Reprinted from
The Journal of Wildlife Management
Vol. 19, No. 3, July, 1955

LOSS OF GAME FISH IN RELATION TO PHYSICAL CHARACTERISTICS OF IRRIGATION-CANAL INTAKES [1]

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Introduction

Numerous efforts have been made in the United States to prevent loss of fish in irrigation diversions. One of the earliest attempts was on Caledonia Creek, New York in 1865 (Leitritz, 1952). Probably the most intensive effort has been in California (Wales, 1948; Leitritz, 1952) where a large number of ditches have been screened.

A fish-screening policy was adopted in Montana in 1893 but was discontinued in 1897 (Clothier, 1953a) and maintenance of screens was abandoned by the Fish and Game Department in 1942 (Montana Fish and Game Department, 1942). Most of the work has been directed toward development of fish screens which are known to be effective, but cost of installation and maintenance has limited their use.

Clothier (1953a) reported a variation in fish loss between irrigation diversions of the West Gallatin River and found much diversity in the physical characteristics of the canals. The present study, conducted from June through October in 1951 and 1952, deals with the relationship between physical characteristics of canal intakes and fish loss. If a relationship exists, then feasible alterations of existing and proposed diversions might reduce fish losses. The U. S. Fish and Wildlife Service and the Montana Fish and Game Department (1952) in a joint report on the Pishkun Supply Canal, suggested that design, location, and operation of canal headings may have a direct effect on fish loss.

Grateful acknowledgment is due to Dr. C. J. D. Brown who directed the project and aided in the preparation of the manuscript and to Mr. William Clothier for his assistance in the field. Thanks are also due to Mr. Melvin Papke for information on diversion flows and to the ranchers of Gallatin Valley for their cooperation. Dr. Bernard Ostle supervised the statistical analysis of the data. Financial assistance was furnished by the Montana Fish and Game Department under the Federal Aid to Fish Restoration Act (Project number F-3-R).

Description of Study Area

A rather complete description of the West Gallatin River and some of the diversions was given by Clothier (1953a). Of the 52 diversions on the West Gallatin, nine (Fig. 1)

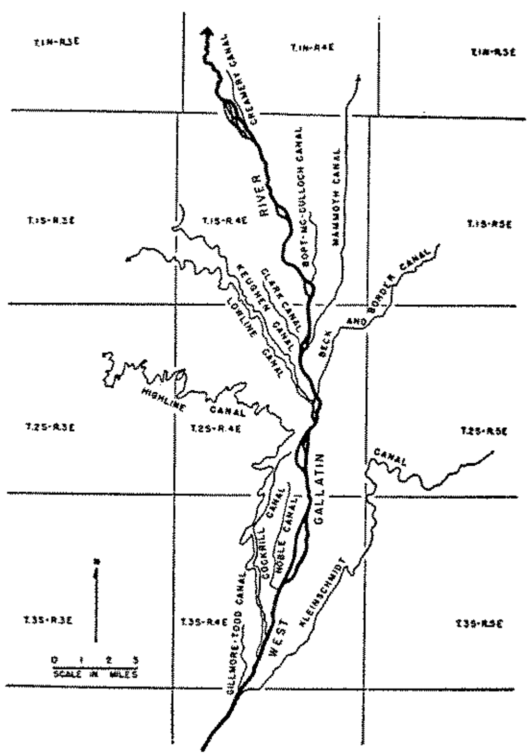

Fig. 1. A 20-mile section of the West Gallatin River, Montana, showing the locations of the canals studied.

were selected for study in 1951. These were as follows: Kleinschmidt, High Line, Low

[1] Contribution from Montana State College, Agricultural Experiment Station, Project No. 844, Paper No. 331 Journal Series and the Fish Restoration Division, Project F-3-R, Montana Fish and Game Department.

Line, Keughen, Beck and Border, Creamery, Clark, Gillmore-Todd and Cockrill (Table 1).

The Kleinschmidt canal was the largest of the diversions studied in 1951 and carried 151 cubic feet of irrigation water at decreed right. This canal, located at the upstream end of the study area (Fig. 1) takes water from a straight section of the river near the mouth of Gallatin Canyon. The canal runs parallel with the river for at least one-half mile downstream and, although a concrete apron extends across the river from the headgate, for the placement of a diversion dam, no dam was operated during the period of the study. The headgate is directly on the river, framed in concrete and regulated by a wooden gate operated vertically by a turnstile.

The High Line and Low Line canals carry 148 cubic feet per second and are located on a bend of the river. Each forms an acute angle with the river at the point of diversion. A rock and gravel dam diverts water from the river into the High Line but no diversion dam is present at the Low Line heading. The headgate of the Highline canal is on the river while that of the Low Line is on an intake downstream from the river. The canal intake is that part of an irrigation diversion between the river and the first, or primary, headgate. Both headgate foundations and frames are constructed of concrete and are regulated vertically. Measurements of the physical characteristics of the High Line in 1951 and those of the Low Line in 1952 were not used since sharp reductions in rate of flow may have influenced game-fish loss (Clothier, 1953a).

The Keughen canal (70 cfs) is located on a bend of the river and leaves it at an angle. The runoff in 1952 altered the river flow past the diversion resulting in considerable change in some of the physical characteristics including angle of the diversion with the river. A concrete apron extends across the river at the headgate but no diversion dam was operated during the period of the study. The headgate is on the river, framed in concrete and regulated vertically.

The Beck and Border canal (50 cfs) removes water from a straight section of the river and leaves it at an angle. The concrete headgate is downstream from the river on an intake and is regulated vertically.

The Creamery canal (20 cfs) is located at the downstream end of the study area (Fig. 1) and takes water from a bend of the river. As a result of bridge construction near the head of this canal in 1952, some of its physical characteristics were altered before they could be measured. The ditch forms an angle with the river and has no diversion dam at its head. The headgate is downstream, framed in concrete, and flow into the diversion is regulated horizontally by standing planks on end from side to side across the headgate opening.

The Clark diversion (16 cfs) takes water from a straight section of the river and runs parallel with it. No diversion dam was oper-

TABLE 1.—PHYSICAL CHARACTERISTICS OF INTAKES OF 12 IRRIGATION CANALS ON THE WEST GALLATIN RIVER, MONTANA, IN 1951 AND 1952

DIVERSION	HEADGATE Material	HEADGATE Location	HEADGATE Kind	Diversion dam	Relation of river flow	Velocity (ft/sec)	Volume (cfs)	Gradient (ft/mi)	Width (ft)	Depth (ft)	Cover (percent)	Angle of canal 1951	Angle of canal 1952
Kleinschmidt....	Concrete	On river	Vertical	...	Straight	3.37	151	4.3	20.0	3.6	68	..	0
High Line.......	Concrete	On river	Vertical	Yes	Bend	4.60	148	19.8	18.8	2.5	33	..	53
Low Line........	Concrete	Downstream	Vertical	...	Bend	....	148	....	....	...	..	33	..
Keughen.........	Concrete	On river	Vertical	...	Bend	3.09	70	2.1	25.0	2.1	1	75	60
Beck & Border ..	Concrete	Downstream	Vertical	Yes	Straight	2.37	50	5.5	47.5	1.2	9	..	30
Creamery........	Concrete	Downstream	Horizontal	No	Bend	1.78	20	....	37.5	1.1	16	46	31
Clark...........	Concrete	O.r. 1951 Ds. 1952	Vertical	No	Straight	4.91	16	15.3	11.3	1.2	24	0	0
Gillmore-Todd...	Concrete	On river	Vertical	No	Straight	....	15	....	....	...	..	0	..
Cockrill.........	Wood	On river	Vertical	No	Straight	2.47	6	1.5	19.0	1.3	36	0	0
Mammoth.......	Concrete	On river	Vertical	Yes	Bend	3.61	74	15.3	11.3	3.0	2	..	40
Noble...........	Wood	On river	Vertical	Yes	Bend	2.55	23	3.2	25.0	1.2	52	..	42
Bopt-McCulloch.	Concrete	On river	Vertical	Yes	Bend	2.56	12	3.2	26.0	1.8	0	..	30

ated during the period of the study. During 1952, the first headgate was inundated and destroyed by the runoff; thus, in 1951, the headgate was directly on the river while in 1952, the second headgate became the primary water-flow regulator and was downstream. The headgate is framed in concrete and is manipulated vertically.

The Gillmore-Todd canal (15 cfs) is located on a straight section of the river and runs parallel with it. The headgate is on the river, constructed of concrete, and regulated vertically. During the summer of 1952, access to this canal was withdrawn. As a result it was impossible to census the diversion and it was eliminated from the 1952 comparisons.

The smallest canal studied was the Cockrill which carries 6 cubic feet per second at decreed right. Occasionally a rock and gravel diversion dam is constructed at its head but none was present during the study period. This canal removes water from and runs parallel with a straight section of the river. The headgate is on the river, is constructed entirely of wood, and is manipulated vertically.

In 1952, the Mammoth, Noble, and Bopt-McCulloch diversions were added to the sample, making a total of 11 canals which were studied.

The Mammoth ditch (74 cfs) is located on a side-channel of the river on a bend and forms an angle with it. A concrete and plank diversion dam was operated in 1952 and completely dewatered the river channel below the headgate during late summer. The headgate is on the river, framed with concrete and regulated vertically.

The Noble ditch (23 cfs) leaves a bend of the river at an angle and a rock and gravel dam diverts water into it. The headgate is on the river, is built of wood, and is manipulated vertically.

The Bopt-McCulloch diversion (12 cfs) is located on a side-channel of the river. It takes water from and forms an angle with a bend of the river. A rock and gravel diversion dam is present and the concrete headgate, which is regulated vertically, is directly on the river.

METHODS

Stations were established at comparable locations near the head of each canal intake, and velocities, widths, depths, and gradients were measured (Table 2). A detailed map of

TABLE 2.—LOSS OF GAME FISH IN DIFFERENT CANALS FOR 1951 AND 1952 (1951 DATA FROM CLOTHIER, 1953A)

Diversion	Estimated legal-game fish loss 1951		Estimated game-fish loss 1952		
			Legal-sized		Under-sized
	No.	Lb.	No.	Lb.	No.
Kleinschmidt	560*	227*	11	3.5	11
High Line	61**	23**	21	11.1	14
Low Line	132	71	8**	1.6**	28**
Keughen	167	44	13	10.4	34
Beck & Border	368*	176*	22	10.0	44
Creamery	44	33	0	0.0	79
Clark	77	20	19	5.9	34
Gillmore-Todd	22	6	..	..	..
Cockrill	16	5	10	3.7	22
Mammoth	..	..	51	22.4	44
Noble	..	..	7	2.5	14
Bopt-McCulloch	..	..	14	3.3	76

* Loss influenced by creeks entering canals.

** Sharp reductions in rate of flow before sampling may have influenced loss.

the intake and adjacent river area was prepared for each ditch. The types of materials used in the construction of the primary headgates and the method of regulating the volume of flow into the diversions were noted.

Clothier (1953b) reported that the greatest movement of fish into irrigation diversions occurred during the high-water period. Accordingly, intake velocities were measured July 7–9 (near the end of the high-water period for 1952). A water-level station was established in the river near the Keughen canal intake. A variation in level of 8.5 inches was recorded during the three days required to obtain velocity readings at all stations.

Water velocity was determined by the float method (Welch, 1948) since high water levels prevented the use of the current meter. A 25- to 50-foot range was established at each intake and surface floats were timed from the upper to the lower end of the range. Three readings were taken at each station and the average velocity determined. A comparison was made between velocities taken by the float method and by a Leupold and Stevens "Midget Current Meter" when water levels permitted. In these comparisons, the float method yielded higher velocities in all cases with a percentage difference which ranged from 10 at the lower velocities to 23 at the higher; the average difference was 16.6 per cent.

Information on volume of flow was secured from the River Commissioner and the decreed rights were used for the study of the relationship between loss of fish and volume of flow. Gradients were determined at each canal intake with a hand level.

In 1952, average widths and depths across the canal intakes were obtained as soon as water levels permitted (July 24–31). The water-level fluctuation at the Keughen station during this period was three inches. Three measurements of width were taken at each station and the average determined. Depths were obtained by measuring the distance from the water surface to the canal bottom at each one-foot interval of width and the average determined by totalling the readings and dividing by one more than the number of observations.

Plane-table maps were completed during the periods June 20–August 21, 1951 and July 23–August 15, 1952. In 1951, the angle between each intake and the river was determined. In 1952, each canal intake and the river adjacent to the diversion from 150 feet downstream to 300 feet upstream was mapped in detail and measurements of physical characteristics obtained. The physical characteristics determined were as follows: locations of primary headgates, location of the canal intakes in relation to the direction of river flow, angle between the intake and river, bottom types, bottom contours, bank cover, and location of diversion dams if present.

Clothier (1953a) estimated the loss of legal-sized game fish (total length, seven inches or over) in certain diversions of the West Gallatin River for 1951. His figures (Table 2) were used for the study of the relationship between loss of fish and the various physical characteristics of the intakes for that year. He found the greatest number of fish in the first half-mile of canal. In 1952, 900 feet of each canal immediately downstream from the headgate was sampled by an alternating-current "shocker." Each area was divided into three sections by the use of blocking nets for convenience in sampling. All fish collected were counted, weighed, and measured and the results were used for the 1952 comparisons. Very few fish smaller than three inches were included because the meshes (one-half inch stretch) were too large to retain them. All diversions were sampled between July 14 and August 8 except the High Line and Low Line canals which were sampled August 21 and September 13 respectively.

LOSS OF FISH IN RELATION TO PHYSICAL CHARACTERISTICS OF CANAL INTAKES

An attempt was made to determine what relationship, if any, existed between fish loss and the various physical characteristics of canal intakes. The characteristics of the headgates considered were location, construction, and method of manipulation. The characteristics of the intakes were velocity of flow, volume of flow, gradient, width, depth, location in relation to river flow, angle with river, diversion dams, bottom types, and cover.

Headgates: The primary headgates of some canals are located directly on the river while in others, they are at varying distances downstream. The loss of legal-sized game fish in 1951 averaged 18.8 pounds (70.5 fish) in the Keughen, Clark, Gillmore-Todd and Cockrill diversions which had headgates on the river and 52.0 pounds (88.0 fish) in the Low Line and Creamery canals which had headgates downstream. Other ditches studied were excluded from this comparison since loss was known to be influenced by water manipulations or other causes (Clothier, 1953a). In 1952, the loss of legal-sized fish averaged 7.1 pounds (15.9 fish) in those diversions which have headgates on the river and 8.0 pounds (20.5 fish) in those which have headgates downstream. The loss of undersized game fish averaged 36.8 fish in the former and 39.0 in the latter. The loss in the Low Line ditch was not used in the 1952 comparisons since water manipulations may have influenced it (Clothier, 1953a).

In 1951, the loss of legal-sized game fish averaged 34.8 pounds (88.4 fish) in the diversions with headgates constructed of concrete and was 5 pounds (16.0 fish) in the Cockrill canal which has a headgate built of wood. In 1952, the loss of legal-sized fish averaged 8.3 pounds (18.9 fish) in the diversions with concrete headgates and 3.1 pounds (8.5 fish) in the Noble and Cockrill canals which have wooden headgates. The loss of undersized game fish averaged 42.0 fish in the former group and 18.0 in the latter.

Water flow into each of the diversions studied is regulated by vertical manipulation of a wooden gate in the headgate opening with the exception of one canal which is regulated by placing planks on end from side to side across the opening. In 1951, the loss of legal-sized game fish averaged 34.6 pounds (82.8 fish) in the ditches which have vertically manipulated headgates and was 33 pounds (44 fish) in the Creamery canal which has a horizontally manipulated headgate. In 1952, the loss of legal-sized fish averaged 8.1 pounds (18.7 fish) in the diversions which have vertically manipulated headgates while there was no loss of legal-sized fish in the Creamery canal which has a horizontally manipulated headgate. The loss of undersized fish averaged 32.6 fish in the former and was 79.0 in the latter.

Velocity, volume, and gradient: A comparison was made between loss of fish in those diversions which had above average and those which had below average velocity, volume, and gradient at the intake (Table 1). In 1952, the average velocity in all canal intakes was 3.13 feet per second. The loss of legal-sized game fish averaged 10.7 pounds (25.5 fish) in the ditches which had velocities above average and 5.0 pounds (11.0 fish) in the canals which had velocities below average. The loss of undersized game fish averaged 24.8 fish in the former and 44.8 in the latter.

In 1951, the average volume of flow at the headgates was 45.8 cubic feet per second. The loss of legal-sized game fish averaged 57.5 pounds (150.0 fish) in the Low Line and Keughen canals which had above-average volumes and 16.0 pounds (39.8 fish) in the Creamery, Clark, Gillmore-Todd, and Cockrill diversions which had volumes below average. In 1952, the average volume was 57.0 cubic feet per second. The loss of legal-sized fish averaged 11.0 pounds (24.0 fish) in the Kleinschmidt, High Line, Mammoth, and Keughen canals which had volumes above average and 4.2 pounds (12.0 fish) in the Beck and Border, Noble, Creamery, Clark, Bopt-McCulloch, and Cockrill ditches which had volumes below average. There was an average loss of 25.8 undersized fish in the former and 44.8 in the latter.

The gradients of all canal intakes averaged 7.8 feet per mile. The loss of legal-sized fish averaged 13.1 pounds (30.3 fish) in the diversions which had gradients above average and 5.6 pounds (12.8 fish) in those which had gradients below average. The average number of undersized fish lost was 30.7 in the former and 33.5 in the latter. The gradient of the Creamery intake was not included because of alteration which resulted from highway construction.

Width and depth: A comparison of fish loss in the diversions in relation to the widths and depths across the canal intakes was made in 1952 (Table 1). The average width across all canal intakes was 24.1 feet. There was an average loss of 5.2 pounds (11.2 fish) of legal-sized game fish in the diversions which have intakes wider than average and one of 9.3 pounds (22.4 fish) in those which have intakes narrower than average. The average number of undersized fish lost was 49.4 in the former and 25.0 in the latter.

The average depth across all canal intakes was 1.9 feet. The loss of legal-sized fish averaged 11.9 pounds (24.0 fish) in those diversions which have intakes deeper than average and 4.2 pounds (12.0 fish) in those which have intakes shallower than average. The numbers of undersized fish lost averaged 25.8 in the former and 44.8 in the latter.

Location in relation to river flow: Some intakes are located on bends and others on straight sections of the river and comparison of fish loss was made between those two types of diversions. In 1951, the loss of legal-sized game fish averaged 49.3 pounds (114.3 fish) in the ditches which have intakes on river bends and 10.3 pounds (38.3 fish) in those which have intakes on straightaways. In 1952, the legal loss averaged 8.3 pounds (17.7 fish) in those diversions which have intakes on bends and 5.8 pounds (15.5 fish) in those which have intakes on straightaways. The loss of undersized fish averaged 43.5 fish in the former and 27.8 in the latter.

Angle with river: Some canal intakes are parallel with the river from their origin to at least 150 feet downstream while others leave the river at an angle (Table 1). Those which are parallel are referred to as forming an angle of zero degrees with the river. A comparison of fish loss was made between diversions which form above-average angles and those which form below average angles with the river. In 1951, the average angle between the intake and the river for all canals was 25.7 degrees. The loss of legal-sized game fish averaged 49.3 pounds (114.3 fish) in the diversions which form greater-than-average angles with the river and 10.3 pounds (38.3 fish) in those which form less-than-average angles. In 1952, the average angle between the intakes and the river was 28.6 degrees. The loss of legal-sized fish averaged 8.5 pounds (18.3 fish) in the diversions which form greater-than-average angles with the river and 4.4 pounds (13.3 fish) in the ones which form less-than-average angles. The loss of undersized fish averaged 43.6 fish in the former and 22.3 in the latter.

Diversion dams: Most of the canals have diversion dams constructed of either rock or concrete and which extend out into the river to divert water into the intake. In 1952, a comparison of fish loss was made between ditches with diversion dams at the intake and those without. The Kleinschmidt and Keughen canals have concrete diversion dams which were not operated and they were excluded from the comparison. The loss of legal-sized game fish averaged 9.9 pounds (23.0 fish) in the ditches which have diversion dams and 3.2 pounds (9.7 fish) in the canals which do not have diversion dams. The loss of undersized fish averaged 38.4 fish in the former and 45.0 in the latter.

Bottom types and cover: Some intakes and the adjacent river bottoms were predominantly silt and sand while others were gravel and rubble. In 1952, a comparison of fish loss in the diversions was made in relation to these two bottom types. An average of 4.3 pounds (11.5 fish) of legal game fish were lost in the diversions which have silt and sand bottoms in the intake and adjacent river as compared with 9.3 pounds (20.3 fish) in those which have bottoms of gravel and rubble. The loss of undersized fish averaged 55.3 fish in the former and 25.2 in the latter.

Cover was classified as pools, overhanging brush, and undercut banks and the area of each type was determined for the area of the intake and the adjacent river (Table 1). The total percentage of cover was obtained by adding the number of square feet of area occupied by water three feet or more in depth, of the area covered by overhanging brush, and of the area covered by overhanging bank, and then dividing by the number of square feet of the total water area. In 1952, a comparison of fish loss was made between diversions having above-average and those having below-average cover on the intakes and adjacent river areas; the average was 24.1 per cent. The loss of legal-sized game fish averaged 5.2 pounds (12.3 fish) in those diversions which have above-average cover and 8.7 pounds (19.8 fish) in those which have below-average cover. There was an average loss of 15.3 undersized fish in the former and 46.8 in the latter.

DISCUSSION

An attempt was made to correlate the loss of legal-sized game fish with the various physical characteristics of canal intakes. The loss of undersized game fish was not considered because the method of sampling did not permit a true estimate of their numbers. The ditches studied were few in number but they are believed to be representative of the irrigation diversions of the West Gallatin River, Montana.

While some of the characteristics of headgates, such as location, construction, and manipulation, could be correlated with fish loss, this information is not considered reliable because other factors may have a greater influence. Among these other factors are the volume of flow, the amount of water diverted into the ditch as compared to the amount retained by the river, and the location of intakes in relation to river flow.

The loss of legal-sized game fish was proportional to the volume of flow in the ditches except for the Kleinschmidt canal. To determine the significance of this relationship, the regression of loss of fish on volume of flow was computed and found to be, $Y = 10.2 + 0.429X$ and, $Y = 3.0 + 0.067X$ for the 1951 and 1952 comparisons respectively, where Y = loss of legal-sized game fish (pounds), and X = volume of flow of canal (cfs). In both cases, the regression was significant at $P \leq 0.05$. therefore; it appears that a reasonably high degree of linear association exists between loss of legal-sized game fish and volume of flow in the diversions.

The measurements for the Mammoth and Kleinschmidt canals were not included in the regression computations. The Mammoth ditch is located on a lateral branch of the West Gallatin River and from early in the irrigation season until the headgate is closed in the autumn, approximately July 1 to

October 15, all but a negligible amount of water is diverted from the river into the canal. In 1952, the Mammoth ditch sustained the highest loss of legal-sized game fish and it is believed that it was the result of this dewatering practice. Although the Kleinschmidt Canal had the largest volume of flow of any of the ditches studied, it sustained a very low fish loss in 1952. This diversion is on the upper part of the study area (Fig. 1) and the river adjacent to the intake is not subject to dewatering. The small loss in the canal may well be accounted for by the fact that the intake is also on a straight section of the river and apparently few fish are present in this area.

The linear regressions of fish loss against velocity, gradient, depth, or width did not prove to be significant. It is therefore assumed that these physical characteristics influence fish loss in irrigation diversions only when in combination.

In considering canal intakes in relation to river flow, the greatest loss of legal-sized game fish was sustained by those on river bends but, in 1951, these canals (Low Line, Keughen and Creamery) also had higher volumes of flow. However, if the Low Line and Keughen diversions were excluded from the comparison, so the canals with intakes located on river bends would be more comparable in volume of flow to those with intakes located on straightaways, the loss in the former would still be almost three times that in the latter. In 1952, the average volume of flow for the diversions with intakes on river bends was practically the same as for those with intakes on straightaways. The loss of legal-sized game fish was highest in canals with intakes on river bends.

The regressions derived from the data on fish loss against the angle of the intake with the river was not significant. The information from this study does not support the inference that the angle by which the intake leaves the river has any influence on legal-sized game fish loss.

When comparing losses of legal-sized game fish in canals which have diversion dams with those in canals which do not, the former group of canals sustained the greater loss; however, this higher loss is thought to result from other factors, particularly volume of flow.

In considering the loss of fish in relation to types of bottom in the intakes and adjacent river areas, the diversions which have bottoms of gravel and rubble sustained a higher loss than those with silt and sand bottoms. Again, this higher loss is thought to be a result of other factors including volume of flow.

Regarding the effect of cover at the intakes and the adjacent river areas, the regression of fish loss on the three types of cover, individually and collectively, was tested and found to be not significant. It is thought that cover may not affect the loss of legal-sized game fish other than whatever influence it may exert in combination with location in relation to river flow.

SUMMARY

1. Fish loss was determined and the various physical characteristics of the canal intakes and headgates were evaluated during the summers of 1951 and 1952 for 12 irrigation diversions of the West Gallatin River, Montana.

2. The physical characteristics considered were: headgate location, construction, and manipulation; intake velocity of flow, volume of flow, gradient, width, depth, and angle with the river; location of intakes in relation to river flow, diversion dams, bottom types, cover, and amount of water diverted in relation to the amount retained by the river.

3. No correlation was apparent between loss of legal-sized game fish and location, construction, or manipulation of headgates.

4. The linear regression of loss of legal-sized game fish on velocity, gradient, width, or depth of intakes did not prove significant by the analysis of variance test.

5. The regression of loss of legal-sized game fish on the angle of the intake with the river or amount of cover at the intake or adjacent river areas did not prove significant.

6. Bottom types in the intake and adjacent river areas or the existence of diversion dams at the intake apparently had no observable influence on the loss of legal-sized game fish.

7. Loss of legal-sized game fish was highest in canals with the higher volumes of flow and in those with intakes located on river bends.

8. The highest loss of legal-sized fish in 1952 occurred in a canal into which all but a negligible amount of water was diverted from the river channel on which it was located.

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Accepted for publication April 24, 1954.