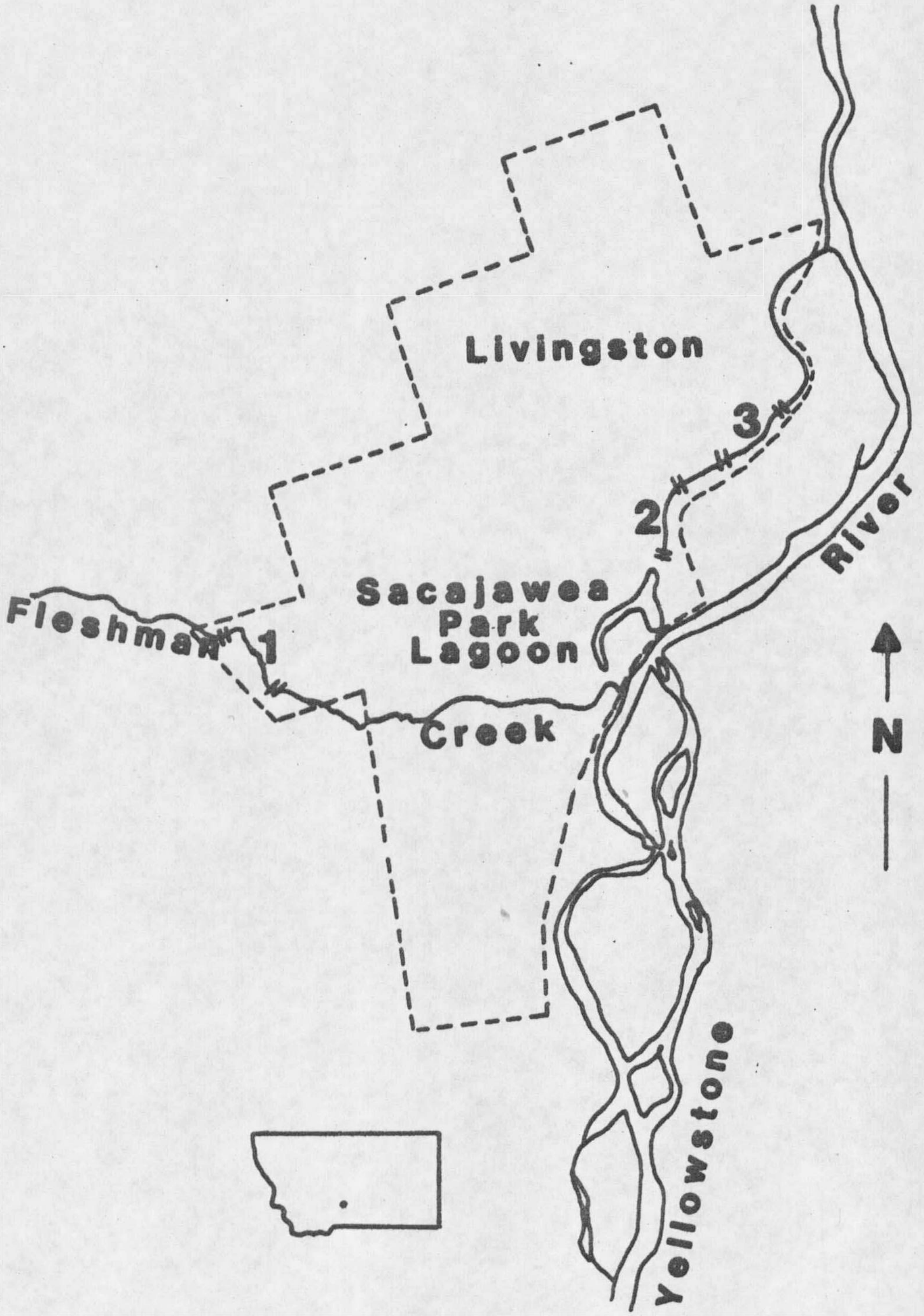

Figure 1. Map of the study area showing the location of study sections (1-3) on Fleshman Creek and the Sacajawea Park Lagoon.

year (Oct. 1980 - Sept. 1981) was 674 m^3/s on June 9, and minimum discharge was 21 m^3/s on February 11. The average discharge for the past 56 years has been 106.4 m^3/s (U.S.G.S., 1981).

Study Sections and Sites

Three study sections were established on Fleshman Creek near the Sacajawea Park Lagoon (Figure 1). Section 1 was established upstream from the lagoon and extended from Sun Avenue to a point 307 m upstream. This section served as a control and had no rehabilitative work performed on it. Section 2 was located immediately below Sacajawea Park Lagoon from South Second Street to South C Street. The channel in this section was originally 368 m in length. During renovation it was narrowed and given meanders by the strategic placement of sediments dredged from the lagoon, thereby lengthening it. Willow shoots and grasses were planted in the newly created banks to prevent erosion and to provide future cover over the stream. This section received water from Fleshman Creek prior to renovation and water from the Yellowstone River after Fleshman Creek was diverted from the lagoon. Section 3 was situated below the lagoon from South F Street to a point 400 m downstream. No physical alterations were performed on this section; however, as in Section 2, its source of water was from Fleshman Creek before renovation and from the Yellowstone River afterwards.

A site for sampling water in the Yellowstone River was also established. This site was located at the water intake structure for the lagoon and the city of Livingston.

From the start of this study on July 10, 1980, until Yellowstone River water was introduced on June 1, 1981, the lagoon contained only a shallow stream from Fleshman Creek which averaged about 21 cm in depth, 3.7 m in width and contained less han 0.28 m^3/s of water. The lagoon was not a lagoon as such because its basin was filled with sediments. The water in the creek at Station 1 (Figure 2) was sampled as the best indicator of what water in the lagoon might have been like.

Renovation was begun on July 31, 1980, when an earthfill dam was constructed at the head of the lagoon to divert Fleshman Creek away from the lagoon and into the Yellowstone River. Following this, the lagoon was excavated to bedrock. Over 22,935 m^3 of sediments were removed and stockpiled. A box type weir was constructed at the point of outflow from the lagoon to control the water level in the lagoon and the flow in Fleshman Creek below the newly formed lagoon. A pipeline then was constructed from the city's water intake on the Yellowstone River to the head of the lagoon to provide water believed to contain a lower suspended sediment load. After all construction and renovation was completed, water from the Yellowstone River filled the Sacajawea Park Lagoon within 24 hours (hrs) of introduction. Following filling, water was initially sampled at Stations 2-4 (Figure 2).

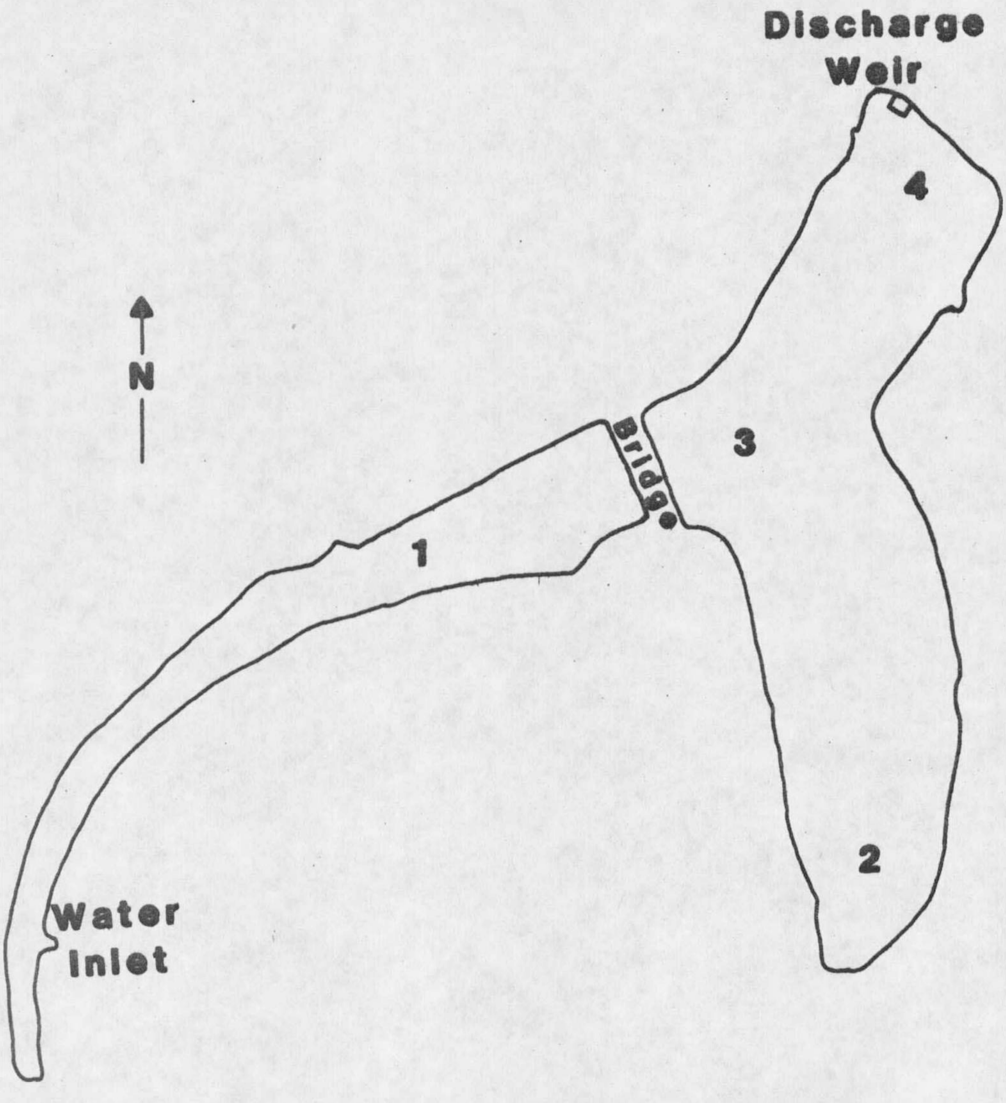

Figure 2. Map showing the location of sampling stations (1-4) in the Sacajawea Park Lagoon.

METHODS

Water Quality Analyses

Water samples taken from Fleshman Creek, the Sacajawea Park Lagoon area, and the Yellowstone River were analyzed for dissolved oxygen (D.O.), turbidity, conductivity, alkalinity, hardness, temperature and hydrogen ion concentration (pH). Concentrations of D.O., alkalinity, and hardness were obtained following Standard Methods (APHA, 1975). Turbidities were measured with a Hach Model 2100 Turbidimeter. A Beckman Model RB3 Solu Bridge was used to measure conductivities. Temperatures were determined with either a Taylor Field Thermometer or an Applied Research Austin Model FT3 Hydrographic Thermometer. An Orion Model 407 Specific Ion Meter was used to measure pH. All temperature and pH readings were made _in situ_. Analyses for D.O., turbidity, conductivity, alkalinity, and hardness were performed at Montana State University.

The precision of methods used to determine conductivity, alkalinity, hardness, and pH values in this study were assessed by analyzing duplicate samples of water from selected sampling sites and periods. The accuracy of methods used in analyses was measured by comparing my results with those obtained by the Chemistry Station Analytical Laboratory on the Montana State University campus from duplicate samples.

Sampling in Stream Study Section

Water samples were collected weekly from July 10, 1980 until September 1, 1981 and at 2 week intervals thereafter through December 21, 1981. Following this date, water samples were taken monthly until the end of the study.

Transects were established 20 m apart on each stream study section. Width, average depth, and thalweg velocity were determined at each transect. Overhanging and instream cover were measured within 1 m on each side of the transect line. Overhanging cover was defined as material no more than 60 centimeters (cm) above the water surface over water at least 10 cm in depth.

Sinuosity was estimated by dividing the thalweg distance by the downvalley distance in each section. Gradients were determined using a stadia rod and transit. Discharge was measured periodically with a Teledyne-Gurley No. 622 or No. 625 current meter.

Trout in the study sections were captured by electro-fishing. Each fish was measured to the nearest millimeter (mm), weighed to the nearest 5.0 grams (g) or nearest 0.1 pound (lb), marked with a fin clip and released.

Recapture runs were made 6 or more days after marking runs. Population estimates were made using the Chapman modification of the Petersen method (Ricker, 1975). Biomass estimates were made by methods outlined by Chapman (1978). Eighty percent confidence intervals were calculated for the estimated population numbers and biomass.

Sampling in the Sacajawea Park Lagoon Basin

From July 10, 1980 - December 8, 1980 (pre-renovation), water of Fleshman Creek in the Sacajawea Park Lagoon Basin was sampled weekly at Station 1 (Figure 2) as a substitute for lagoon water. From June 30, 1981 - December 21, 1981 (post-renovation), water samples were taken weekly or biweekly at Stations 2, 3, and 4 in the lagoon (Figure 2). Because water quality analyses from the above stations were virtually identical, monthly samples were taken only from Station 4 from December 21, 1981, to the end of the study. Samples from the stream in the basin were collected in glass or polyvinyl bottles. Those from the lagoon were collected from near the surface in a polyvinyl bottle and from near the bottom with a Van Dorn water sampler.

Morphological measurements of the stream in the lagoon basin prior to renovation were made in the same manner as in the three stream sections associated with the lagoon. Depth measurements of the renovated lagoon were made with a weighted tape measure and visibility was estimated using a Secchi disc.

Estimates of the weight of suspended material entering Sacajawea Park Lagoon were made weekly or biweekly by filtering 250 ml of water through a filter with 0.45 micron pores. Water samples were collected periodically and sent to the Montana Water Quality Bureau for nutrient analyses. Vertical plankton tows were made with a Wisconsin plankton net to assess the major kinds of zooplankton present.

Aerial photographs of Sacajawea Park Lagoon were taken in October 1981 to detemine the extent of the growth of macrophytes in the renovated lagoon. Analysis was performed on a Spatial Data Image Enhancement Computer by Dr. Stephan Custer, Earth Sciences Department, Montana State University.

Sampling in the Yellowstone River

Water samples from the Yellowstone River were collected at the lagoon intake structure beginning on April 23, 1981. From that time until the end of the study, frequency of collections was the same as for the stream study sections.

Statistical Testing

Statistical tests were made according to methods in Snedecor and Cochran (1980) and Huntsberger and Billingsley (1981). Student's t-test was used to compare mean values obtained prior to renovation with those obtained afterwards. Tests of significance were performed at the 95% level of confidence.

RESULTS

Stream Sections

Water Quality Parameters

The measurements of the water quality parameters monitored in each study section are listed in Tables 1 - 7. The monthly averages of D.O. ranged from 6.7-11.5 mg/l and the values of samples taken once per month were 9.0-13.0 mg/l (Table 1). All but one of the 51 monthly average values and all of the 18 single monthly values of D.O. were at or above the 7.0 mg/l level Cooper (1967) cited as a minimum acceptable level for trout. Twelve of the 13 monthly D.O. averages determined during the post-rehabilitation period (July-November, 1981) were greater than in the corresponding months in 1980 before rehabilitation. The average levels of D.O. concentrations in Sections 1, 2, and 3 were 1.9, 2.7 and 2.9 mg/l greater, respectively, following rehabilitation and all increases were significant. The greater increases of D.O. in Sections 2 and 3 indicate they were in part caused by the introduction of water from the Yellowstone River. The greater D.O. concentrations in 1981 were not due to lower temperatures, as the average water temperatures in all sections were greater in 1981 (Table 6).

The average monthly turbidities in the stream sections varied from less than 1.0 to about 41.0 Jackson Turbidity Units (JTU) and single

Table 1. Values of dissolved oxygen concentrations (mg/l) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

	Section 1			Section 2			Section 3		
Month	Pre-renovation	Post-renovation		Pre-renovation	Post-renovation		Pre-renovation	Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June	9.0(0.0)	7.3(0.6)	9.0		7.0(0.0)	10.0		7.0(0.0)	10.0
July	9.0(0.0)	8.0(1.0)	9.0	7.0(0.0)	7.6(0.6)	9.0		8.0(1.0)	9.0
August	8.0(0.0)	9.0(0.0)		7.0(0.8)	9.0(0.0)				
September	7.8(0.5)	9.3(0.6)		7.0(0.7)	8.7(0.6)		8.5(0.7)	9.7(0.6)	
October	7.3(0.6)	10.0(1.2)		6.7(0.6)	10.3(0.5)		8.0(1.0)	10.5(0.6)	
November	8.0(0.0)	11.3(1.2)		7.0(1.4)	10.5(0.7)		7.0(1.0)	10.5(0.7)	
December	8.0(1.0)	12.0		7.5(1.3)	12.0		7.5(1.3)	12.0	
	1981	1982		1981	1982		1981	1982	
January	9.0(0.8)	12.0(0.0)		8.8(1.7)	11.5(0.7)		9.0(2.0)	11.5(0.7)	
February	11.0(0.0)			9.0(1.4)			10.5(2.1)		
March	9.0(1.0)	12.0		8.0(0.0)	12.0		8.0(0.0)	12.0	
April	8.2(0.8)	13.0		8.8(1.5)	11.0		7.2(0.8)	11.0	
May	8.0(0.8)	10.0		7.8(0.5)	10.0		7.8(0.5)	10.0	

Table 2. Values of turbidity (JTU) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

	Section 1			Section 2			Section 3		
Month	Pre-renovation	Post-renovation		Pre-renovation	Post-renovation		Pre-renovation	Post-renovation	
June		22.25 (7.85)	19.0		14.0 (3.37)	4.70		15.0 (4.76)	4.5
July	4.67 (1.85)	8.85 (3.66)	14.0	5.17 (2.01)	6.45 (1.92)	8.50		5.15 (1.29)	8.0
August	2.66 (1.71)	5.73 (2.15)		1.52 (1.05)	2.43 (0.71)			2.13 (0.15)	
September	2.83 (1.10)	4.59 (0.17)		5.96 (10.6)	2.03 (0.46)		1.05 (0.49)	1.48 (0.33)	
October	1.65 (0.44)	4.93 (4.21)		0.89 (0.22)	1.08 (0.25)		1.15 (0.41)	1.23 (0.26)	
November	1.30 (0.0)	2.81 (0.85)		1.33 (0.46)	1.30 (0.57)		2.75 (1.32)	1.88 (0.88)	
December	2.50 (0.26)	3.25		8.18 (10.04)	4.80		13.68 (12.44)	3.40	
January	2.23 (1.00)	4.50 (0.0)		3.58 (1.70)	3.10 (1.98)		4.38 (1.39)	3.05 (6.0)	
February	7.63 (7.60)			24.33 (24.79)			41.0 (18.30)		
March	2.97 (6.70)	7.50		12.23 (7.89)	2.50		12.73 (7.29)	3.50	
April	18.30 (13.42)	5.70		26.80 (22.06)	2.50		30.6 (13.16)	2.50	
May	33.75 (8.18)	19.0		23.25 (13.05)	5.50		40.25 (22.04)	5.60	

Table 3. Values of conductivity (μmhos/cm at 25 C) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

Month	Section 1 Pre-renovation	Section 1 Post-renovation		Section 2 Pre-renovation	Section 2 Post-renovation		Section 3 Pre-renovation	Section 3 Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June		445.0 (10.0)	360.0		347.5 (114.4)	220.0		350.0 (111.1)	190.0
July	455.0 (7.1)	484.0 (32.1)		395.0 (7.1)	260.0 (31.6)			260.0 (31.6)	
August	524.0 (11.4)	526.7 (46.2)		504.0 (26.1)	323.3 (5.8)			323.3 (5.8)	
September	476.0 (15.2)	562.5 (26.3)		516.0 (32.1)	317.5 (12.6)		530.0 (14.1)	317.5 (12.6)	
October	490.0 (25.8)	495.0 (30.0)		542.5 (26.3)	340.0 (0.0)		550.0 (25.8)	340.0 (0.0)	
November	505.0 (35.4)	486.7 (11.6)		527.5 (35.9)	340.0 (0.0)		505.0 (66.1)	340.0 (0.0)	
December	456.7 (15.3)	460.0		518.0 (30.3)	350.0		486.0 (49.8)	350.0	
	1981	1982		1981	1982		1981	1982	
January	442.5 (17.1)	460.0 (0.0)		430.0 (20.0)	350.0 (0.0)		447.5 (27.5)	350.0 (42.4)	
February	430.0 (42.4)			390.00 (17.3)			385.0 (7.1)		
March	396.7 (40.4)	460.0		386.7 (11.6)	360.0		390.0 (36.1)	360.0	
April	400.0 (14.1)	450.0		384.0 (5.8)	340.0		352.0 (40.9)	340.0	
May	372.5 (9.6)	420.0		400.0 (16.3)	240.0		367.5 (34.0)	240.0	

Table 4. Values of alkalinity (mg/l as $CaCO_3$) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

Month	Section 1 Pre-renovation	Section 1 Post-renovation		Section 2 Pre-renovation	Section 2 Post-renovation		Section 3 Pre-renovation	Section 3 Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June		210.0 (8.2)	190.0		147.5 (55.6)	70.0		150.0 (58.3)	70.0
July	260.0 (10.0)	218.0 (19.2)	220.0	196.7 (46.2)	86.0 (5.5)	200.0		88.0 (8.4)	200.0
August	248.0 (28.5)	260.0 (36.1)		214.0 (13.4)	120.0 (0.0)			120.0 (0.0)	
September	238.0 (4.5)	282.0 (20.6)		224.0 (15.2)	112.5 (5.0)		225.0 (7.1)	112.5 (5.0)	
October	235.0 (10.0)	265.0 (17.3)		232.5 (5.0)	128.0 (5.0)		230.0 (8.2)	130.0 (0.0)	
November	235.0 (7.1)	250.0 (0.0)		230.0 (8.2)	126.7 (7.1)		235.0 (5.8)	130.0 (0.0)	
December	220.0 (10.0)	220.0		216.0 (18.2)	110.0		214.0 (19.5)	110.0	
	1981	1982		1981	1982		1981	1982	
January	220.0 (8.2)	220.0 (0.0)		205.0 (23.8)	115.0 (7.1)		210.0 (21.6)	115.0 (7.1)	
February	190.0 (14.1)			156.7 (15.3)			150.0 (14.1)		
March	200.0 (0.0)	240.0		156.7 (30.6)	110.0		166.7 (35.1)	110.0	
April	194.0 (8.9)	240.0		164.0 (5.5)	100.0		146.0 (29.7)	100.0	
May	190.0 (8.2)	190.0		170.0 (8.2)	80.0		165.0 (17.3)	80.0	

Table 5. Values of hardness (mg/l as $CaCO_3$) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

Month	Section 1 Pre-renovation	Section 1 Post-renovation		Section 2 Pre-renovation	Section 2 Post-renovation		Section 3 Pre-renovation	Section 3 Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June		197.5	180.0		130.0	70.0		130.0	.70.0
		(9.8)			(58.3)			(58.3)	
July	193.3	208.0	210.0	173.3	80.0	180.0		80.0	190.0
	(50.3)	(8.4)		(49.3)	(10.0)			(10.0)	
August	228.0	223.3		230.0	116.7			116.7	
	(17.9)	(15.3)		(14.1)	(5.8)			(5.8)	
September	218.0	235.0		230.0	117.5		230.0	117.5	
	(8.4)	(12.9)		(17.3)	(15.0)		(0.0)	(15.0)	
October	227.5	237.5		237.5	130.0		235.0	130.0	
	(5.0)	(15.0)		(5.0)	(0.0)		(5.77)	(0.0)	
November	220.0	217.5		232.5	120.0		222.5	120.0	
	(14.1)	(9.6)		(5.0)	(0.0)		(5.0)	(0.0)	
December	206.7	200.0		216.0	110.0		214.0	110.0	
	(11.6)			(11.4)			(20.7)		
	1981	1982		1981	1982		1981	1982	
January	210.0	200.0		202.5	120.0		207.5	120.0	
	(0.0)	(0.0)		(9.6)	(0.0)		(158.3)	(0.0)	
February	195.0			170.0			180.0		
	(7.1)			(26.5)			(42.4)		
March	200.0	210.0		156.7	120.0		160.0	120.0	
	(10.0)			(25.2)			(30.0)		
April	182.0	220.0		166.0	110.0		138.0	110.0	
	(14.8)			(8.9)			(32.7)		
May	182.0	180.0		145.0	80.0		142.5	70.0	
	(15.0)			(43.6)			(28.7)		

Table 6. Values of temperatures (C) measured in the stream study sections. Values with standard deviations (in parentheses) are averages of two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

Month	Section 1			Section 2			Section 3		
	Pre-renovation	Post-renovation		Pre-renovation	Post-renovation		Pre-renovation	Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June		10.8 (1.9)			13.5 (1.0)			14.0 (1.4)	
July	12.0 (2.8)	11.8 (1.0)	12.0	17.0 (2.8)	17.3 (1.0)	15.0		18.0 (0.8)	15.0
August	9.5 (0.7)	12.7 (1.2)		12.5 (2.1)	17.7 (1.2)			18.3 (1.7)	
September	9.2 (1.3)	10.3 (2.8)		11.0 (0.7)	13.8 (2.6)		11.0 (2.8)	14.0 (2.7)	
October	6.3 (1.7)	8.0 (0.0)		10.0 (1.6)	9.0 (0.0)		10.0 (2.5)	9.0 (0.0)	
November	3.0 (1.4)	3.5 (0.7)		6.5 (2.1)	5.0 (1.4)		4.3 (1.7)	5.0 (1.4)	
December	1.7 (1.5)	1.0 (0.0)		3.5 (0.6)	3.0		0.8 (0.5)	3.0 (0.0)	
	1981	1982		1981	1982		1981	1982	
January	0.5 (0.6)	0.0 (0.0)		0.5 (0.6)	0.5 (0.7)		0.5 (0.6)	0.5 (0.7)	
February	4.0 (0.0)			4.3 (4.5)			5.5 (2.1)		
March	3.0 (1.7)	2.0		5.0 (1.7)	3.0		4.67 (2.1)	3.0	
April	9.3 (5.1)			14.5 (8.1)			15.0 (9.3)		
May	9.0 (0.8)	7.0		12.5 (2.1)	9.0		12.5 (2.1)	9.0	

Table 7. Values of pH measured in the stream study sections. Values with standard deviations (in parentheses) are averages of hydrogen ion concentrations in two to five samples. Other values represent one sample per month. All sections contained water from Fleshman Creek prior to renovation (June 1, 1981). Afterwards Sections 2 and 3 contained water from the Yellowstone River.

	Section 1			Section 2			Section 3		
Month	Pre-renovation	Post-renovation		Pre-renovation	Post-renovation		Pre-renovation	Post-renovation	
	1980	1981	1982	1980	1981	1982	1980	1981	1982
June		8.21 (3.43×10^{-9})	8.20		7.87 (7.44×10^{-9})	8.00		8.10 (1.87×10^{-9})	8.10
July	8.10 (0.0)	8.25 (1.85×10^{-9})	7.30	7.35 (7.29×10^{-9})	7.94 (4.16×10^{-9})	7.60		8.26 (1.77×10^{-9})	7.80
August	8.17 (2.71×10^{-9})	8.20 (0.0)		7.65 (8.06×10^{-9})	7.88 (4.56×10^{-9})			8.12 (4.74×10^{-9})	
September	8.03 (4.56×10^{-9})	8.20 (1.09×10^{-9})		7.38 (1.44×10^{-9})	7.81 (6.66×10^{-9})		7.78 (1.21×10^{-8})	7.99 (6.59×10^{-9})	
October	8.14 (5.84×10^{-9})	8.10 (0.0)		7.55 (9.09×10^{-9})	7.93 (7.14×10^{-9})		8.02 (3.72×10^{-9})	8.06 (6.26×10^{-9})	
November	7.96 (6.75×10^{-9})	7.90 (0.0)		7.48 (1.18×10^{-9})	7.84 (3.00×10^{-9})		7.69 (3.80×10^{-9})	7.75 (2.05×10^{-9})	
December	8.00 (0.0)	8.40		7.64 (6.80×10^{-9})	7.80 (0.0)		7.53 (1.28×10^{-8})	8.20 (0.0)	
	1981	1982		1981	1982		1981	1982	
January	7.75 (8.78×10^{-9})	7.95		7.78 (9.91×10^{-9})	7.95 (0.0)		7.62 (1.08×10^{-8})	7.92 (9.68×10^{-10})	
February	7.79 (5.21×10^{-9})	-- --		8.16 (2.87×10^{-9})	-- --		7.82 (7.04×10^{-9})	-- --	
March	7.85 (9.65×10^{-9})	-- --		8.04 (4.15×10^{-9})	-- --		7.82 (7.04×10^{-9})	-- --	
April	8.12 (1.54×10^{-9})	-- --		8.48 (1.77×10^{-9})	-- --		8.23 (3.81×10^{-9})	-- --	
May	7.99 (1.90×10^{-9})	-- --		7.98 (3.99×10^{-9})	-- --		8.01 (4.06×10^{-9})	-- --	

monthly values ranged from 2.5-19.0 JTU (Table 2). The average turbidities for Section 1, 2 and 3 for the period of July through November 1980, were 2.62, 2.97 and 1.65 JTU, respectively. For the same period in 1981, following renovation, the average values were 5.38, 2.65 and 1.53 JTU. The turbidity in Section 1 in 1981 was significantly greater than in 1980, but the turbidities in Sections 2 and 3 in 1981 were less, but not significantly so, than in 1980, indicating the Yellowstone River may have been contributing less particulate matter to the renovated lagoon system than Fleshman Creek would have. The Yellowstone River generally has lower turbidity concentrations than Section 1 (Table 19).

Monthly averages of conductivity range from 260.0-562.5 micromhos/cm (μmhos/cm) at 25 C and single monthly values varied from 190-460 μmhos/cm at 25 C (Table 3). In Section 1, four of the five conductivity values for July through November were greater in 1981 than in the same months in 1980; however, only the value for September 1981 was significantly greater. The pattern of conductivities in Sections 2 and 3 were opposite to those in Section 1. Values for these sections were consistently lower in 1981 after renovation than in 1980 before renovation. Conductivities for July through November and in January for Section 2 and September through November and in January in Section 3 were significantly less after rehabilitation than before. The introduction of water from the Yellowstone River in June 1981, coupled with the greater volume of water and its diluting affect in those two sections are probably the reasons for the contrasting pattern of conductivities in Sections 2 and 3 following renovation.

The monthly alkalinity averages ranged from 86.0-282.0 mg/l (as $CaCO_3$) and the values of samples taken once per month were 70.0-240.0 mg/l (Table 4). Four of the five monthly alkalinity averages in Section 1 were higher in 1981 than in 1980 with those in September and October 1981 being significantly so. Alkalinity also decreased significantly between July 1980 and 1981. All alkalinities in Sections 2 and 3 were significantly lower following rehabilitation than before. These reductions were probably a function of the low alkalinity values of the new water source, the Yellowstone River (Table 19), used after June 1, 1981 and of the diluting affect of the greater volume of water present in these sections after rehabilitation. The high values obtained in July 1982 in Sections 2 and 3 were a result of Fleshman Creek flooding over the diversion dam and into Sacajawea Park Lagoon while the entrance of water from the Yellowstone River was eliminated due to extremely high flows in the river. Regardless of the water source, all values were above the minimum of 20 mg/l recommended by the National Technical Advisory Committee (EPA, 1976) to buffer natural changes that result from photosynthetic activity.

The average monthly hardness values varied from 80.0-237.5 mg/l (as $CaCO_3$) and samples taken once a month varied from 70.0-220.0 mg/l (Table 5). Values for hardness exhibited the same trend as those for conductivity and alkalinity. Generally, there were similar values in Section 1 for July through November 1980 and 1981, but significant decreases in Sections 2 and 3 for those months in 1981. The new water source and the increased volume of water in those sections were probably the reasons for the decrease. Less calcium and magnesium contained within a greater volume of water lead to reduction of hardness and conductivity. The high value for hardness in July 1982 is due to the flooding of Fleshman Creek into the system. These reduced concentrations of hardness should not decrease productivity in Sections 2 and 3, as the new water is still moderately hard as defined by Sawyer (1960).

Average monthly temperature values ranged from 0.0-13.8 Celsius (C) and single monthly values were 2.0-15.0 C (Table 6). Average temperatures in Sections 1, 2 and 3 for July through December 1980 were about 6.9, 10.1 and 6.5 C, respectively. For this period in 1981, temperatures were 7.8, 11.0 and 7.7 C. Although the average temperature in each section was higher in 1981 than in 1980, none of the increases were significant. The increases in water temperatures in 1981 were probably due to the higher air temperatures (NOAA, 1980 and 1981), and in Sections 2 and 3 may have been partially caused by water in the lagoon absorbing heat from the sun. These increases in temperatures may have been beneficial to trout by more closely approximating their optimum temperatures for growth and spawning, which are 19 and 9 C, respectively (Environmental Research Laboratory, 1976).

Average monthly pH values varied from 7.35-8.48 and values for samples taken once per month ranged between 7.30-8.20 (Table 7). Average pH values for July through November were higher in all sections in 1981 following renovation than in 1980 prior to renovation except for values during October and November in Section 1. Hydrogen ion concentrations were significantly less in July, September and October, 1981 in Section 2 than in the corresponding months in 1980. All pH values measured both before and after rehabilitation were well within acceptable limits for trout (EPA, 1976).

The measurements on duplicate samples in four series of tests to determine the precision of methods used in this study were virtually identical (Table 20). However, the values obtained from the two sets of duplicate samples analyzed concurrently by my methods and those of the Chemistry Station at MSU differed by 5.9-25.5% for conductivity, 4.2-15.7% for alkalinity, 0.0-7.1% for hardness and 0.0-3.9% for pH.

Physical Measurements

The maximum monthly discharges measured in each stream section (Table 8) show flows in Sections 2 and 3 were lower before renovation than afterwards. The increased discharge in these two sections may help prevent the bottom of the channel from becoming adversely impacted by fine sediments and provide better habitat for trout. The highest flows in Sections 2 and 3 occurred in May 1981 and were caused by Fleshman Creek spilling over the diversion dam and into the system.

The measurements of selected characteristics of the channel of each study section are presented in Table 9. An attempt was made to make measurements within each section at similar discharges before and after rehabilitation.

In Section 1, the average stream width and average depth did not differ significantly before and after renovation. However, the average

Table 8. Maximum monthly discharges measured in cubic meters/second (m^3/s) in the stream study sections of the Sacajawea Lagoon System. Water from Fleshman Creek flowed into Sections 2 and 3 prior to July 31, 1980 and water from the Yellowstone River afterwards.

Month	Section 1			Section 2			Section 3		
	1980	1981	1982	1980	1981	1982	1980	1981	1982
April		0.18			0.03			0.05	
May		1.36	0.66		0.99	0.30		0.91	0.32
June		0.90	0.70		0.41	1.03		0.45	0.93
July	0.15	0.40	0.38	0.20	0.48	0.63		0.46	0.65
August	0.08	0.10		0.22	0.28			0.29	
September	0.07	0.01		0.12	0.53		0.06	0.54	
October		0.07		0.08	0.33		0.05	0.30	
November	0.03	0.06		0.02	0.30		0.03		
December									

Table 9. Mean values of selected physical characteristics in study sections on Fleshman Creek in 1980 and 1981. Standard deviations of means are in parentheses.

Parameter	Section 1		Section 2		Section 3	
	1980	1981	1980	1981	1980	1981
Average width (m)	1.6 (0.5) n=15	1.4 (0.5) n=15	7.9 (3.6) n=17	3.1 (0.7) n=18	4.7 (1.6) n=19	4.3 (1.3) n=18
Average depth (cm)	19.1 (8.8) n=15	17.5 (11.4) n=15	28.1 (8.6) n=17	14.7 (4.2) n=18	15.8 (6.0) n=19	18.6 (6.1) n=18
Average velocity (m/s)	0.56 (0.3) n=15	0.16 (0.1) n=15	0.02 (0.3) n=17	0.13 (0.1) n=18	0.18 (0.1) n=19	0.25 (0.2) n=18
Total cover (m^2)	103	18	256	1	7	25
Sinuosity	1.11	1.12	1.05	1.09	1.10	1.09
Gradient (%)	0.94	0.93	0.34	0.33	0.55	0.55
Discharge at time of measurement	0.05	0.02	0.13	0.09	0.04	0.08

velocity was significantly less following rehabilitation, probably because of the lower flows.

In Section 2, the average stream width and average depth were both significantly less after renovation (Table 9). The change in channel width is a result of the channel modification work. A possible cause for the decrease in average depth is that the narrowing of the channel coupled with the increase in water volume caused a loss of friction between the water and the stream channel, thus increasing velocity and decreasing depth (Dr. Donald Reichmuth, personal communication).

The average stream width in Section 3 was 0.4 m less in 1981 than in 1980 but the difference was not significant. The average depth and velocity were greater in 1981 but not significantly so.

Measurements of total cover decreased in Sections 1 and 2 by 83 and 100%, respectively, following rehabilitation, while total cover in Section 3 increased by 257%. The reason for the decrease in Section 1 is not known, but may be due to cleaning debris out of the channel and trimming of streamside vegetation by residents of the area. The loss of cover in Section 2 was a direct result of the renovation of that section. The entire stream channel of this section was rebuilt, and in the process all of the cover was destroyed. The artificial undercut banks installed during rehabilitation accounted for nearly all of the cover present in Section 2 following renovation. A possible explanation for the increase in Section 3 is that the same transects were not used before and after rehabilitation. Transect markers used before renovation were removed by unknown individuals.

Sinuosities for Sections 1 and 3, which were not altered during rehabilitation, differed by about 1% between years (Table 9) giving a measure of accuracy of the procedure. The sinuosity for Section 2, which was altered, differed by about 4% between years, indicating that its sinuosity was increased by about 3% by the physical alterations.

The gradient was greatest in Section 1 and least in Section 2 (Table 9). Measurements of the gradients showed values within 0.01% between years in the unaltered sections and about a 0.01% reduction in Section 2 due to the meanders built into it.

Trout Populations

Estimates of the total numbers and biomass of trout in the study sections are presented in Table 10. Brook trout (Salvelinus fontinalis) was the only species present in Section 1. No significant change occurred in their numbers before and after rehabilitation. However, the length of fish used in the calculation of population numbers was 125-290 mm in 1980 and 75-305 mm in 1981. Forty-three of the fish used in the computation of the 1981 estimate were less than 125 mm, the smallest size used in the 1980 estimate. Deleting fish 125 mm and smaller from the population estimate in 1981 results in an estimate of 50 (±8), which would be a significant decrease from the 1980 level.

The total number of brown trout (Salmo trutta) taken in Section 2 before and after rehabilitation could not be compared because no estimate could be made for this section following rehabilitation. The total number of brown trout captured in the section and the number of trout/m

Table 10. Estimates of population numbers and biomass of trout in three study sections of Fleshman Creek before (1980) and after (1981) rehabilitation. Eighty percent confidence intervals are in parentheses.

Year	Section 1		Section 2		Section 3	
	N	B(kg)	N	B(kg)	N	B(kg)
1980	91(±11)	5.83(±1.12)	67(±13)	11.0(±3.56)	86(±8)	3.72(±0.82)
1981	105(±15)	5.57(±1.36)	--	--	79(±14)	2.43(±0.66)

were calculated as indices of change in the population from 1980 to 1981. The total numbers in 1980 and 1981 were 64 and 4, respectively. The number of trout/m in 1980 was 0.17 and in 1981 was 0.01. Before rehabilitation fish were 150-430 mm in total length, and afterwards were 113-126 mm, indicating that recolonization was in an early stage.

The estimated numbers of brown trout in Section 3 before and after rehabilitation were not signficantly different. The size ranges used in the 1980 and 1981 calculations were 75-315 mm and 100-305 mm, respectively. Only five of the fish used in the 1980 computation were less than 100 mm, so the size groups were virtually identical between years.

Neither the total biomass of the brook trout present nor the biomass of the comparable size groups were significantly different before or after rehabilitation in Section 1. A dramatic loss of biomass in brown trout occurred in Section 2. The four trout in the section in 1981 represented less than 1% of the biomass present in that section in 1980. The biomass of brown trout in Section 3 showed no significant change between years.

Rainbow trout (Salmo gairdneri) were also present in Sections 2 and 3, but their numbers were too low to allow the calculation of population estimates. Consequently, no estimates of biomass could be made either.

The mean backcalculated length and weight at age for fish from Sections 1, 2 and 3 are presented in Tables 11, 12 and 13. Age I+ brook trout in Section 1 were significantly larger in 1981 than in 1980 (Table 11). This may have been because electrofishing was done in July in 1980 and in September in 1981, allowing the trout more time to grow