The effects of channelization and mitigation on the morphology and trout populations of the St. Regis River, Montana
by Barry Milton Schaplow

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Fish and Wildlife Management
Montana State University
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Abstract:
To determine the effects of stream channelization caused by highway and railroad construction, trout population estimates and stream morphology measurements were made in eight sections of the St. Regis River, Montana. During the summers of 1973 and 1974, electrofishing techniques were used in sampling trout populations in unaltered, partially altered, recently altered with mitigating structures (step dams, random rocks, jetties) and "old" altered sections. A simple mark and recapture method was used for population estimates. Cutthroat trout predominated, numerically comprising 70 and 89% of the trout population in the Lookout and Saltese zones, respectively. Mitigative devices designed to alleviate the adverse effects of channelization were effective. Following two scouring periods in the step dam and random rock sections and one high water period in the jetty section, the average trout population in these three mitigated sections was significantly (P=.20) greater in number (36%) and about equal in weight when compared to the control areas.

With the exception of pools per stream width, physical measurements in the step dam and jetty sections indicate less available trout habitat than in the control sections. Morphological parameters, with the exception of thalweg deviation, suggest more trout habitat available in the random rock area than in the control section. In the Lookout zone, comparing physical parameters with trout populations, the highest correlation (r=.98) was found between number of trout and pools per stream width. Pool frequency was also important in the Saltese zone as the jetty section had the greatest pool-riffle periodicity and contained significantly more trout than any section in the study area. In 1974, when compared to the control (50% cutthroat), cutthroat in the step dam area (82% of the trout population) were able to repopulate relatively faster than brook trout. In the Saltese zone, invasion of the mitigated sections numerically occurred in about the same proportions as the control. Point estimates of average trout populations and values of physical parameters indicate old alterations have the least trout habitat in the study area. Trout. in the old alterations were significantly (P=.20) less (49 and 25% by number and weight, respectively) than in the mitigated sections. In 1974, comparing old alterations and controls, cutthroat trout were significantly (P=.20) less (43 and 40% by number and weight, respectively) in old alterations although brook trout were about equal.

Following one scouring period in the step dam and random rock sections and recent installation in the jetty section, trout 2 years and older were about equal in number and weight in these mitigated sections and the controls.

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THE EFFECTS OF CHANNELIZATION AND MITIGATION ON THE MORPHOLOGY AND TROUT POPULATIONS OF THE ST. REGIS RIVER, MONTANA

by

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

of

MASTER OF SCIENCE

in

Fish and Wildlife Management

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December, 1976

ACKNOWLEDGMENT

The author wishes to extend his appreciation to those who assisted him during the course of the investigation: Dr. Richard J. Graham initiated the project and aided in the field work; Dr. William R. Gould directed the study for a short time in 1974; Dr. Richard W. Gregory directed the study to completion and assisted in preparation of the manuscript; Drs. Robert L. Eng and Harold D. Picton critically reviewed the manuscript; Rodney Berg and John Lund aided in the field work and prepared quarterly and final reports for the U. S. Fish and Wildlife Service; Montana Fish and Game Department biologists added suggestions for data analyses; student technicians were instrumental in gathering the data; the U. S. Forest Service, Lolo National Forest, provided aerial photographs and lodging for the field crew; Mr. Gordan Haugan, U. S. Forest Service biologist, was particularly helpful in organizing the study, and my wife, Annette, added encouragement and assisted in preparation of the manuscript. The project was financed by the Office of Biological Services, Fish and Wildlife Service, under contract number 14-16-0008-737.

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ABSTRACT

To determine the effects of stream channelization caused by highway and railroad construction, trout population estimates and stream morphology measurements were made in eight sections of the St. Regis River, Montana. During the summers of 1973 and 1974, electrofishing techniques were used in sampling trout populations in unaltered, partially altered, recently altered with mitigating structures (step dams, random rocks, jetties) and "old" altered sections. A simple mark and recapture method was used for population estimates. Cutthroat trout predominated, numerically comprising 70 and 89% of the trout population in the Lookout and Saltese zones, respectively. Mitigative devices designed to alleviate the adverse effects of channelization were effective. Following two scouring periods in the step dam and random rock sections and one high water period in the jetty section, the average trout population in these three mitigated sections was significantly (P=.20) greater in number (36%) and about equal in weight when compared to the control areas. With the exception of pools per stream width, physical measurements in the step dam and jetty sections indicate less available trout habitat than in the control sections. Morphological parameters, with the exception of thalweg deviation, suggest more trout habitat available in the random rock area than in the control section. In the Lookout zone, comparing physical parameters with trout populations, the highest correlation (r=.98) was found between number of trout and pools per stream width. Pool frequency was also important in the Saltese zone as the jetty section had the greatest pool-riffle periodicity and contained significantly more trout than any section in the study area. In 1974, when compared to the control (50% cutthroat), cutthroat in the step dam area (82% of the trout population) were able to repopulate relatively faster than brook trout. In the Saltese zone, invasion of the mitigated sections numerically occurred in about the same proportions as the control. Point estimates of average trout populations and values of physical parameters indicate old alterations have the least trout habitat in the study area. Trout in the old alterations were significantly (P=.20) less (49 and 25% by number and weight, respectively) than in the mitigated sections. In 1974, comparing old alterations and controls, cutthroat trout were significantly (P=.20) less (43 and 40% by number and weight, respectively) in old alterations although brook trout were about equal. Following one scouring period in the step dam and random rock sections and recent installation in the jetty section, trout 2 years and older were about equal in number and weight in these mitigated sections and the controls.

INTRODUCTION

The term "channelization" is usually applied to a river or stream that is displaced from its natural course by removing meanders and directing flow down a straighter and, therefore, much shorter route. Channelization often accompanies highway construction and railroad right-of-way projects. By removing meanders, construction costs are lowered but aquatic habitat is considerably reduced, velocity is increased and larger quantities of streambed material are transported downstream. Thus stream alterations generally result in a reduction in fish populations.

Channelization due to highway construction resulted in a 94% reduction in number and weight of trout greater than 15.2 centimeters in length in a small Montana stream (Whitney and Bailey, 1959). Elser (1968) found the number and weight of brown trout and rainbow trout were about 78% less in a segment of mountain stream straightened by railroad construction than in a natural section in Little Prickly Pear Creek, Montana. Johnson (1964) found channel alteration of the Shields River in Montana resulted in a reduction of 90% in the number and weight of game fish. Reductions in fish populations are due to the alteration of several important physical factors of a water course. Removal of undercut banks and brush in a section of stream caused a decrease in numbers and weight of trout with greatest losses among

larger fish (Boussu, 1954). Lewis (1969) concluded that cover (brush, overhanging vegetation, undercut banks, and dead submerged portions of bank vegetation) and velocity were the two most significant physical factors affecting variations in trout populations in streams. Shuck (1945) reported volume and depth of water were significant factors in determining the population density of brown trout 21.4 centimeters and larger in a section of stream. Greater numbers of larger fish were present in areas of greater depth and volume of water.

Certain stream habitat improvements have proven effective in increasing or restoring fish population levels. Tarzwell (1937, 1938), Shetter, Clark and Hazzard (1946) and Saunders and Smith (1962) have shown that population levels respond to increases in shelter and food. Various combinations of rock deflectors have been useful in mitigating the effects of stream channelization from highway construction. Barton and Winger (1973) reported a combination of gabion deflectors, random rocks, rock V-deflectors and rock wing deflectors were effective in mitigating the effects of stream channelization. Two years following alteration, fish population numbers were essentially equal in altered areas with mitigative devices and unaltered areas of the Weber River in Utah. In a jetty deflector section on the East Gallatin River, total game and rough fish population numbers were comparable to pre-alteration levels two years after construction (Elser, 1970). Following alteration, physical characteristics of rock deflector sections on

Little Prickly Pear Creek and the East Gallatin River (Elser 1968, 1969) were comparable to unaltered sections except for lack of vegetative cover.

The objectives of the present study were: 1) to compare the physical and biological characteristics of "old" (86 years) altered areas with unaltered areas; 2) to determine the physical and biological characteristics of affected areas prior to, during and following alterations resulting from construction of Interstate 90; and 3) to determine the effectiveness of mitigating devices.

Field studies were carried out during July, August and September of 1973 and 1974.

DESCRIPTION OF STUDY AREA

The St. Regis River is a clear trout stream of high gradient located in the northwestern corner of Mineral County, Montana. It originates from upper St. Regis Lake on the east slope of the Montana-Idaho divide at an elevation of 1707 meters. Below the lake, the stream flows southeasterly about 59 kilometers entering the Clark Fork River 806 meters above sea level at St. Regis, Montana. The drainage basin contains relatively dense conifer stands interspersed with alpine meadows, and encompasses an area of 488 square kilometers. The soils of the drainage are primarily derived from bedrocks of the Belt supergroup, including argillite, siltite, quartzite and some carbonated rocks. The majority of soils in the floodplain are loamy in texture (McConnell, 1969).

For this study, the upper St. Regis River was divided into two areas, designated the Lookout and Saltese zones. The uppermost (Lookout) zone begins 5.0 kilometers downstream from Upper St. Regis Lake, at the convergence of Borax Creek and continues 7.6 kilometers to the junction of Rainy Creek (Figure 1). In that distance, the floodplain width and average 1974 summer discharge increase from 22 meters to 153 meters and from $3.0m^3/s$ to $7.5m^3/s$, respectively. The gradient is 29 meters/stream mile.

From Rainy Creek, the stream flows 8.0 kilometers through the Saltese zone to the confluence of Silver Creek. The average floodplain width is 107 meters while the gradient has decreased to 16

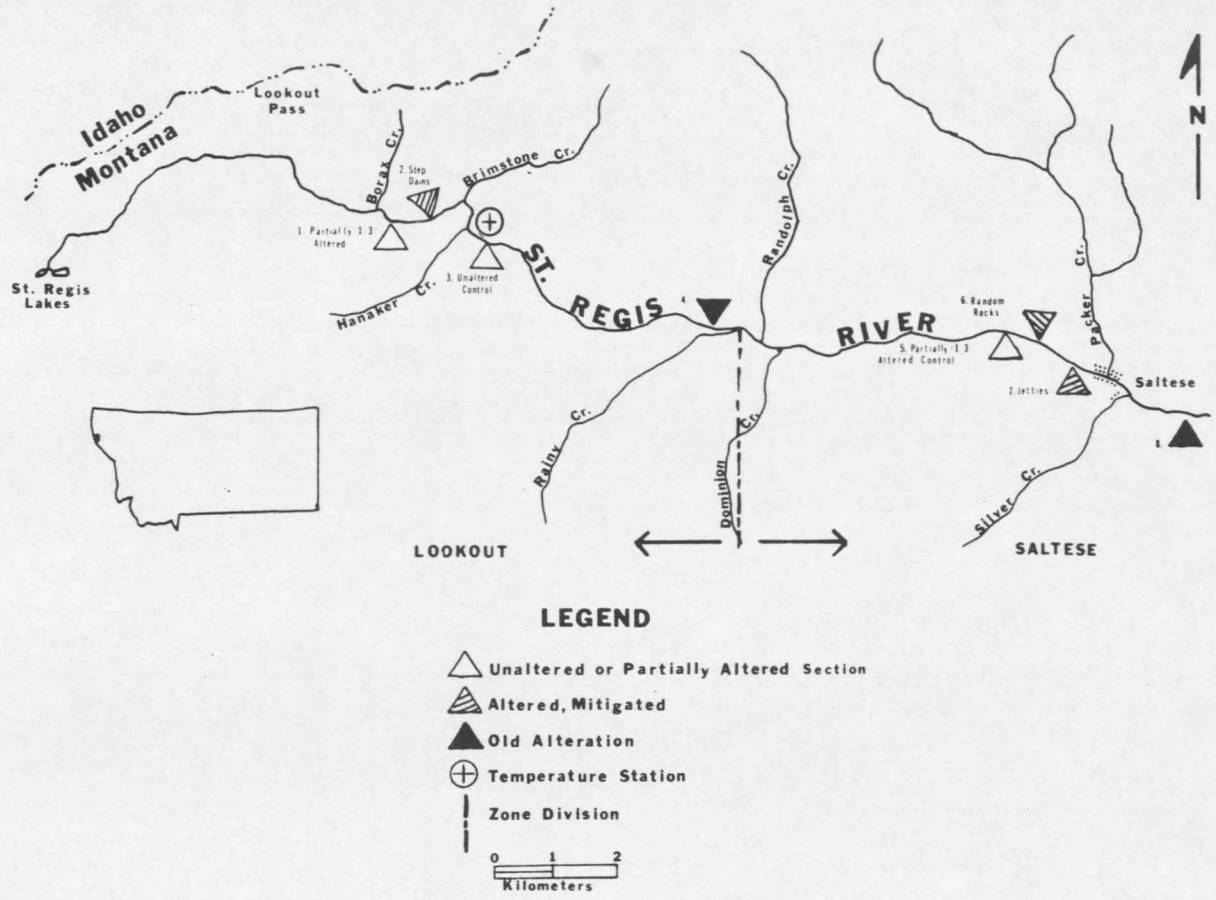

Figure 1. Map of study area, showing location and extent of alteration of the study sections.

meters/stream mile. The average summer discharge from the Saltese zone was $15m^3/s$.

In both zones, bank vegetation in unaltered sections consisted primarily of red dogwood *(Cornus stolonifera)* and willow *(Salix* spp.*)*. Conifers, including alpine fir *(Abies lasiocarpa)*, Engelmann spruce *(Picea engelmanni)* and lodgepole pine *(Pinus contorta)*, provide considerable shade. In 1890, the Northern Pacific and Montana Railroad Company constructed 61 kilometers of track from St. Regis to Lookout Pass, straightening portions of the channel in the study area. In these old alterations, red dogwood *(Cornus stolonifera)* and willow *(Salix* spp.*)* continue to dominate while conifers are practically non-existent.

Eastern brook trout *(Salvelinus fontinalis)* and cutthroat trout *(Salmo clarkii)* were the predominant game fish in the study area. Mountain whitefish *(Prosopium williamsoni)* and a few dolly varden *(Salvelinus malma)* were also sampled. The slimy sculpin *(Cottus cognatus)* was common throughout the study area. There was no stocking in the area during the study.

A water temperature station was established 0.40 kilometers below Hanaker Creek in the Lookout zone. In 1973, temperatures were highest in mid-August (maximum 18°C-August 14) and declined throughout the period (Figure 2). The mean diurnal difference between the average maximum and minimum temperature was 5.1C°. In 1974, temperatures were

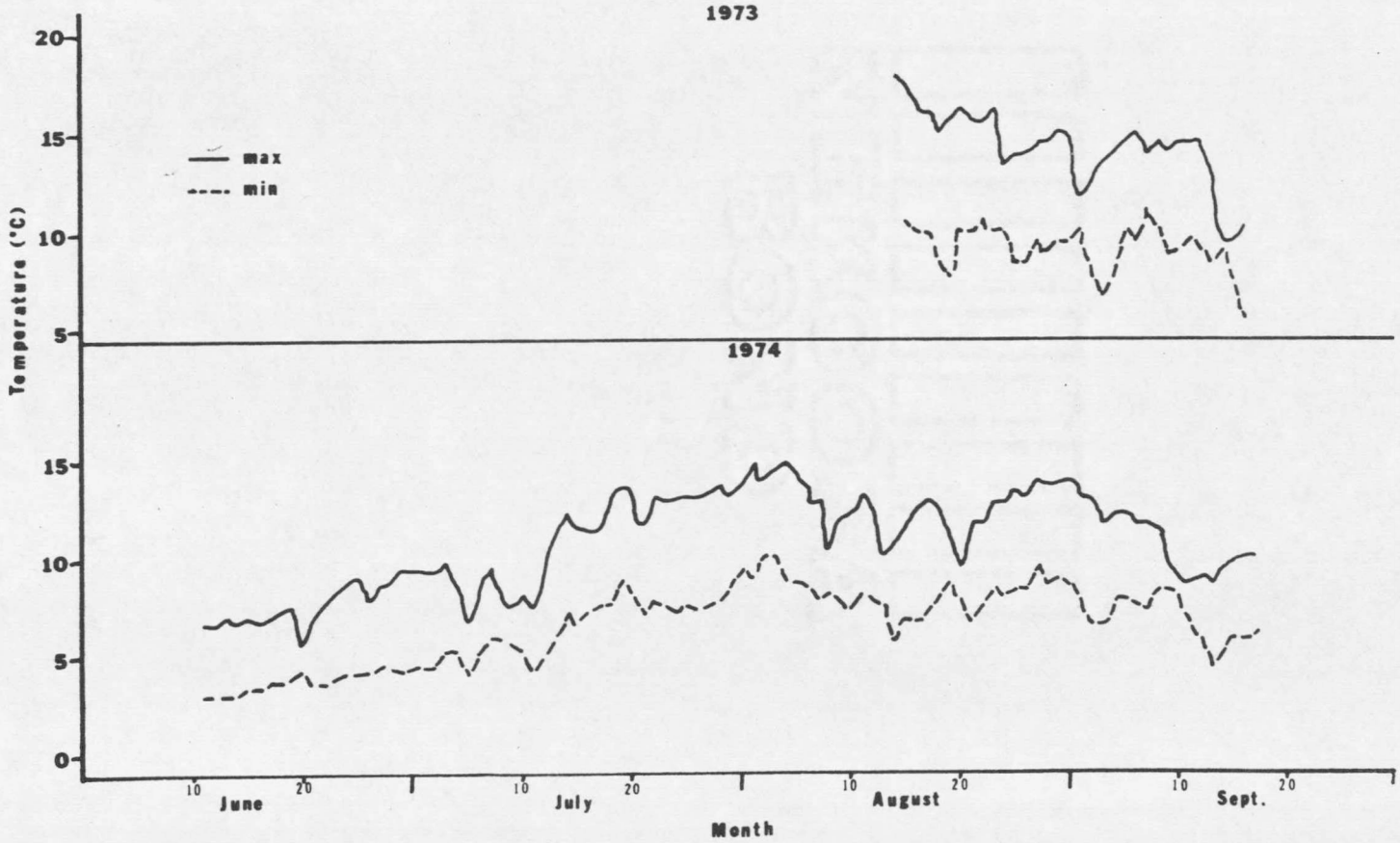

Figure 2. Daily maximum-minimum water temperatures for the St. Regis River .4 kilometer below Hanaker Creek for August 14-September 16, 1973 and June 11-September 16, 1974.

coolest in early June. With the exception of a short cooling period in early July, temperatures gradually warmed to a maximum of 15°C on August 4th. Highest temperatures were achieved during July and August. During the period from July 15th to September 1st, water temperatures reached or exceeded 13.9°C on seven days. The mean diurnal temperature fluctuation was 4.2C°. The stream did not become ice covered in winter.

In the Lookout zone, step dams were used as a mitigative device in the recently channelized section while in the Saltese zone, individual rocks (random rocks) were used in one altered reach and jetties (rock deflectors) were installed in another channelized area. The step dams and random rocks were established in 1972 and the jetties were positioned in 1973. These three sections were completely displaced due to highway construction. The intent of these mitigative devices is generally to create a deeper (pool scouring), more varied channel, with physical parameters comparable to those in the "control" sections.

METHODS

The upper 23.3 kilometers of stream were divided into two zones based primarily on water discharge. Aerial photographs and highway construction plans aided in selecting eight study sections, four in each zone (Figure 1). A Traverscan computer program was used in delineating stream morphology from Montana Highway Department aerial photos (scale 2.5 cm:152 m) taken in April 1971. The jetty section was 344 meters long while the other sections ranged from 427-457 meters in length. Channel alterations, stream length, surface area, and extent of visible vegetative bank cover were measured in each zone. A Taylor thermograph was operated in August and September in 1973 and June through September in 1974.

The ratio of channel length to down valley distance or sinuosity (Leopold, Wolman, and Miller, 1964) was determined for each zone. A stream segment was considered meandering if the sinuosity was greater than 1.5. Meanders, defined as freely shifting S-shaped channels fashioned in alluvial materials (Matthes, 1941) were counted.

Physical measurements were taken in late August, 1973 and early September, 1974. Discharge was two to three times greater in 1974 than 1973. Transects were placed at 3 meter intervals in sections 1, 2, 3, 5 and 6, at 7.6 meter intervals in section 4 and at 15.2 meter intervals in section 8. Transects in section 7 (jetties) were placed

3 meters above and below, at the tip of, and halfway between each jetty. Depths were taken at 0.6 meter intervals to the nearest centimeter. Average depth was computed excluding readings of two or more consecutive zeros. Thalweg velocities were measured at each transect using a 622-F Gurley current meter. Pool frequency was determined by measuring the thalweg, with pool arbitrarily defined as a vertical drop in the stream bed greater than the summation of average thalweg depth and deviation.

In 1974, fish cover was measured at 15 meter intervals, 1.5 meters on either side of the transect on both banks. Total area of cover provided by overhanging brush, undercut banks, rock shelves, and debris such as snags and logs was recorded. Brush and debris were considered cover if overhanging branches were within 1.5 meters of the water surface or if living or dead branches and roots were immediately above or beneath the water surface.

The fish population of each section was sampled by electrofishing. A portable 1500 watt AC generator was used in conjunction with a Fisher Model FS-102 rectifying unit to change the alternating current to various forms of DC current. Captured fish were anesthetized with MS-222 (Tricaine Methanesulfonate), measured to the nearest 0.25 centimeter, weighed to the nearest 4.5 grams and marked with a partial fin clip. Scale samples were taken for age determination in sections where population estimates were desired, and the fish were released

near the capture site.

Population estimates were made using the Petersen mark-recapture formula as modified by Chapman (1951). Multiple marking and recapture runs were often needed to collect an adequate sample size. A period of at least 48 hours was allowed to elapse between mark and recapture runs. When possible, blocking nets were installed at the lower end of each section prior to shocking operations.

The actual population estimate computations were made using a computer program developed by the Montana Fish and Game Department. The program uses methods described by Vincent (1971 and 1974). Total numbers and total biomass were determined for each study section. Confidence limits at the 80% level (P=.20) were calculated for each parameter. Overlapping confidence intervals were not considered to be significantly different. Age group composition for each species was also computed. Standard deviation of thalweg depth and average depth is used as an absolute index to indicate the diversity or variation of the stream bed.

RESULTS

Stream Morphology

Physical parameters of the St. Regis River obtained from aerial photos and highway plans are shown in Table 1. Low sinuosity values in both zones reflect channel length lost through alteration prior to I-90 construction. Recent construction in the two zones altered an additional 17% (34 to 51%) and resulted in the loss of 0.16 kilometers of stream length. Bank cover in each zone was reduced about 10%. Except in the random rock section, average stream width increased with progression downstream in 1973. Construction in this section created a narrow channel with the greatest depth in the study area (Table 2).

Average depth in unaltered and partially altered sections increased in a downstream direction while altered sections exhibited no trend. In the Lookout zone average depth deviation was less in the altered sections than the unaltered control. The step dam section had the least deviation (3.0). In the Saltese zone scouring in the random rock section resulted in the greatest depth deviation in the study area (6.1), while the partially (1/3) altered control in this zone contained the second greatest deviation (4.6). The old alteration had the least depth development (3.5). Gradients decreased in a downstream direction with the exception of the random rock section which had the steepest slope in the Saltese zone.

TABLE 1. CHANNEL MEASUREMENTS FROM AERIAL PHOTOS AND HIGHWAY PLANS BEFORE AND AFTER INTERSTATE-90 ALTERATION.

Zone	Length (Kilometers)		Area (Hectares)		Bank Cover (%)		Sinuosity		# of Meanders/ Kilometer		Altered (%)	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Lookout	7.63	7.50	7.1	7.0	90.0	78.9	1.30	1.28	2.4	2.1	29.6	43.7
Saltese	8.03	8.00	8.9	8.9	95.0	85.2	1.14	1.14	.6	.6	39.0	57.3
Total	15.66	15.50	16.0	15.9	93.0	82.0	1.21	1.20	1.5	1.3	34.0	51.0

TABLE 2. PHYSICAL MEASUREMENTS OBTAINED FROM EIGHT STUDY SECTIONS ON THE ST. REGIS RIVER DURING THE SUMMER PERIODS OF 1973 AND 1974.

	1973 Lookout Zone				1973 Saltese Zone				1974 Lookout Zone		1974 Saltese Zone		
Parameter	Partially Altered	Step Dams[1]	Unaltered Control	Old Alteration	Partially Altered Control	Random Rocks[1]	Jetties	Old Alteration	Step Dams[2]	Unaltered Control	Partially Altered Control	Random Rocks[2]	Jetties
Area (Hectares)	0.17	0.17	0.30	0.36	0.49	0.28	0.44	0.73	0.23	0.31	0.41	0.31	0.42
Ave. Width (m)	3.7	3.8	6.2	7.6	10.6	6.3	12.5	17.1	5.0	6.4	9.7	7.2	12.0
Ave. Depth (cm)	9.4	8.1	13.2	13.7	19.8	21.6	14.5	13.7	10.2	14.5	22.4	28.4	18.5
[Std. Dev.]	3.3	3.0	4.1	3.7	4.6	6.1	4.1	3.5	3.4	5.0	6.1	8.3	5.4
Gradient (%)	2.68	2.43	1.65	1.24	-	1.48	.91	.69	-	-	1.06	-	-
Ave. Thalweg Depth (cm)	17.8	16.0	26.2	25.4	32.5	41.7	28.4	25.9	22.0	30.7	42.7	53.1	38.1
[Std. Dev.]	2.4	3.2	4.1	1.8	3.9	5.3	3.9	.9	2.9	4.1	6.8	5.3	4.7
Pool-Riffle Periodicity	8.4	10.1	7.1	12.5	8.6	3.6	4.7	12.5	8.4	8.3	8.6	5.5	3.3
Ave. Thalweg Velocity (m/s)	0.25	0.30	0.47	0.48	0.45	0.67	0.56	0.52	0.38	0.52	0.52	0.69	0.61
Thalweg Length[3] / Down Valley Distance	1.10	1.11	1.23	1.02	1.03	1.08	1.13	1.03	1.18	1.23	1.14	1.09	1.13
Section Length (Meters)	466	461	483	471	457	432	353	427	-	-	428	-	-

[1]Following one high water period.

[2]Following two high water periods.

[3]Comparisons in Saltese zone not made because each section was mapped at a different interval.

In the Lookout zone average thalweg depth was greatest in the unaltered control being 47, 64 and 3% greater than the partially altered, step dam and old altered sections, respectively. The deviation of thalweg depth was also greatest in the unaltered control (4.1). In the Saltese zone thalweg depth and deviation were second greatest in the control being 22 and 26% less, respectively, than in the random rock section. Thalweg development was least in the old alterations, averaging 1.4.

Leopold and Langbein (1966) maintain the spacing of successive riffles in a natural reach of stream is ordinarily from 5 to 7 stream widths. Pools in the control sections of the Lookout and Saltese zones were spaced at 7.1 (Figure 3) and 8.6 widths, respectively. Of the recently altered sections, the step dams had the least number of pools (10.1 widths) and the random rock section the greatest (3.6 widths) (Figure 3). In both zones, old alterations had the least variety of habitat, displaying riffles every 12.5 widths. In both years average thalweg velocities in the Lookout zone generally increased in a downstream direction. Channelized sections of the Saltese zone had higher thalweg velocities than the control.

Distinct differences in cover exist between unaltered and altered sections in the Lookout and Saltese zones (Table 3). Considering the entire study area, the unaltered control has 36, 265, 620 and 906% more total cover than the partially altered control, random rock, jetty and

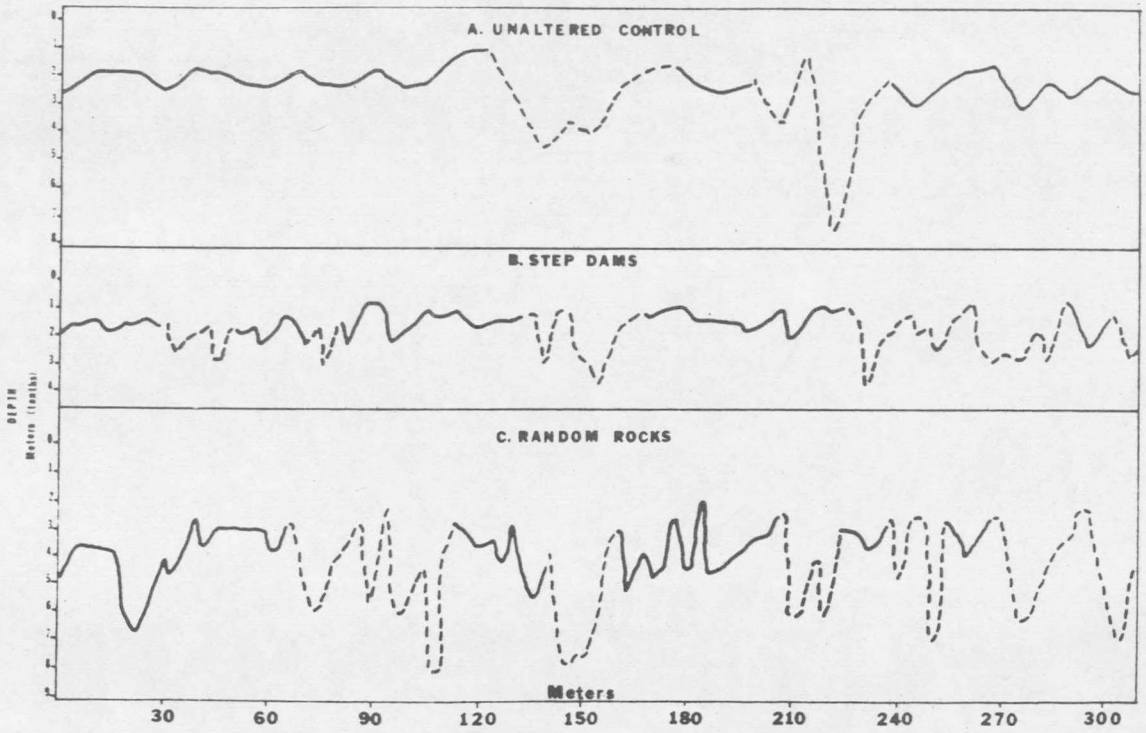

Figure 3. Stream bottom profiles of pools (dotted line) and riffles as measured along the thalweg. A. Unaltered control, Lookout zone. B. Step dam section. C. Random rock section.

TABLE 3. THE AREA OF EACH CLASSIFICATION OF COVER (SQUARE METERS PER 300 METERS) AS MEASURED FROM TRANSECTS TAKEN AT 15.2 METER INTERVALS.

		Step Dams	Unaltered Control	Partially Altered Control	Random Rocks	Jetties
Brush[1]	(%)	3.5	87.0	62.4	-	-
	Total	.6	149.9	79.0	-	-
Undercats[2]	(%)	-	3.4	17	-	-
	Total	-	5.9	21.6	-	-
Debris[2]	(%)	-	9.6	20.6	-	-
	Total	-	16.2	26.1	-	-
Rock[2] Shelves	(%)	96.5	-	-	100.0	100.0
	Total	16.5	-	-	47.0	23.9
	Total	17.1	172.0	126.7	47.0	23.9

[1]Includes submerged up to 5 feet above the waters surface.

[2]Includes submerged up to 2 feet above the waters surface.

step dam sections, respectively. In the unaltered and partially altered controls, 87 and 62%, respectively, is brush cover while in the random rock, jetty and step dam sections, 100, 100 and 96.5%, respectively, of the cover is rock shelves. Excepting cover, physical measurements of the random rock section indicate the greatest variety of habitat in the study area.

Sinuosity, or the ratio of thalweg length to down valley distance, is used as an index of the ability of the stream to provide fish

habitat (Hunt and Graham, 1972). In the Lookout zone, this ratio is greatest for the unaltered control (1.23) and least in the old alteration (1.02).

Because of the greater water volume in 1974, widths, depths and velocities were generally greater in all sections than in 1973. In the Lookout zone following two high water periods, average and thalweg depth were 30 and 29% less in the step dam section than in the unaltered control. Depth deviations were also less in the step dam area than in the control. The number of pools in the step dam section had increased in 1974 and was comparable to the unaltered section. Sinuosity increased slightly in the step dam section although remained lower in the unaltered control. Thalweg deviation decreased 9% in the step dam section.

In 1974 in the Saltese zone average depth and deviation were 27 and 36% greater in the random rock section than in the partially altered control. Average thalweg depth was 24% greater in the random rock section while thalweg deviation was 28% greater in the control than in the random rock area. The random rock section displayed the greatest gain in average depth deviation (36%) of any mitigated area. There was a greater number of pools per stream width in the random rock section than in the control (5.5-8.6), respectively.

Average depth and deviation in the jetty section were the lowest in the Saltese zone being 17 and 11% less, respectively, than the

partially altered control. Average thalweg depth and deviation were also the lowest in this zone being 11 and 31% less, respectively, than the control. The jetties displayed the greatest increase in thalweg deviation (21%). Following one high water period, the jetty section contained over twice as many pools per stream width (3.3) as the partially altered control (8.6). Scouring among the rocks of the remaining jetties was primarily responsible for the increase in the number of pools (Figure 4).

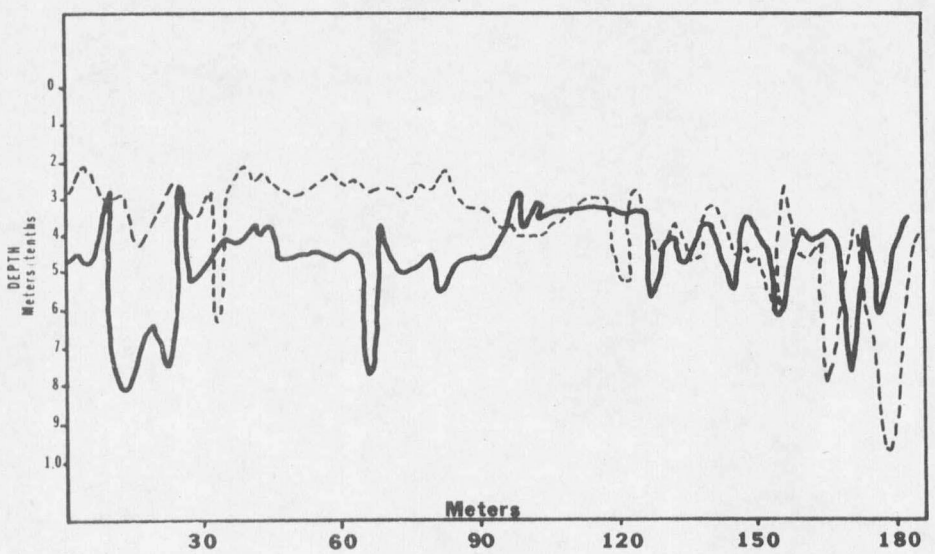

Figure 4. Bed profile along the thalweg of the jetty section before (dotted line) and after (solid line) one scouring period.

Trout Populations

Lookout Zone

The number and weight of cutthroat, brook trout (Table 4) and total trout (Figure 5) per 300 meters was computed for four sections. In both years, cutthroat trout in the Lookout zone was the most abundant species averaging 70 and 58%, respectively, of the number and weight of trout.

During both years a small difference in fish populations existed between the unaltered control and a partially (1/3) altered section. In the partially altered section brook trout were significantly less than the control, being 31 and 40% (2 kgs.) less by number and weight, respectively, in 1973 and 66% (2 kgs.) less by weight in 1974. Although differences were not significant, in both years point estimates of number and weight of total trout were slightly less in the partially altered section than the control. In 1973 total trout were 3 and 10% (1 kg.) less by number and weight, respectively. In 1974 trout were 7 and 17% (1 kg.) less, respectively, in the partially altered than in the control section.

In the step dam section in both years, there was significantly less brook trout number and weight than in the control section. In 1973 brook trout were 57 and 60% (3 kgs.) less in number and weight, respectively, while in 1974 brook trout were 49 and 33% (1 kg.) less,

TABLE 4. THE NUMBER AND BIOMASS (KILOGRAMS) PER 300 METERS OF CUTTHROAT AND BROOK TROUT ONE YEAR AND OLDER FOR: A) EIGHT SECTIONS IN 1973 AND 1974; AND B) AVERAGE OF THE CONTROLS AND OLD ALTERATIONS IN BOTH ZONES IN 1974. (confidence intervals in parentheses)

		Lookout Zone					Saltese Zone			
		Cutthroat		Brook Trout			Cutthroat		Brook Trout	
Section		Number	Biomass	Number	Biomass	Section	Number	Biomass	Number	Biomass
					[A]					
Partially (1/3) Altered	1973	153	6	29	3	Partially (1/3)[1] Altered Control	50	4	16	3
		(12)	(1)	(4)	(1)		-	-	-	-
	1974	126	3	59	1		319	7	29	2
		(29)	(1)	(28)	(1)		(107)	(2)	(7)	(0)
Step Dams	1973	124	5	18	2	Random Rocks[1]	22	2	8	1
		(12)	(1)	(2)	(0)		-	-	-	-
	1974	223	4	50	2		232	7	30	3
		(36)	(1)	(16)	(1)		(77)	(2)	(10)	(1)
Unaltered Control	1973	146	5	42	5	Jetties[1]	36	3	6	2
		(35)	(1)	(4)	(1)		-	-	-	-
	1974	100	3	99	3		611	12	66	4
		(19)	(1)	(22)	(1)		(113)	(3)	(13)	(1)
Old Alteration	1973	48	4	36	3	Old Alteration[1]	21	2	14	3
		(11)	(1)	(5)	(1)		-	-	-	-
	1974	45	2	85	3		194	4	37	5
		(15)	(1)	(20)	(1)		(91)	(1)	(13)	(1)

		Lookout and Saltese Zones			
		Cutthroat		Brook Trout	
Section		Number	Biomass	Number	Biomass
			[B]		
Controls	1974	210	5	61	3
		(54)	(1)	(12)	(1)
Old Alteration	1974	120	3	61	4
		(46)	(1)	(12)	(1)

[1]Trout two years and older. Confidence intervals not available.

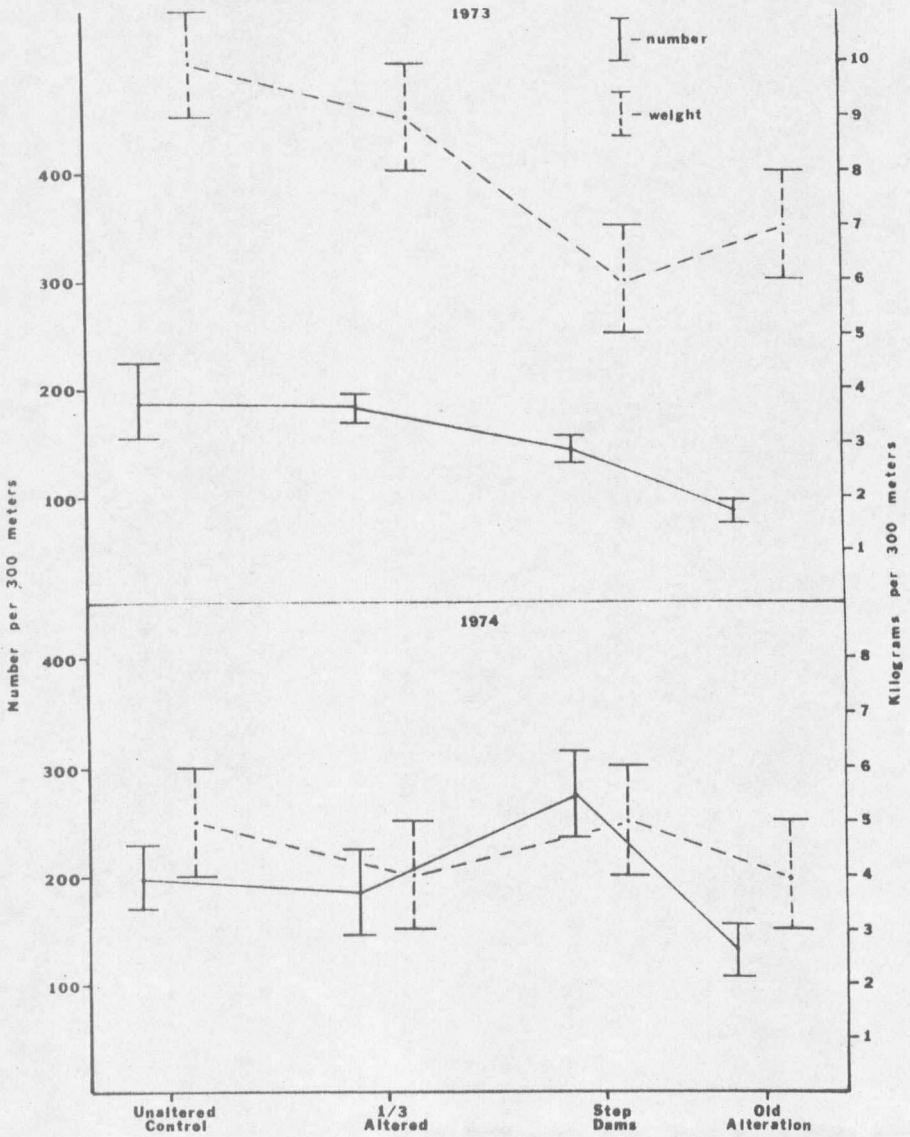

Figure 5. Total number and biomass of trout (cutthroat and brook), age 1 and older, in four sections of the Lookout zone during 1973 and 1974.

respectively, in the step dam area than in the control. Although differences were not restricted to any particular age group, in both years each age group was less in the step dam section than the control (Table 5).

In the step dam section cutthroat, following one high water period, were 15% less and equal in number and weight, respectively, when compared to the control. Confidence limits displayed a large overlap. Yearlings were the only age group which was less in the step dam area (33%) than the control. Following two high water periods there were significantly more total cutthroat number in the step dam section being 123% greater than in the control. This relative increase in cutthroat trout between years was due mostly to 149% increase in age-1 cutthroat in the step dam area while they decreased 32% in the unaltered section.

Following one high water period in the step dam area, total trout were significantly less (25 and 30% by number and weight, respectively) than in the control. In 1974 the step dam section contained 93% more and 20% less total trout number and weight, respectively, than in 1973. During this period the trout population in the control section increased 6% and decreased 40% in number and weight, respectively. This resulted in the step dam area, following two high water periods, containing significantly (37%) more in number and about equal weight of trout as the unaltered control.

TABLE 5. THE NUMBER AND WEIGHT PER 300 METERS OF CUTTHROAT AND BROOK TROUT IN EACH AGE GROUP FOR EIGHT SECTIONS IN 1973 AND 1974. (Kilograms in parentheses)

Section		Age Group					
		Cutthroat			Brook Trout		
		I	II	III and Older	I	II	III and Older
Lookout Zone							
Partially (1/3) Altered	1973	89 (1)	45 (2)	19 (3)	7 (1)	14 (1)	8 (2)
	1974	87 (1)	32 (2)	7 (1)	49 (1)	9 (1)	1 (1)
Step Dams	1973[1]	70 (1)	38 (2)	16 (2)	7 (1)	10 (1)	1 (1)
	1974[1]	174 (2)	46 (2)	3 (1)	45 (1)	3 (1)	2 (1)
Unaltered Control	1973	105 (1)	25 (1)	16 (2)	12 (1)	15 (2)	15 (3)
	1974	71 (1)	25 (1)	4 (1)	79 (1)	15 (1)	5 (1)
Old Alteration	1973	17 (1)	14 (1)	17 (3)	21 (1)	3 (1)	12 (2)
	1974	36 (1)	5 (1)	4 (1)	70 (1)	14 (1)	1 (1)
Saltese Zone							
Partially (1/3) Altered Control	1973	196 (2)	34 (2)	16 (2)	- -	9 (1)	7 (2)
	1974	219 (3)	95 (4)	5 (1)	23 (1)	4 (1)	2 (1)
Random Rocks	1973[1]	- -	13 (1)	9 (1)	5 (1)	3 (1)	5 (1)
	1974[2]	163 (3)	62 (3)	7 (1)	21 (1)	6 (1)	3 (1)
Jetties	1973	147 (2)	33 (2)	3 (1)	54 (1)	3 (1)	3 (1)
	1974[1]	487 (6)	122 (5)	2 (1)	42 (1)	16 (1)	8 (2)
Old Alteration	1973	69 (1)	13 (1)	8 (1)	- -	8 (1)	6 (2)
	1974	150 (2)	41 (2)	4 (1)	23 (1)	4 (1)	10 (4)

[1]Following one high water period.

[2]Following two high water periods.

In both years, the numerical and weight ratio of cutthroat to brook trout was higher in the step dam section than the unaltered control. This suggests that cutthroat were able to recover from alteration and repopulate the step dam section relatively faster than brook trout. Following two high water periods, yearlings composed a slightly higher percentage (average 6%) of the population of trout in the step dam area than in the control.

In both years the number of eastern brook trout was 14% less in the old alteration than the control. These differences were not significant. In 1973 the brook trout weight in the old alteration was significantly less, 40% (2 kgs.) than the control, while in 1974 the weight of brook trout was equal in these two sections. Differences were not restricted to any particular age group although in 1974 each age group was slightly less in the old altered section than in the control.

In both years the number of cutthroat was significantly less in the old alteration than the control being 67 and 55% less in 1973 and 1974, respectively. In both years there was no significant difference in cutthroat weight although point estimates were 1.0 kilogram less in the old alteration than the control. In both years all age groups were generally less in the old alteration than the control with the least difference being age-3^{+}.

In 1973 total trout were significantly less (56 and 30% in number and weight, respectively) in the old alteration than the control. In 1974 trout in both sections followed the same trends (increasing numbers, decreasing weight) resulting in total trout being 35 and 17% (1 kg.) less by number and weight, respectively, in the old altered section than the control. Only differences in number were significant. An increase in cutthroat yearlings (112%) in the old alteration, accounted for most of the relative increase in number of total trout between years (Table 5). With the exception of weight in the unaltered section in 1973, the old alteration contained the smallest proportion of cutthroat and highest proportion of brook trout number and weight of any section in the zone in both years. This indicates, relative to controls, cutthroat are presently not thriving as well as brook trout in the old alteration.

In 1973 yearling cutthroat in the Lookout zone were least abundant in altered sections, being 15, 33 and 84% less in number in the partially altered, step dams and old alteration, respectively, than in the control section (Table 5). Despite low flows in the fall of 1973 and a severe winter flood in 1974, good recruitment of the 1973 year class as yearlings was generally noted in both species. Successively older age groups decreased in abundance in all sections.

Saltese Zone

The number and weight of cutthroat and brook trout per 300 meters are presented in Table 4. The total trout populations in 1973 and 1974 are presented in Figure 6. Unless otherwise specified, comparisons in 1973 are made between trout 2 years and older since yearling estimates were not available in all sections. Cutthroat trout also predominated in the Saltese zone comprising 74 and 54% of the number and weight, respectively, of trout 2 years and older in 1973. In 1974, cutthroat one year and older comprised 89 and 74% of the number and weight, respectively, of all trout present.

In 1973, following one high water period, brook trout 2 years and older were 50 and 66% (2 kgs.) less by number and weight, respectively, in the random rock section than in the partially altered control. Following two high water periods, brook trout were about equal in number and weight in the random rock area when compared to the control. The large overlap of confidence intervals indicated practically no difference in populations. Numbers in each age group were about the same in both sections.

In 1973 cutthroat 2 years and older were 56 and 50% (2 kgs.) less by number and weight, respectively, in the random rock section than the control. In 1974 cutthroat were 27% less in number and equal in weight in the random rock area when compared to the control. These differences are not significant. In both years all age groups are

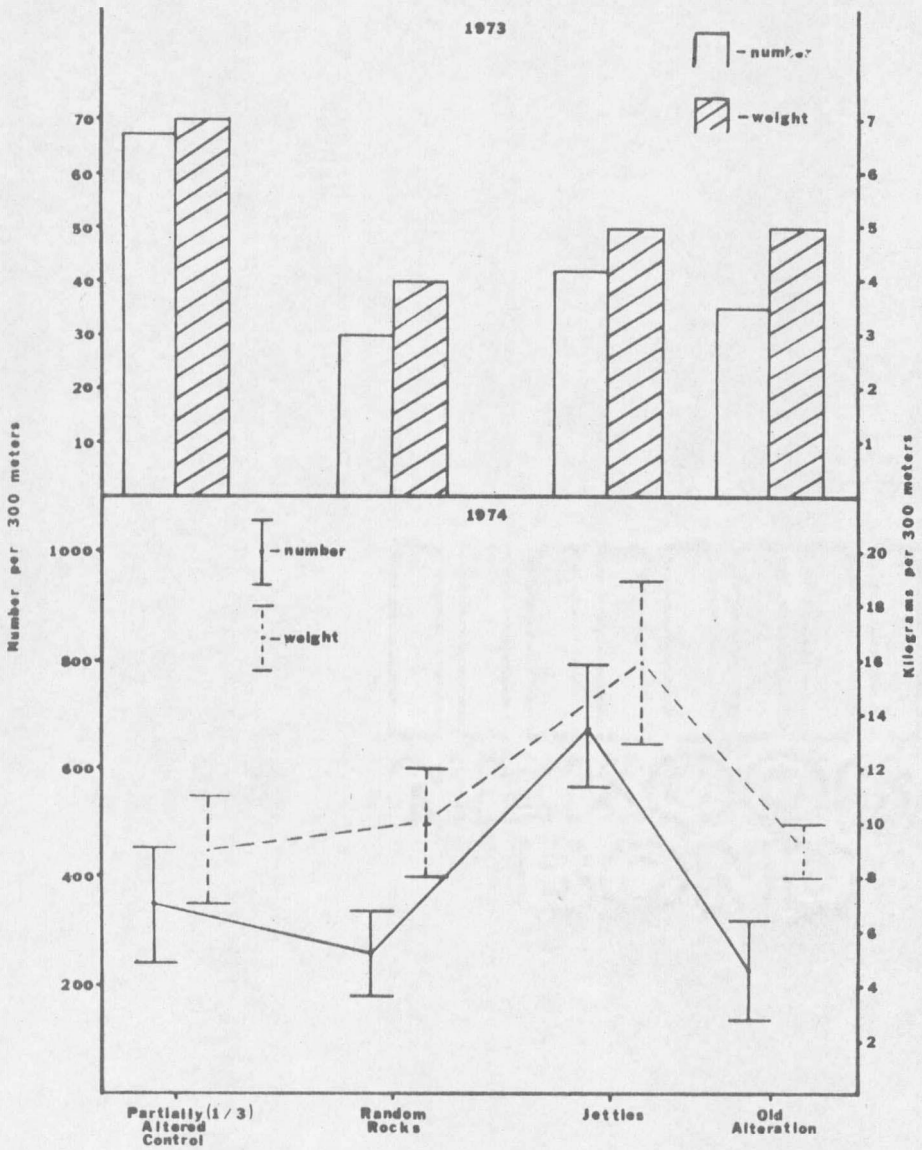

Figure 6. Total number and weight of trout (cutthroat and brook) in four sections of the Saltese zone in 1973 (age 2 and older) and 1974 (age 1 and older).

less in the random rock section than the control with the least difference in age-3^{+}.

Total trout 2 years and older in 1973 were 55 and 43% less, respectively, in the random rock section than the control. In 1974, following two scouring periods, the random rock area contained 160 and 50% (2 kgs.) more number and weight, respectively, of trout 2 years and older than in 1973. In 1974 point estimates indicate there were 25% less trout by number and about equal weight in the mitigated section (random rocks) as in the control. There was a wide overlap in confidence limits. Relative gains in number and weight between years were made among 2 year olds of both species in the random rock section.

The percentage of the number and weight of cutthroat and brook trout in the population in both years is about the same in the random rock area as the control indicating that trout repopulated this section in about the same proportions as the control.

In 1973, about one month after installation, brook trout 2 years and older were 63 and 33% (1 kg.) less by number and weight, respectively, in the jetty section than in the partially altered control. Following one high water period, in 1974 brook trout were significantly greater in the jetty area than in the control (128 and 100% (2 kgs.) in number and weight, respectively). All age groups were greater in the mitigated section (jetties) than the control.

In 1973 cutthroat 2 years and older were 28 and 25% (1 kg.) less by number and weight, respectively, in the jetty section than in the control. In 1974 cutthroat were significantly greater in the jetty area (92 and 71% by number and weight, respectively) than in the control. There was no increase in age-3^+ cutthroat. Yearlings showed the greatest difference between the two sections, being 122% greater in the jetty area.

Total trout one month following installation were 37 and 29% less by number and weight, respectively, in the rock deflector (jetty) section than in the partially altered control. In 1974, following one scouring period the jetty area contained 252 and 80% more number and weight, respectively, of trout 2 years and older than in 1973. In 1974 trout one year and older were significantly greater in number and weight (94 and 78%, respectively) in the jetty section than in the partially altered control. Relative increases in the jetty section were not restricted to any one age group.

In both years the percentage of the number of cutthroat and brook trout in the population was about the same in the jetty section as the control indicating trout numerically repopulated this area in about the same proportion as the control area.

In 1973 the old alteration contained about an equal number and weight of brook trout two years and older as the control. There was no difference in age groups. In 1974 eastern brook one year and older

were greater in number (28%) in the old alteration although the difference was not significant. Brook trout weight was significantly greater (150%, 3 kgs.) in the old alteration than the control because of the larger number of age-3^+ brook trout. Most of these larger brook trout were found in small pockets scoured behind individual pieces of rip-rap along the railroad tracks.

In 1973, the old alteration contained significantly less (63 and 50% in number and weight, respectively) cutthroat 1 year and older than the partially altered control. In 1974 cutthroat one year and older were 39 and 43% less by number and weight, respectively, in the old altered section than the control. Because of wide confidence intervals, these differences were not significant. In both years all age groups were less in the old alteration than the control, with the least difference in age-3^+ cutthroat. As in the old alteration in the Lookout zone, cutthroat are not thriving as well as brook trout, particularly in age groups 1 and 2.

In 1973 total trout 2 years and older were 48 and 29% less in the old alteration than the control section. In 1974 trout one year and older in the old alteration were 34% less and about equal in number and weight, respectively, as in the partially altered control. These differences were not significant as confidence intervals displayed a large overlap. The major difference in population changes between years was an increase in age-3^+ brook trout of 66% in the old

alteration while this age group decreased 71% in the control section.

In both years the old alteration contained the smallest proportion of number and weight of cutthroat and largest proportion of brook trout of any section in the zone. This indicates cutthroat, relative to brook trout, are not thriving as well in the old alteration as in the other sections in this zone. In 1973 there were fewer cutthroat of all age groups in the altered sections of the Saltese zone than in the control (Table 5). In both years successively older age groups generally decreased in abundance in both species.

Comparisons Between the Lookout and Saltese Zones

The rapid repopulation of the step dam, random rock, and jetty sections following complete relocation indicates a great deal of mobility in the trout population. Following one scouring period the average number and weight of trout 2 years and older in these sections was about equal to the control sections.

In 1974, trout populations in the controls, mitigated sections, and old alterations were generally greater in the Saltese than the Lookout zone. With the exception of trout numbers in the old alterations, confidence intervals of number and weight did not overlap between zones. The average flow in the Saltese zone increased nearly two-fold over the Lookout zone and could have been largely responsible for this difference.

The average number and weight of total trout for the controls, mitigated sections, and old alterations are shown in Figure 7. Although average weight was about equal, there was a significantly (36%) greater number of trout in the mitigated sections than in the controls in 1974.

In 1974 the jetty area contained significantly more number and weight than the other mitigated sections being 158 and 60% more, respectively, than the random rock and 148 and 220% more, respectively, than the step dam sections. The old alterations contained 34% less in number and 13% less weight of total trout as the controls. The confidence limits overlapped although the overlap for numbers was very small and differences may have been real. Obvious differences occurred in cutthroat (Table 4) which were significantly less (43 and 40% by number and weight, respectively) in the old alterations than in the controls. The average number and weight of brook trout in the old alterations and controls, were about equal. Relative to the controls, cutthroat are not thriving as well as brook trout in the old alterations. Numerically cutthroat averaged 65% of the population in the old alterations and 75% in the controls. The effectiveness of the mitigating devices is further emphasized in considering total trout in old alterations (no mitigative devices) were significantly less in number and weight (51 and 22%, respectively) than the mitigated sections.

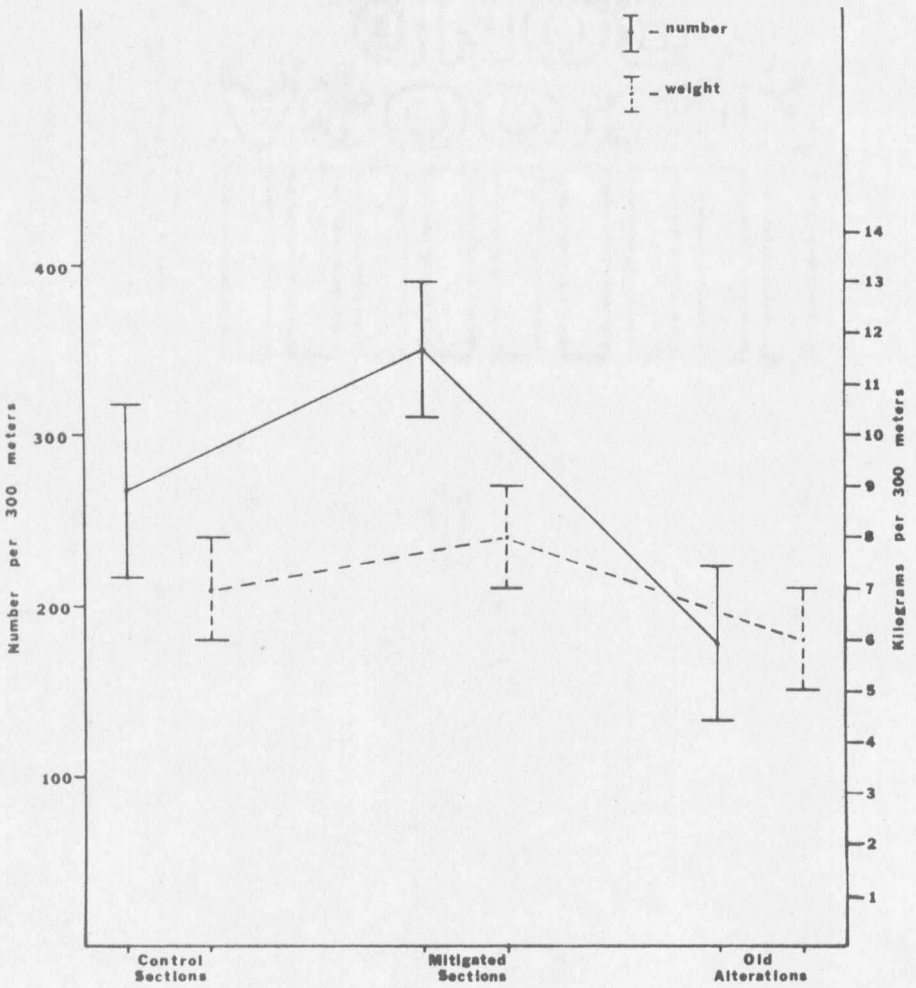

Figure 7. The average number and weight of trout (cutthroat and brook), 1 year and older, in the controls, mitigated and old altered sections in 1974.

Trout 3 years and older generally decreased in 1974 in both zones. Decreases ranged from 22 to 92% and apparently were unrelated to alteration. Decreases in the larger trout may have been the result of the abnormally severe winter flood which peaked at 9,640 c.f.s. ($273m^3/s$) on January 16, 1974. Since 1910, this discharge rate has been exceeded on only two occasions. Extensive alteration resulting in a straightened channel increased velocity and may have magnified the effects of the flood. Substantial increases in yearlings were noted in nearly all sections. This could be the result of increased survival following 3^+ natural mortality. In several trout streams in southwestern Montana, decreases in larger 3^+ trout are generally associated with increases in younger trout, particularly 2 year olds (Richard Vincent, personal communication).

During both years the average length of cutthroat trout in age groups 1, 2, and 3 was 10, 16, and 25 centimeters, respectively, while brook trout averaged 12, 18, and 26 centimeters, respectively. There was no indication of differential growth between sections in either zone. Cutthroat had similar growth rates in both zones, although brook trout in the Saltese zone averaged 2 centimeters longer in both age groups 1 and 2 than in the Lookout zone.

Relationships of Stream Morphology and Trout Populations

Lookout Zone

In 1973 in the Lookout zone, a positive correlation was found in all sections between the number and weight of trout per 300 meters and average thalweg depth, pool-riffle periodicity and average depth deviation. The highest correlation (r=.98) was found between numbers of trout and pools per stream width (Figure 8).

There appeared to be no consistent relationship between trout numbers and surface area or average width. Average depth correlated positively with trout populations in all sections except the old alteration while thalweg deviation correlated with populations in all sections except the step dam area.

In 1974 there was another indication of the importance of pools in this zone. While other physical measurements indicated less available trout habitat, pool-riffle periodicity in the step dam section was comparable to the unaltered control. Most pools in the mitigated section were associated with an individual piece of rip-rap. Trout collected from the step dam area were 37% more abundant and equal in weight to the unaltered control.

Saltese Zone

There was also evidence trout are associated with pools in the

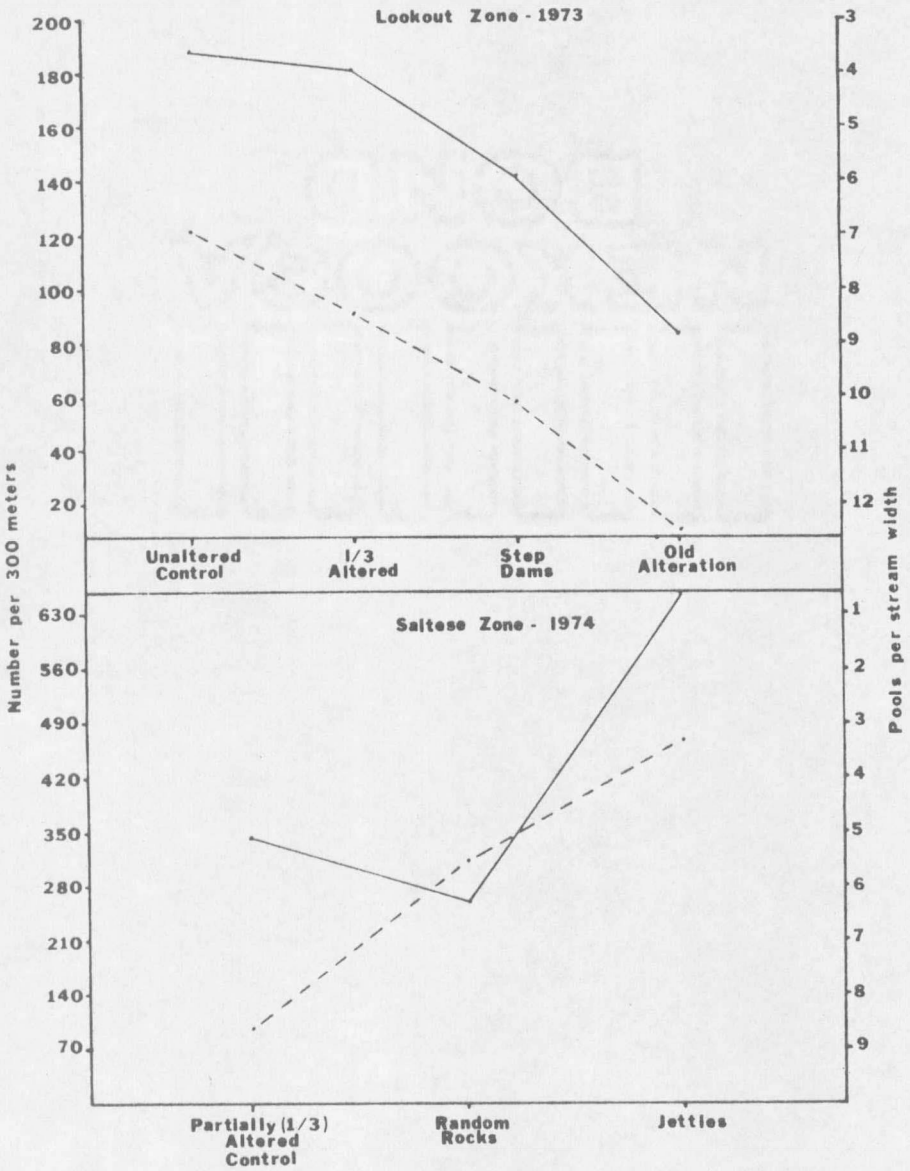

Figure 8. The relationship of total trout numbers (solid line) and pool-riffle periodicity (dotted line) in 1973 in the Lookout zone (r=.98) and 1974 in the Saltese zone.

Saltese zone. In 1974, although depths and deviations were the lowest in the jetty section, the number of pools per stream width was the highest (Figure 8). This section contained a significantly greater trout population than any section in this zone.

Although the random rock section contained the greatest depths and deviations in the zone and contained a greater number of pools than the control section, there were 25% less trout in this section than the control. Apparently either two years was not enough time to allow movement of trout into this section or, other factors were depressing trout populations.

In 1973, although the old alteration contained the least number of pools per stream width (12.5), it contained the greatest weight of trout in the Saltese zone. Most of the larger trout were found in small pockets around individual pieces of rip-rap. In mapping this section at 7.6 meter intervals, some small pockets were missed and were not defined as pools.

DISCUSSION

Prior to construction of Interstate-90, two-thirds of the St. Regis River had been altered either by railroad or previous highway construction (Alvord and Peters, 1963). Alterations above control sections have resulted in higher flows, greater velocities and increased erosion. These factors have undoubtedly had a detrimental effect on the fish populations in the control sections as well as the altered sections. Therefore, trout populations in the mitigated sections and old alterations appear higher when compared to these controls than may actually happen if the control sections were completely unaffected by previous alteration.

Profiles of the thalweg indicated meander in channelized sections without mitigative devices (old alterations) approximates that found in natural channels. On the East Gallatin River in Montana (average width, 9.7 meters), thirty jetties were spaced 15.2 meters apart in a section channelized for highway construction. Two years later Elser (1971) notes that eleven remained functional, nine were partially washed out and ten were completely destroyed. As only some of the structures were forcing the stream to scour, he suggests deflectors spaced 5-7 stream widths (pool-riffle periodicity in a natural section) may have been more effective.

Although the mitigating structures have been effective in restoring trout populations, channelization should be avoided because of the irreversible loss in stream length, cover, streamside vegetation and aesthetic value. Further, the long term effectiveness of these structures is not known. During the unusually high flood in the spring of 1974, five of the jetties in the center of the section were completely demolished and several others were partially destroyed. As flood waters surged over the top of the jetties, a depression was probably created on the downstream side in a process that buried the rocks. This occurs before actual rock movement (Dr. Reichmuth, personal communication) and tops of several large stones could be observed level with the stream bed. During the following year, one of slightly above average flows, there was very little change in the number of functional mitigative devices. This suggests, given normal flows, the remaining jetties may be effective for several years.

Visually, in the center portion of the jetty section on the St. Regis River, there was considerable sediment deposition following one high water period. A combination of factors is probably responsible. A large part of the river upstream is confined and channelized, increasing the down valley movement of sediment. Secondly, the width-depth ratio in the jetty section is relatively high. The higher this ratio, the less ability the channel has to transport sediment. Also, the slope is comparatively level, and, as the water slows deposition occurs.

CONCLUSIONS

1) With the exception of pools per stream width, physical measurements in the step dam and jetty sections in 1974 suggest less trout habitat available than in the control sections.

2) With the exception of thalweg deviation, physical measurements in the random rock section in 1974 suggest more available trout habitat than in the control section.

3) Pools created around each rock and mitigating device are probably the most important factor in maintaining trout populations in altered stream sections. Pools generally correspond to the number of functional mitigative devices.

4) Point estimates of average trout populations and values of important physical parameters (thalweg deviation, average depth deviation and pool-riffle periodicity) indicate old alterations (86 years) have the least trout habitat in the study area.

5) Relative to the controls, cutthroat are not thriving as well as brook trout in old alterations.

6) Old alterations (no mitigative devices) contain significantly ($P=.20$) less trout than mitigated sections.

7) In both years cutthroat in all age groups were generally less in the old alterations than the controls with the least difference occurring in 3^+ trout.

8) Devices designed to mitigate the adverse effects of channelization were effective as average total trout estimates in the mitigated sections were significantly (P=.20) greater in number (36%) and about equal in weight when compared to the controls. This represents two scouring periods in the step dam and random rock sections and one high water period in the jetty area.

9) At this time jetties appear to be the most effective mitigative device as this section contained the greatest number of pools per stream width and the highest trout population in the study area.

10) The Lookout zone cutthroat were able to recover relatively faster in the step dam section than brook trout while in the Saltese zone both species numerically invaded the mitigated sections in about the same proportions as the control.

RECOMMENDATIONS

1) If possible, mitigative devices should be placed in old alterations as the average trout population in these sections was significantly less than trout in mitigated sections.

2) In rock deflector (jetty) sections, scouring efficiency and longevity of the structures may be improved if (1) channel width remains about the same as before alteration, (2) jetties are spaced on alternating banks at intervals comparable to the pool-riffle periodicity in the unaltered areas and (3) jetties are composed of enough rock volume to armor the scour hole that develops and still leave a functional structure (Miller and Skinnner, ed., 1972).

3) To define the long term effectiveness of the strucutres, physical and biological characteristics should be measured every 4-5 years.

4) Although, after 2 years, the present mitigating structures have been biologically effective, future alteration projects should emphasize evaluation of structure combinations which are hydrologically sound as a step toward long term solution.

5) In sections where topsoil and vegetation are removed during alteration, enough soil should be replaced to support trees and shrubs (willow, red dogwood etc.) common in the unaltered areas. This will not only help provide fish habitat but will improve bank stability.

LITERATURE CITED

Alvord, W. and J. C. Peters. 1963. Channel changes in thirteen Montana streams. Mont. Fish and Game Dept., Helena, Montana. 23 pp.

Barton, J. R. and P. V. Winger. 1973. A study of the channelization of the Weber River, Summit County, Utah. Final research report to Utah Division Wildlife Res. and Utah State Dept. Highway., 188 pp.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Mgmt. 18(2): 229-239.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. Univ. of Calif. Pub. in Stat. 1(7): 131-160.

Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc., 97(4): 389-397.

_____. 1969. Evaluation of stream improvement structures on Prickly Pear Creek and the East Gallatin River. D. J. Completion Report, Project F-9-R-17, Job V. Mont. Fish and Game Dept., 17 pp.

_____. 1970. Evaluation of stream improvement structures on Prickly Pear Creek and the East Gallatin River. D. J. Completion Report, Project F-9-R-18, Job II-a. Mont. Fish and Game Dept., 13 pp.

_____. 1971. Evaluation of stream improvement structures on Prickly Pear Creek and the East Gallatin River. D. J. Completion Report, Project F-9-R-19, Job II-a. Mont. Fish and Game Dept., 7 pp.

Hunt, W. A. and R. J. Graham. 1972. Preliminary evaluation of channel changes designed to restore fish habitat. Report to Mont. Dept. of Highways and Dept. of Fish and Game. Environment Bureau., 42 pp.

Johnson, R. L. 1964. Southwest Montana fishery study-stream channel alteration survey-Shields River. D. J. Completion Report. Project F-9-R-12. Montana Fish and Game Dept. Multilithed, 4 pp.

Leopold, L. B., M. G. Wolman and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman Co., San Francisco and London, 522 pp.

Leopold, L. B. and W. B. Langbein. 1966. River Meanders. Sci. Amer., 214(6): 60-70.

Lewis, S. L. 1969. Physical factors influencing fish populations and cover on a small stream. J. Wildl. Mgmt. 18(2): 229-239.

Matthes, G. H. 1941. Basic aspects of stream meanders. Am. Geophys. Union Trans., 22: 632-636.

McConnell, R. C. 1969. Soil Survey--St. Regis--Nine mile area, Montana. U. S. Dept. of Agric. For. Ser., Northern Region, Missoula, Mont.

Miller, W. H. and M. M. Skinner, ed. 1972. Proceedings of river mechanics seminar. Mont. Fish and Game Dept., Helena, Montana. 1963. 120 pp.

Saunders, J. W. and M. W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Amer. Fish. Soc. 21(2): 185-188.

Schuck, Howard A. 1945. Survival population density, growth and movement of the wild brown trout in Crystal Creek. Trans. Amer. Fish. Soc. 73: 209-230.

Shetter, D. C., O. H. Clark and A. S. Hazzard. 1946. The effects of deflectors in a section of a Michigan trout stream. Trans. Amer. Fish. Soc. 76: 248-278.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Am. Fish. Soc. 66: 177-187.

Tarzwell, C. M. 1938. An evaluation of the methods and results of stream improvement in the southwest. Trans. N. Amer. Wildl. Conf. 3: 339-364.

15 Vincent, E. R. 1971. River electrofishing and fish population estimates. The Prog. Fish Culturist. 33(3): 163-169.

_____. 1974. Addendum to river electrofishing and fish population estimates. Prog. Fish. Cult. 36(3): 182.

16 Whitney, A. N. and J. E. Bailey. 1959. Detrimental effects of highway construction on a Montana stream. Trans. Amer. Fish. Soc., 88(1): 72-73.

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