



Fish loss to irrigation canals and methods to reduce these losses on the West Gallatin River, Montana
by Eric William Reiland

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:

Agriculture and recreational fisheries are important to Montana's economy, however they compete for the state's water resources. Conflicts over the number of trout entering irrigation canals, and subsequently being lost from a river's fishery, prompted concern, in Montana, as early as 1893. Yet few studies have examined the effects of fish loss to irrigation diversions on trout populations. I estimated the number of trout ($\geq 150\text{mm}$) in gravity-fed irrigation canals on the West Gallatin River, Montana, by trapping and electrofishing, in 1993 and 1994. It was presumed that fish entering the canals were lost from the West Gallatin River fishery. Trout abundance was related to habitat types and canal characteristics and operations. Multiple regression was used to assess the relationship between these factors and population abundance. Trout population densities varied from 0-16 fish/100m (median 1.5 fish/100m). Total trout populations ranged between 0 and 1,905 fish/canal (median 215 fish). Repeated electrofishing of identical transects found no significant differences between trout populations in 1993 and 1994 ($P\text{-values} > 0.26$, $Betas \geq 0.92$) or between June 1994 and September 1994 ($P\text{-values} > 0.12$, $Betas \geq 0.83$). Most trout entered the irrigation canals during periods of maximum river flow. I measured the following canal characteristics: headgate size, manipulation, construction materials and habitat; intake size, habitat and angle in relation to the river's thalweg; and flow; which were used to develop a predictive model of the number of trout found in a canal. The model contained headgate area, intake angle in relation to the river's thalweg and intake length [canal populations = $-2,429.7 + 0.7246(\text{earea}) + 0.5405(1/50\text{m angle}) - 0.3287(\text{sqrt}(\text{intake length}))$] (model $R^2 = 0.87$, $P\text{-value} = 0.00483$). Large canals, with short intake channels, located on the outside of river bends captured more fish than canals with opposite characteristics. A jackknife bias-estimation procedure indicated that the model overfit the data ($R^2 = 0.25$, $P\text{-value} > 0.80$). The model predicted canal trout populations to be four times greater than the West Gallatin River's study area trout population (140,353 and 34,132, respectively). Two canals contained 87% of the model's predicted trout abundances, and the headgate area variables for both canals were above the range of data collected in the study canals. Rapid (90%) and staged (30%) drawdown regimes were evaluated to encourage trout movement. Among the regimes examined, reducing canal flow by 90% while leaving adequate flows for fish movement was most effective in stimulating up-canal movement. Therefore, altering the time of canal openings to avoid a river's period peak discharge and reducing canal flows by 90%, with leaving the remaining flow at least 2 d before completely closing the headgate, might decrease the numbers of fish stranded in canals at the end of an irrigation season.

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of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY - BOZEMAN
Bozeman, Montana

December 1997

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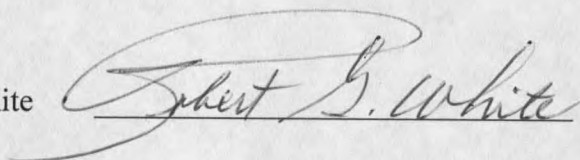
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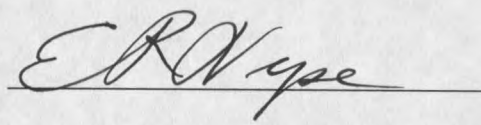
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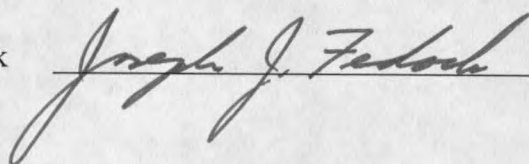
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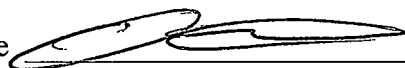
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ACKNOWLEDGMENTS

I would like to extend my sincere appreciation to those who assisted me during this research effort. A special thanks to the West Gallatin River irrigators, for without their cooperation and assistance I could not have conducted this research. I would like to thank my committee members - Drs. Robert White (advisor), Thomas M^cMahon, Jay Rotella and Pat Munholland. Thanks to Judd Stewart, John Wyrzykowski, Todd Becker, Chris M^cQuery, Brian Vaughn, John Jorgenson and the numerous volunteers for their dedication to collecting quality data. Mark Taper, Dan Gustafson, and Kristie Allen were instrumental in the model development and interpretation. Drs. Pat Munholland, John Borkowski and Jeff Banfield offered everlasting statistical knowledge. Thank you to the personnel of the Biology Department, especially Dee Topp, for assisting me through my graduate student crises. Finally, I need to thank Rick Henderson, Greg Widner, and Mark Williams for their endless offerings of distractive activities during my imprisonment at MSU. Together we summited Mt. M^cKinley, fulfilling one of my childhood dreams.

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ABSTRACT

Agriculture and recreational fisheries are important to Montana's economy, however they compete for the state's water resources. Conflicts over the number of trout entering irrigation canals, and subsequently being lost from a river's fishery, prompted concern, in Montana, as early as 1893. Yet few studies have examined the effects of fish loss to irrigation diversions on trout populations. I estimated the number of trout ($\geq 150\text{mm}$) in gravity-fed irrigation canals on the West Gallatin River, Montana, by trapping and electrofishing, in 1993 and 1994. It was presumed that fish entering the canals were lost from the West Gallatin River fishery. Trout abundance was related to habitat types and canal characteristics and operations. Multiple regression was used to assess the relationship between these factors and population abundance. Trout population densities varied from 0 - 16 fish/100m (median 1.5 fish/100m). Total trout populations ranged between 0 and 1,905 fish/canal (median 215 fish). Repeated electrofishing of identical transects found no significant differences between trout populations in 1993 and 1994 ($P\text{-values} > 0.26$, $Betas \geq 0.92$) or between June 1994 and September 1994 ($P\text{-values} > 0.12$, $Betas \geq 0.83$). Most trout entered the irrigation canals during periods of maximum river flow. I measured the following canal characteristics: headgate size, manipulation, construction materials and habitat; intake size, habitat and angle in relation to the river's thalweg; and flow; which were used to develop a predictive model of the number of trout found in a canal. The model contained headgate area, intake angle in relation to the river's thalweg and intake length [canal populations = $-2,429.7 + 0.7246(e^{\text{area}}) + 0.5405(1/50\text{m angle}) - 0.3287(\text{sqrt(intake length)})$] (model $R^2 = 0.87$, $P\text{-value} = 0.00483$). Large canals, with short intake channels, located on the outside of river bends captured more fish than canals with opposite characteristics. A jackknife bias-estimation procedure indicated that the model overfit the data ($R^2 = 0.25$, $P\text{-value} > 0.80$). The model predicted canal trout populations to be four times greater than the West Gallatin River's study area trout population (140,353 and 34,132, respectively). Two canals contained 87% of the model's predicted trout abundances, and the headgate area variables for both canals were above the range of data collected in the study canals. Rapid (90%) and staged (30%) drawdown regimes were evaluated to encourage trout movement. Among the regimes examined, reducing canal flow by 90% while leaving adequate flows for fish movement was most effective in stimulating up-canal movement. Therefore, altering the time of canal openings to avoid a river's period peak discharge and reducing canal flows by 90%, with leaving the remaining flow at least 2 d before completely closing the headgate, might decrease the numbers of fish stranded in canals at the end of an irrigation season.

INTRODUCTION

Long before effective water management plans were developed in the western United States, ranchers and farmers had acquired water rights. As resource demands have increased, so have conflicts between recreational user groups and the agricultural industry. Concern has escalated over the potential effects of removing water from a stream (dewatering), including the loss of fish to irrigation canals. One solution to fish being lost to irrigation canals is fish screening programs, which began in New York in 1865 (Leitritz 1952). Fish screening consists of installing and maintaining devices (i.e.- types of screens) which prevent fish from entering irrigation diversions. Most screening program evaluations have concentrated on anadromous species, and only a few studies have evaluated resident fish losses. Anadromous salmonids, which migrate to the ocean and return to freshwater to spawn, have different life histories than resident fish, which remain within a freshwater system throughout their life cycle. This study was initiated to address resident fish loss to irrigation canals.

The irrigation of Montana's crops by Euro-American settlers began in 1842 in the Bitterroot River Valley (Howard 1992). By 1864, settlers were establishing farms in the Gallatin Valley, and in 1865 the Gallatin Valley's first "ditch company" was formed (Howard 1992). A resident fish screening program was implemented in 1893 when legislation was passed requiring screens to be placed in irrigation canals from 1



September to 1 March, a period when irrigators use little or no water (Clothier 1953a). This legislation was repealed in 1897, for it had no practical value. Other screening programs in Montana have been adopted, but installation and maintenance costs have restricted their use. It is currently the responsibility of Montana Department of Fish, Wildlife and Parks (MDFWP) to fund, construct and maintain any device to prevent fish from entering irrigation ditches (Fish and Wildlife 1993) (Appendix A).

Where resident fish losses to irrigation withdrawals are large, Montana's streams may not be providing their full recreational potential. Montana's world-renowned recreational fishing/tourism industry produces a multi-million dollar market. Many small towns rely on tourism as their primary source of revenue. Duffield et al. (1987) calculated the total 1985 expenditures for Montana's resident and non-resident stream anglers to be \$52.4 million and the overall net economic benefit from stream fishing at \$122 million. In the Gallatin River, angler expenditures were \$4.5 million (Duffield et al. 1987). There are approximately 1,585km (984 miles) of irrigation canals in the Gallatin River Valley alone, and every major drainage in Montana contains irrigated cropland.

Agriculture is also a principal source of revenue and a strong source of Montana's heritage. Over the past century, Montana's agricultural industry has grown to a \$2.1 billion commodity market (Montana Agricultural Statistics Service 1994). The Gallatin County agricultural market produces a gross receipt of approximately



\$56 million annually (Montana Agricultural Statistics Service 1994). Agriculture is currently the largest revenue source for Gallatin County, as well as the state of Montana (U. S. Department of Commerce 1992). As resource demands continue to burden Montana's waterways (i.e.- irrigation and recreation), methods of evaluating and resolving resource conflicts will need to be incorporated into management strategies.

Biologists in other areas were concerned over the declining anadromous stocks in the early 1900's, which prompted many western states to begin screening irrigation diversions. However, the effects of fish losses were rarely understood because no quantitative data were obtained (Wales 1948; Schill 1984). Wales (1948) reported that California began screening streams used by anadromous species, although low numbers of juveniles did not justify the costs associated with the program. Gebhards (1958, 1959) sampled irrigation canals in the Salmon River drainage, Idaho. He estimated that a screening program could save over one million chinook smolts (*Onchorhynchus tshawytscha*) in years of heavy downstream migration. Sixty Salmon River canals were electrofished to identify the diversions with the largest numbers of juvenile salmon and to prioritize the placement of fish screens (Gebhards 1958). Although only 60 canals were sampled, Gebhards' study resulted in the screening of over 200 diversions on the Salmon River drainage in 8 years (1958-1966) (Herring 1983, in Schill 1984).

Screening evaluations were conducted to ascertain the number of fish entering and safely bypassing the Idaho canals. Between 1960-62, Corley trapped 147 rainbow



trout (*O. mykiss*) in 8 canals, 971 rainbows in 14 canals, and 651 rainbows in 17 canals in 1960, 1961, and 1962, respectively (Corley 1962, in Schill 1984). No distinctions were made between juvenile rainbow trout and steelhead trout (*O. mykiss*). Corley also estimated that 91,500 and 279,000 juvenile chinook salmon were bypassed by 84 irrigation canal screens in 1961 and 1962, respectively. To determine the percentage of total downstream migrants entering canals, marked juvenile chinook salmon and steelhead trout were released above irrigation diversions (Reingold 1967a and 1967b, in Schill 1984; Reingold 1971). Population losses were estimated at 0.3 - 6.5% for juvenile chinook salmon (average 2.6%) and 1.3 - 5.9% for steelhead trout (average 2.6%).

Several authors have documented the need for devices to prevent anadromous species from entering canals (Gebhards 1958, 1959; Corley 1962; Reingold 1967a, 1967b, in Schill 1984; Reingold 1971; Herring 1983, in Schill 1984; Fleming et al. 1987). Sullivan and Mattice (1986) found that no single protection system is reliable, economically feasible, and biologically effective. Rotary drum, traveling, and stationary screens are the most common fish protection technologies. Rotary screens on the Sunnyside Canal (Yakima River, Washington), Wapato Canal (Yakima River), and Toppenish Canal (Toppenish Creek, Washington) were found to be 98%, 99%, and 99% efficient, respectively (Neitzel et al. 1986, 1990a). Rotary drum screens cost \$2,000 - \$4,000 per 0.28 m³/s (10 cfs) and the average installation cost for smaller canals is \$25,000 (Chuck Keller, Idaho Department of Fish and Game, personal



communication). The value of these fisheries and the listing of anadromous stocks under the Endangered Species Act (Nehlsen et al. 1991) justifies the cost of installing fish protection devices (Schill 1984). These technologies have been extensively used to protect anadromous species in the Pacific Northwest and California, but Sullivan and Mattice (1986) concluded that screening could not be justified for resident fisheries due to high costs. It is important to note that, due to different behavioral patterns, it would not be reliable to apply the results of studies on anadromous species to resident trout populations.

Although much work has been done on anadromous fish, losses of resident fish to irrigation diversions are not well documented. Although fish may be capable of leaving the irrigation canals and returning to the river, fish loss refers to the number of fish found (or estimated) in the irrigation canals. In 1904, MDFWP estimated a single canal's loss in the thousands (Clothier 1953a), but little quantitative information was obtained. Clothier (1953a, 1954) and Spindler (1955) confirmed fish losses in irrigation canals on the West Gallatin River, Montana. Fleming et al. (1987) recorded resident fish losses that nearly equaled those of anadromous species in several irrigation canals (3700 rainbow trout and 4100 chinook salmon). Evarts et al. (1991) studied fish losses in canals operated by the Flathead Agency Irrigation Division, Montana, recovering 8,679 trout over 4 years (1988-1991) while electrofishing 16 canals. They also reported that they recovered over 20,000 fish (various species) from these canals, which was only a fraction of the fish present, and that the reservations

fisheries would not reach their potential until these canals were screened. Other attempts to document resident fish losses were either vague or not the primary purpose of the investigation, and resident fish losses were therefore reported as supplementary information.

The variability between trout densities in irrigation canals makes it difficult to ascertain the effects of irrigation canals on resident salmonid populations. To gather more specific information on impacts to resident trout, Clothier (1953a) sampled 13 canals on the West Gallatin River (1950 and 1951) and estimated a loss of 2,835 catchable sized trout (total length $\geq 180\text{mm}$). Only 9 of the 13 canals he sampled contained salmonid species. In 1954, Clothier found 2,002 salmonids of all sizes (including mountain whitefish - *Prosopium williamsoni*) in four West Gallatin River irrigation canals (West Gallatin, Farmers, Spain & Ferris and Lower Middle Creek canals). Densities ranged from 0.023 - 0.295 fish/m (average - 0.186 fish/m) for all size classes of trout. Spindler (1955) found 168 catchable sized salmonids (total length $\geq 180\text{mm}$) and 400 smaller salmonids in 11 of the canals sampled by Clothier. Thurow (1980) conducted population estimates on the Allen Ranch Diversion in Idaho and calculated a cutthroat trout (*O. clarki*) density of 0.053 fish/m. Only 63 cutthroat trout were sampled, with 68% of these being juveniles. Culpin (1961, in Thurow 1980) observed low numbers of cutthroat trout (10 adults and 250 juveniles) in this same canal. Both Clothier (1953a, 1954) and Spindler (1955) noted that trout population densities were greatest in the upper 1.6 km of most canals.

Young-of-the-year (YOY) salmonids are lost to irrigation canals, as well as adult fish. In 1992, Clancy estimated the number of juvenile rainbow trout entering a Blodgett Creek irrigation canal. Blodgett Creek is a tributary of the Bitterroot River, Montana. He found this canal to be capturing 41% of the tributary's YOY rainbow trout (Chris Clancy, MDFWP, personal communication). Clancy also reported large losses (9,579) of rainbow trout YOY to irrigation canals on a Jefferson River tributary, Montana. Good and Krongberg (1986) estimated that 2,787 salmonids were lost to a single canal on the Bitterroot River. Of these, 2,440 (88%) were YOY salmonids, primarily whitefish, and eight (0.3%) were bull trout (*Salvelinus confluentus*), a species of special concern in Montana. The remaining 11.7% were legal sized salmonids (total length ≥ 150 mm). Good and Krongberg (1986) suggested that YOY salmonids may be incapable of escaping the velocity of water at the canal's headgate (a water control intake structure).

Physical factors of irrigation diversions and their intake structures may contribute to the number of fish entering canals (Figure 1). Headgate characteristics considered by Spindler (1955) were: headgate location, construction materials and method of manipulation (i.e. - lifting gates, sideways sliding gates, check damming boards, etc.). The intake characteristics he considered were: intake gradient, width, depth, velocity, discharge, diversion dam position, substrate, amount of cover,

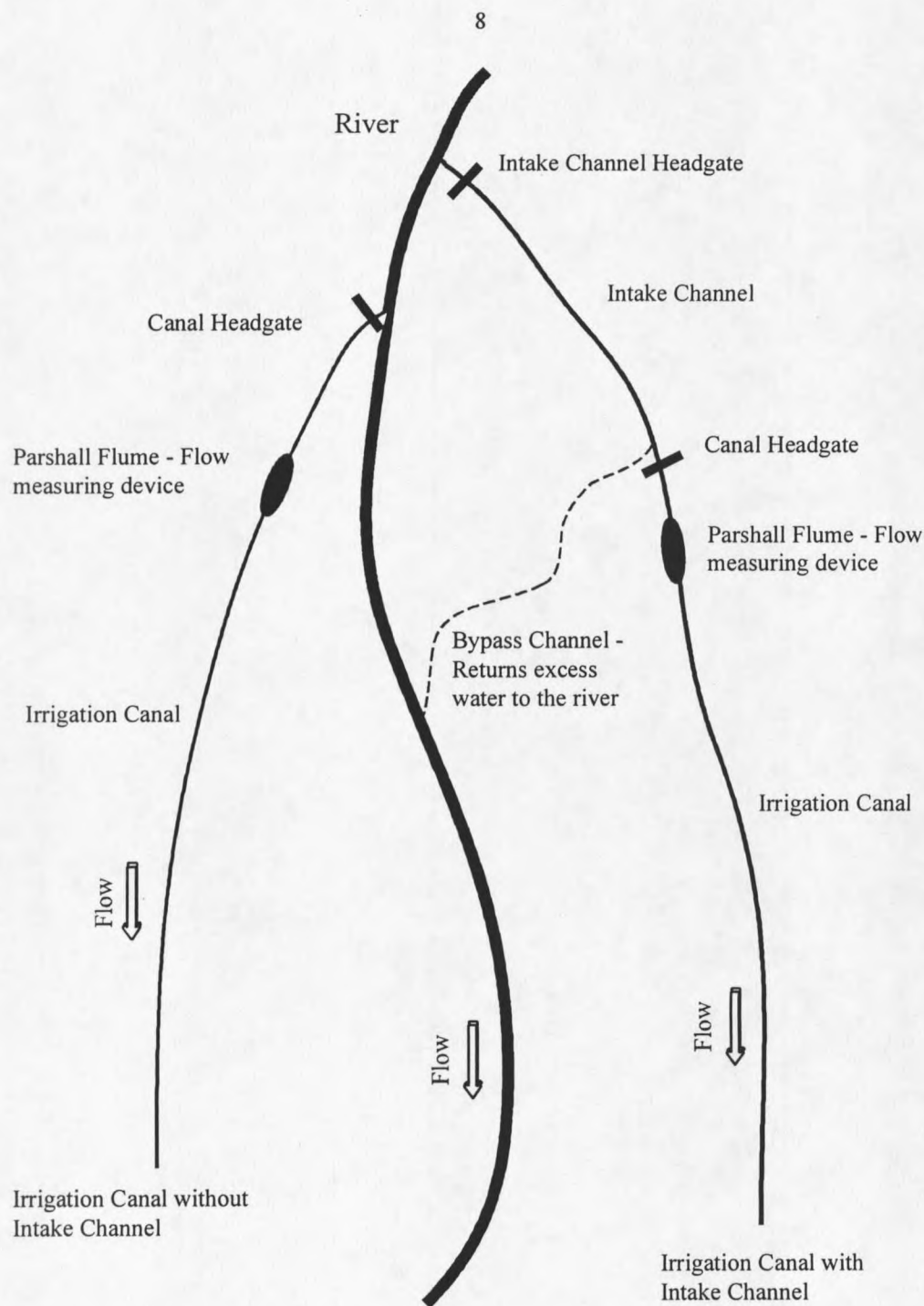


Figure 1. Diagram of the types of irrigation canals and their intake structures. Irrigation water passing through the canal's headgate is not returned to the river.

flow ratio and the intake's location in relation to direction of river flow. Spindler (1955) found that canals with high flow ratios (percentage of river flow diverted) and intake structures located on the outside of river meanders have the highest fish loss.

Thurrow (1980) indicated that fish densities in canals appeared to be influenced by the quantity of water in the river. Clothier (1953b, 1954) recorded increased fish losses in canals with structure (habitat) in the upper 1.6 km. Hiding cover provides security and may reduce fish movement out of irrigation canals (Clothier 1953b, 1954; Evarts et al. 1991).

Staged drawdowns are one possible method to reduce the number of fish stranded or lost in canals at the end of the irrigation season. Drawdowns are accomplished by incrementally decreasing canal flow after the irrigation season. Adult fish respond to decreasing flows through upstream migration (Clothier 1953a, 1954; Fuller 1981). Clothier (1953a, 1953b, 1954) found drawdowns to be an effective method for moving fish out of canals, although habitat and headgate velocities could impede movements (Clothier 1954). Although no quantitative data were obtained, Shepard (1990) reported a reduction in the number of fish stranded when irrigators employed staged flow reduction procedures on irrigation canals of the Bighole River drainage, Montana. Clothier (1953a, 1954) found up-canal movement of fish in irrigation canals when three equal reductions in water volume were used as a method to close these canals. Staged reductions may concentrate fish and ease salvage operations,

but without reliable accessibility and volunteer assistance, salvages can only be justified through public relation benefits (Good 1990).

Resident fish are known to enter irrigation canals, but no studies have quantified the importance of the loss of those fish to the stream populations. Therefore, I designed this study to examine some of the unresolved questions about trout loss to irrigation canals. The West Gallatin River was selected for this study because of its irrigation diversion data, past fisheries data, and availability for study. The objectives of this project were to: (1) review and summarize the literature on salmonid losses to irrigation canals; (2) measure resident salmonid losses to irrigation canals on the West Gallatin River; (3) determine the factors associated with fish loss in canals; (4) test and evaluate irrigation ditch drawdown procedures as a method of reducing fish losses; and (5) develop canal selection criteria that could be used to predict which canals would have large fish losses.

STUDY SITE

The study was conducted in the West Gallatin River drainage of southwestern Montana. The West Gallatin River trout fishery extends from its headwaters in Yellowstone National Park, approximately 139 km (84.5 miles) downstream to Amsterdam Road in the Gallatin Valley. I constructed the study area boundaries around the region of greatest irrigation withdrawal which still contains an excellent trout fishery because: (1) irrigation withdrawal is limited upstream of the mouth of the Gallatin canyon, and (2) the number of trout and angling pressure declines downstream from Amsterdam Road. I made the upper study site boundary (T4S R4E S5 SW1/4) at the mouth of the Gallatin canyon and the lower boundary (T1S R4E S33 SW1/4) at Amsterdam Road (Figure 2). There are 26 irrigation canals extracting water from the West Gallatin River between these boundaries (Appendix B). The elevation of the study region ranges from 1,570 - 1,350 m (5,150 - 4,430 ft) and encompasses 38.7 km (24.2 mi.) of the West Gallatin River.

The fluvial geomorphology of the West Gallatin River changes within the study area. In the upper reaches of the study area, the river is a single channel comprised of riffles with an occasional scour-pool located at bends and/or constrictions. The channel has a 2 - 4% gradient and low sinuosity (Rosgen channel type B, Rosgen 1994, 1996). The river gradually changes to a braided channel approximately 10 km below

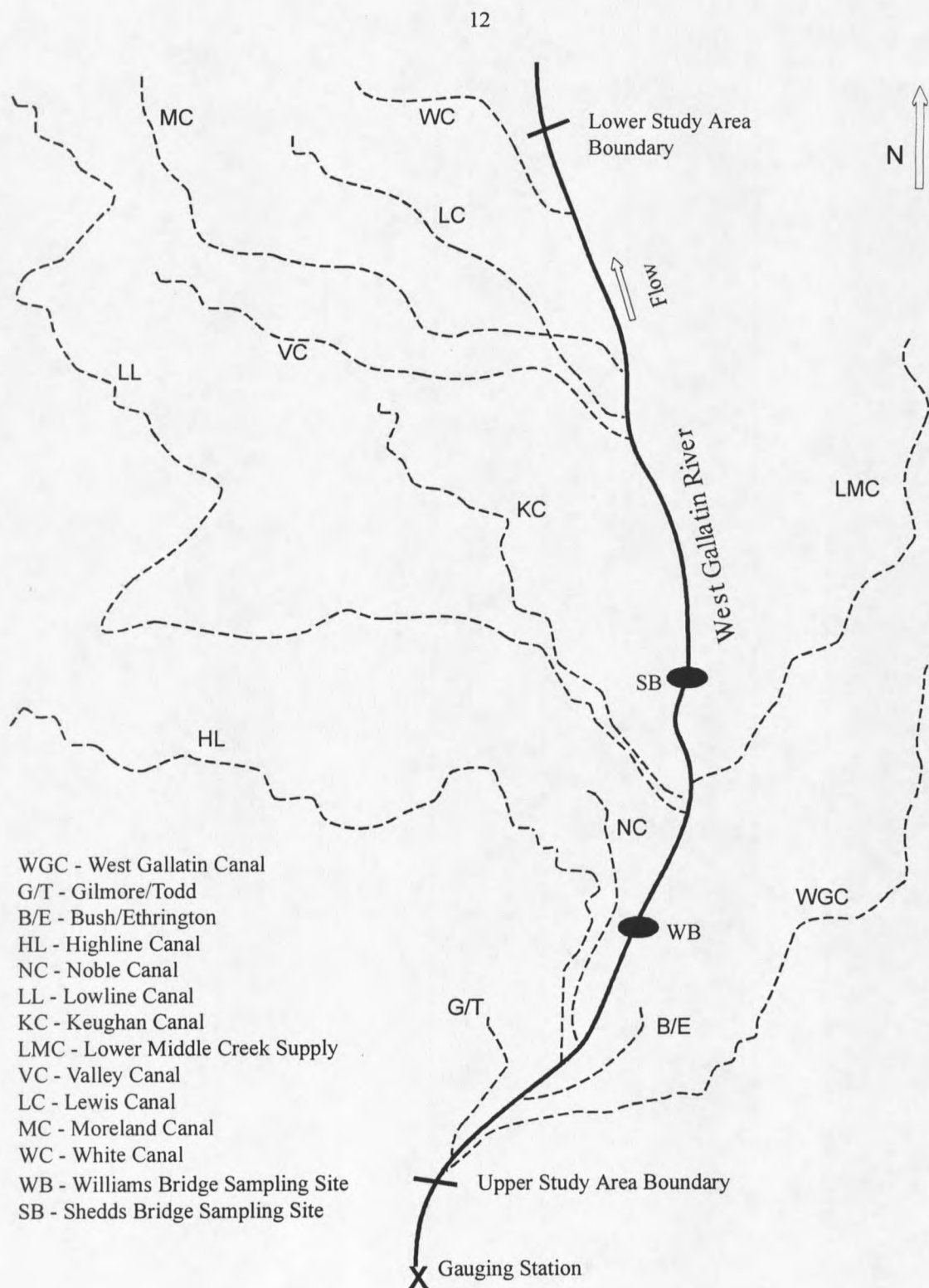


Figure 2. Location of the study canals and the USGS gauging station on the West Gallatin River, Montana.

the upper boundary. The braided region is laterally active and carries an abundant sediment load (Rosgen channel type D, Rosgen 1994, 1996). Substrate in the upper reaches is characterized by boulder/cobble mix and changes to cobble/gravel in the lower reaches. The riparian area ranges from 0.5 - 1.9 km wide (0.3 - 1.2 mi.) and is dominated by cottonwoods (*Populus* spp.), willows (*Salix* spp.), and dogwoods (*Cornus* spp.).

Fish species in the study area include rainbow trout, brown trout (*Salmo trutta*), cutthroat trout, brook trout (*Salvelinus fontinalis*), Arctic grayling (*Thymallus arcticus*), mountain whitefish, white sucker (*Catostomus commersoni*), longnose sucker (*C. catostomus*), mottled sculpin (*Cottus bairdi*), and longnose dace (*Rhinichthys cataractae*) (Clothier 1953a). The numerous rainbow/cutthroat hybrids present in the area (Clothier 1953a) were classified as rainbow trout or cutthroat trout, depending on dominant traits. The West Gallatin River trout population is primarily rainbow trout in the upper reaches of the study area and progressively changes to predominantly brown trout downstream. The West Gallatin River is not thought to be recruitment-limited (Dick Vincent, MDFWP, personal communication).

The West Gallatin River drains 2,146 km² (825 mi²), most of which is Gallatin National Forest land (Shields et al. 1993, 1994). Its average annual flow is 22.8 m³/s (806 cfs), and ranges from 11.6 - 33.3 m³/s (408 - 1,184 cfs). The average flows for the

1993 and 1994 field seasons (May - November) were $29.9 \text{ m}^3/\text{s}$ (1,055 cfs) and $19.4 \text{ m}^3/\text{s}$ (683 cfs), respectively (Figures 3 and 4). The historic maximum flow was recorded in 1974 at $254.2 \text{ m}^3/\text{s}$ (8,970 cfs). The 1993 maximum flow was at $155.6 \text{ m}^3/\text{s}$ (5490 cfs) and the 1994 peak at $106.8 \text{ m}^3/\text{s}$ (3,770 cfs) (Figure 5). The historic minimum flow was recorded in 1931 at $4.9 \text{ m}^3/\text{s}$ (174 cfs). Minimum flows for 1993 and 1994 were $5.6 \text{ m}^3/\text{s}$ (197 cfs) and $8.5 \text{ m}^3/\text{s}$ (299 cfs), respectively. These discharge readings were taken from U. S. Geological Survey - Water Resources Division (USGS) gauging station (number 06043500) located 0.5 km downstream from the mouth of Spanish Creek on the West Gallatin River. The West Gallatin River drains approximately 85% of the Gallatin River Valley.

The primary land use in the Gallatin Valley is agriculture and the valley is sparsely developed (U. S. Department of Commerce 1992). Gallatin Valley irrigators produce hay, small grains and commodity food crops (Howard 1992). Cropland comprises 104,678 ha (258,593 acres) in the Gallatin Valley with 40,865 ha (100,950 acres) under irrigation (U. S. Department of Commerce 1992). An additional 162,744 ha (402,036 acres) are classified as grazing lands (U. S. Department of Commerce 1992). Hay and barley comprise 84% of the irrigated lands with wheat, seed potatoes, and oats planted on the remaining irrigated lands (Montana Agricultural Statistics Service 1994).

West Gallatin River irrigation water is removed by gravity-fed canals and applied by above ground sprinkler systems and flood irrigation (Howard 1992). The

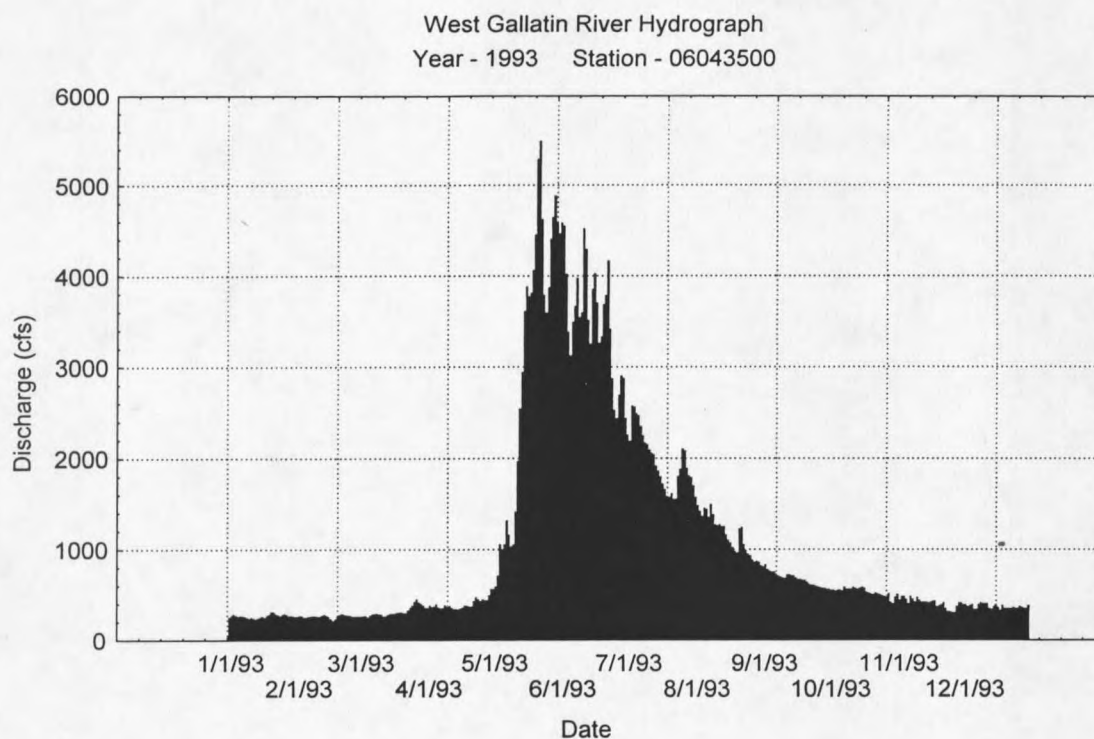


Figure 3. Hydrograph of the West Gallatin River for 1993. Discharge readings were obtained from U. S. Geological Survey - Water Resources Division gauging station number 06043500.

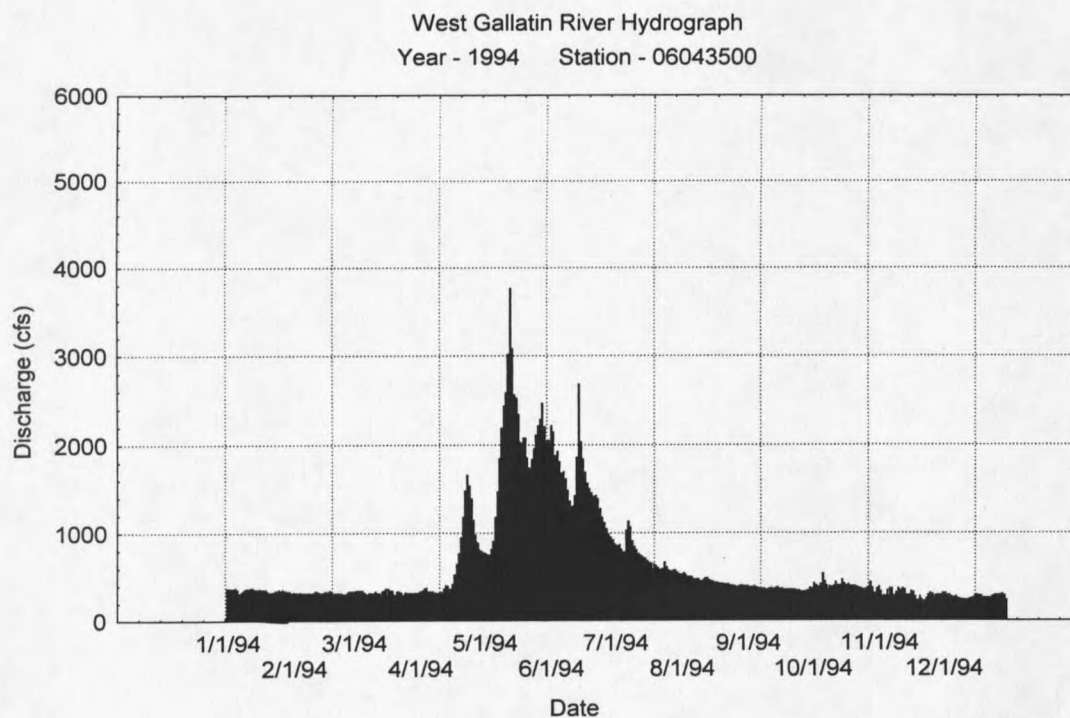


Figure 4. Hydrograph of the West Gallatin River for 1994. Discharge readings were obtained from U. S. Geological Survey - Water Resources Division gauging station number 06043500.

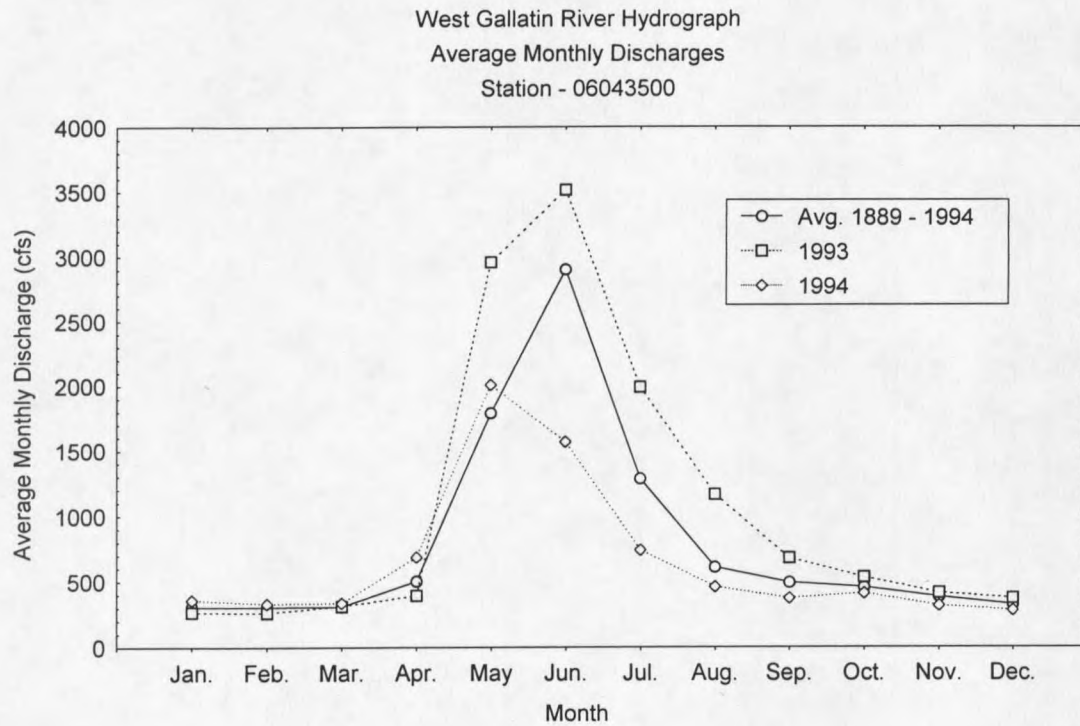


Figure 5. Average monthly discharges for the West Gallatin River, comparing 1993 and 1994 flows to historic discharges (1889-1994). Discharge readings were obtained from U. S. Geological Survey - Water Resources Division gauging station number 06043500.

irrigation season usually begins in May and extends into November. The duration of the irrigation season and the amount of water drawn from the West Gallatin River is determined by summer precipitation and mid-summer temperatures (Howard 1992).

The 12 canals examined in this study are used for agricultural irrigation (Figure 2) (Table 1). The decreed flows of the studied canals range from 0.37 - 4.82 m³/s (13 - 170 cfs). Decreed flows are based on the amount of water the canal is legally allocated to withdrawal from the river. Water rights, with an appropriation date prior to January 1, 1900, were used to calculate the canal's decreed flows. Canal flows are recorded by Parshall flumes (Chow 1959; Howard 1992). None of the canals have return systems, and therefore fish entering these canals can only exit through the headgate.

Canal or intake channel headgates control the amount of water that enters the diversion. They can be constructed of wood, concrete, metal and/or metal culverts. Large or newly built headgates are usually constructed of concrete with metal sliding gates or removable wood slats to control the withdrawal. Metal sliding gates usually allow the water to enter under the gate, creating a high velocity pathway for the water (all study canals except Gilmore/Todd, Bush/Ethrington and Valley). The ability of fish to exit these headgates depends on their burst swimming speed. Wood slat control structures regulate canal flows by restricting the amount of water that can flow

Table 1. Study canal characteristics for the 1993 and 1994 field seasons on the West Gallatin River. (For additional information on all canals see Appendix B.)

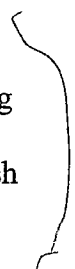
Canal	Years sampled	Decreed flow ¹		Total length ²	
		m ³ /s	cfs	km	miles
West Gallatin	93-94	4.28	151	31.9	19.8
Gilmore/Todd	93-94	0.43	15	2.9	1.8
Bush/Ethrington	93-94	0.37	13	4.0	2.5
Highline	94	4.82	170	50.8	31.5
Noble	93	0.65	23	8.3	5.2
Lowline	94	4.82	170	56.6	35.1
Keughan	93-94	2.52	89	16.8	10.4
Lower Middle Creek	93	2.21	78	10.1	6.3
Valley	94	2.13	75	19.3	12.0
Lewis	93-94	2.15	76	12.8	7.9
Moreland	94	3.46	122	28.7	17.8
White	94	1.42	50	20.7	12.9

¹ - Decreed flow was based on the West Gallatin River water commissioner's tables for the Parshall flumes of each canal. Water rights with an appropriation date prior to 1 January 1900 were used in calculating decreed flows.

² - Total length was extrapolated from 7.5 minute series topographical maps using a planimeter, tracing the length of each canal.

over the boards. Fish attempting to exit canals with these headgate types must be capable of jumping the wood slat structures.

The physical state of the channels can vary between canals. Small tributaries enter the West Gallatin and Lewis canals, but these tributaries are dewatered during the irrigation season. Small springs enter the Moreland canal at two locations. Portions of the Valley, Lewis, Moreland and White canals follow old stream channels. Most canals are typically shallow ($<1\text{m}$ deep), narrow ($<2\text{m}$ wide), and low gradient (<0.02 slope) with sand/silt to gravel substrate, particularly in the upper 2.5 km. The Lewis, Valley, Moreland and White canal substrates are sand/silt to cobble/rubble, depending on water velocity. Habitat consists of overhanging vegetation, small debris, and road culverts. The Lewis, Valley and Moreland canals have several culvert plunge pools, areas of overhanging vegetation and bottom structures that create cover. Each study canal's headgate was closed during the winter, eliminating flow. Therefore, remaining fish populations were assumed lost each winter and renewed by movement of river fish into the canals the following spring.



METHODS

Each year, the West Gallatin River fishery loses fish to irrigation canals. The effects of this resident trout loss are not well-documented or well-understood. I undertook this project to ascertain whether or not the abundance of trout loss warrants concern, to identify factors that may be influencing the numbers of fish in a canal and to identify methods of reducing the number of trout stranded in the canals at the end of each irrigation season. To obtain this information, I estimated the number of trout in each canal, determined when most fish entered the canals, and determined whether or not fish could escape the canals. If trout abundances warrant concern and if trout can escape the canals, then drawdown methods may be able to reduce the numbers of trout stranded in the canals at the end of the irrigation season.

Canal Selection

There are 25 irrigation canals within the study area boundaries on the West Gallatin River (Appendix B). Clothier (1953a, 1954) and Spindler (1955) studied 15 of these canals. To select canals for study, I first contacted the water commissioner, irrigators, landowners and ditch riders for access permission and canal information. I was especially interested in including canals with past fishery abundance data, water

withdrawal information, and ease of accessibility. Accessibility included vehicle access to the headgate, down-canal landowners who would allow trespass, and road access to points down-canal from the headgate. Of the canals I received permission to sample, 18 provided the necessary access requirements. Because I could not logistically handle 18 canals, I randomly selected 12 study canals using simple random sampling without replacement. Of the canals I studied, six of them were examined by both Clothier (1953a, 1954) and Spindler (1955).

Fish Loss Estimates

I considered fish that entered the canals to be lost to the West Gallatin River population. Therefore, I estimated the number of trout in the canals and the time that fish entered the canals using two methods: (1) trapping fish entering the canals (1993) and (2) electrofishing (1993, 1994). In 1993, efforts concentrated on trapping fish entering the canals to determine their time of entry (Table 2). Electrofishing was used to verify the fish trapping abundance estimates (1993) and to compare trout population estimates between years (1993 to 1994). In 1994, electrofishing was used to estimate the abundance of trout in the canals.

Table 2. Methods used to examine populations and fish movements in irrigation canals during the 1993 and 1994 field seasons on the West Gallatin River, Montana.

Canal	1993 Field season			1994 Field season		
	Trapping	Electrofishing	Movement	Trapping	Electrofishing	Movement
West Gallatin	X	X			X	X
Gilmore/Todd	X				X	
Bush/Ethrington	X				X	
Highline					X	X
Noble	X					
Lowline					X	X
Keughan	X	X		X		
L. Middle Creek	X		X			
Valley					X	X
Lewis	X	X	X		X	X
Moreland					X	X
White					X	

Trapping Methods and Trap Site Selection

* Box traps were used to quantify salmonid movement in and out of irrigation canals during the 1993 field season. The box traps resembled large minnow traps with open tops and consisted of PVC frames enclosed in 13 mm square mesh galvanized hardware cloth with one-way openings on each end. A center partition enabled separation of upstream and downstream migrant fish. Plastic hardware cloth (10 mm square mesh) was secured to the trap bottoms and extended 450mm beyond the trap openings to prevent fish movement under the traps. Hardware cloth wings were used to funnel fish into the traps. Wings were attached to the upstream and downstream trap openings and extended across the entire width of the canal. The bottom 300 mm of hardware cloth was folded over along the canal bed and lined with rocks to prevent fish movement under the wings. The wings and traps were fastened to metal fence posts secured in the substrate. The traps completely blocked the canal to fish passage.

All fish species captured were identified and recorded. Measurements (metric) were taken only on salmonids. Species, total length, weights and marks (i.e.- injuries, previous fin clips, scars, etc.) were recorded for all sizes of trout and all whitefish ≥ 150 mm. Young-of-the-year trout were measured but not weighed, while YOY whitefish were only counted. To assess age structure of trout populations inhabiting canals, scales were removed from all trout ≥ 150 mm captured during electrofishing. Scales were taken from below the dorsal fin (Jearld 1989). All trout ≥ 150 mm were marked by adipose fin removal and anchor tags (Floy Tag and Manufacturing

Company, Inc.). Individually numbered and color coded tags enabled monitoring of fish movement. Anchor tags were inserted between the dorsal pterygiophores (Wydoski and Emery 1989). Adipose clips were used to identify tagged trout in the event that tags were lost. Technicians were trained in anchor tag placement. All salmonids captured were anesthetized in a 10% solution of MS-222 (tricaine methanesulfonate) during handling (Stickney 1989). Fish were held in live wells for at least a 10 minute recovery period before being released back into the canal.

All salmonids captured were recorded and released 5 - 6m from the trap. Tagged fish were released in the same direction as their original movement (i.e.- downstream migrants were released downcanal of the trap), unless a tagged fish was recaptured within 24 h of its release, then it was re-released on the downcanal side of the trap.

The traps were installed after peak runoff (1 July - 31 October) and placed in the canal downstream from the headgates. Traps were installed in accessible areas that were acceptable to the irrigators, thus trap placement was non-random. Where possible, traps were installed below the Parshall flumes to prevent interference with irrigation withdrawals. When placed below the Parshall flumes, the traps were installed within 30m of the flume. Other traps were placed within 50m up-canal of the flumes, except the Keughan canal trap which was 210m above the flume.

Trapping duration was intended for the entire irrigation period, but debris from flow increases interrupted continuous trapping. Traps were removed immediately if

they began to restrict canal flows. The traps in the Noble and Lower Middle Creek canals were in place throughout the entire irrigation season, and were removed ≤ 7 d after the canals were closed. All other traps were removed prior to canal closure. The Lewis canal trap was reinstalled 25 d prior to canal closure to monitor fish movement. Traps were checked and cleaned twice daily to prevent debris build-up.

Source: Phillips?
Trap efficiency was evaluated in 1993 by releasing hatchery rainbow trout in the West Gallatin and Lewis canals. The rainbow trout (160mm - 250mm total length) were obtained from the U. S. Fish and Wildlife Service's Fish Technology Center, Bozeman, MT. In both canals, two groups of 30 trout were stocked below the canal headgate (10m and 250m from headgate). Trap escapement was tested by placing 10 trout in the traps for 16 d. Pectoral, pelvic, and adipose fin clips were used to identify stocking locations. Caudal and anal fin clips were used to mark recaptures for the trap efficiency test. After 16 d, the hatchery rainbow trout were removed from the traps and canals by backpack electrofishing.

Electrofishing

I evaluated the extent of fish loss to canals, by performing electrofishing population estimates. Because two-pass removal estimates can underestimate population size, at least three passes were used in order to estimate capture probabilities (Otis et al. 1978; Riley and Fausch 1992). Estimation methods for multiple-pass removal were therefore used to estimate the number of trout in each

electrofished reach in 1993 and 1994 (Zippen 1958) (Table 2). I based the number of electrofishing passes on the depletion rate of trout ($\geq 150\text{mm}$) captured between each pass (Rodgers et al. 1992). A depletion ratio of 70% between passes was desired. Two-pass removals were used if no salmonids $\geq 150\text{mm}$ were captured in either pass, because a third pass would not improve the estimate's confidence intervals. The trout populations in these two pass electrofishing reaches were considered zero.

Electrofishing estimates were made during mid-summer (1994) and in early fall (1993 and 1994) when the canal flows had sufficiently decreased to allow access in the canals. In 1993 and summer 1994, I used two Coffelt model BP-6 generator-powered backpack electrofishing units operating at 130-190 V pulsed DC with diamond-shaped anode probe tips and trailing cathodes made of 10 mm diameter stainless steel wire rope to sample fish. In fall 1994, electrofishing was conducted with two Smith-Root model 15-C generator-powered backpack electrofishing units operating at 1-3 pulsed wavelength at 500-700 volts with circular shaped anode probe tips and 6mm stainless steel wire rope for trailing cathodes. Conductivity was not measured but was considered adequate for effective electrofishing. Electrofishing was conducted walking up-canal with both operators netting and electrofishing. A third netter assisted on the larger canals. The ends of each reach were blocked with 6mm bar mesh seines (1.2m X 14m). The bottom 300 mm of the seines were folded over along the canal bed and lined with rocks, ensuring population closure.



Canal Strata and Habitat Type Identification

In 1994, electrofished canals were divided into three strata based on the distance from the headgate (0 - 1.6 km, 1.6 - 4.8 km, and > 4.8 km) (Figure 6). Distances were based on the variability in trout population densities explained by Clothier (1953a, 1954), Spindler (1955), Thurow (1980) and Evarts et al. (1991). All canals contained strata one and two, but two canals were ≤ 4.8 km, and therefore did not contain a third stratum.

Within each stratum, habitat types (pools, glides or runs, riffles and pocketwater) were identified (Bisson et al. 1982; Dolloff et al. 1983). Pools are typically low gradient reaches with smooth, non-turbulent surface flows. They are caused by channel constrictions, large protrusions from the streambed or woody debris which produces streambed scouring and eddies. Runs also lack pronounced surface turbulence. Runs are usually found in long, low gradient canal reaches with no major flow obstructions that could create streambed scouring. Riffles have a higher gradient with swiftly flowing water and considerable surface turbulence. Pocketwater was defined as a reach with numerous small pools that are less than half the canal's width.

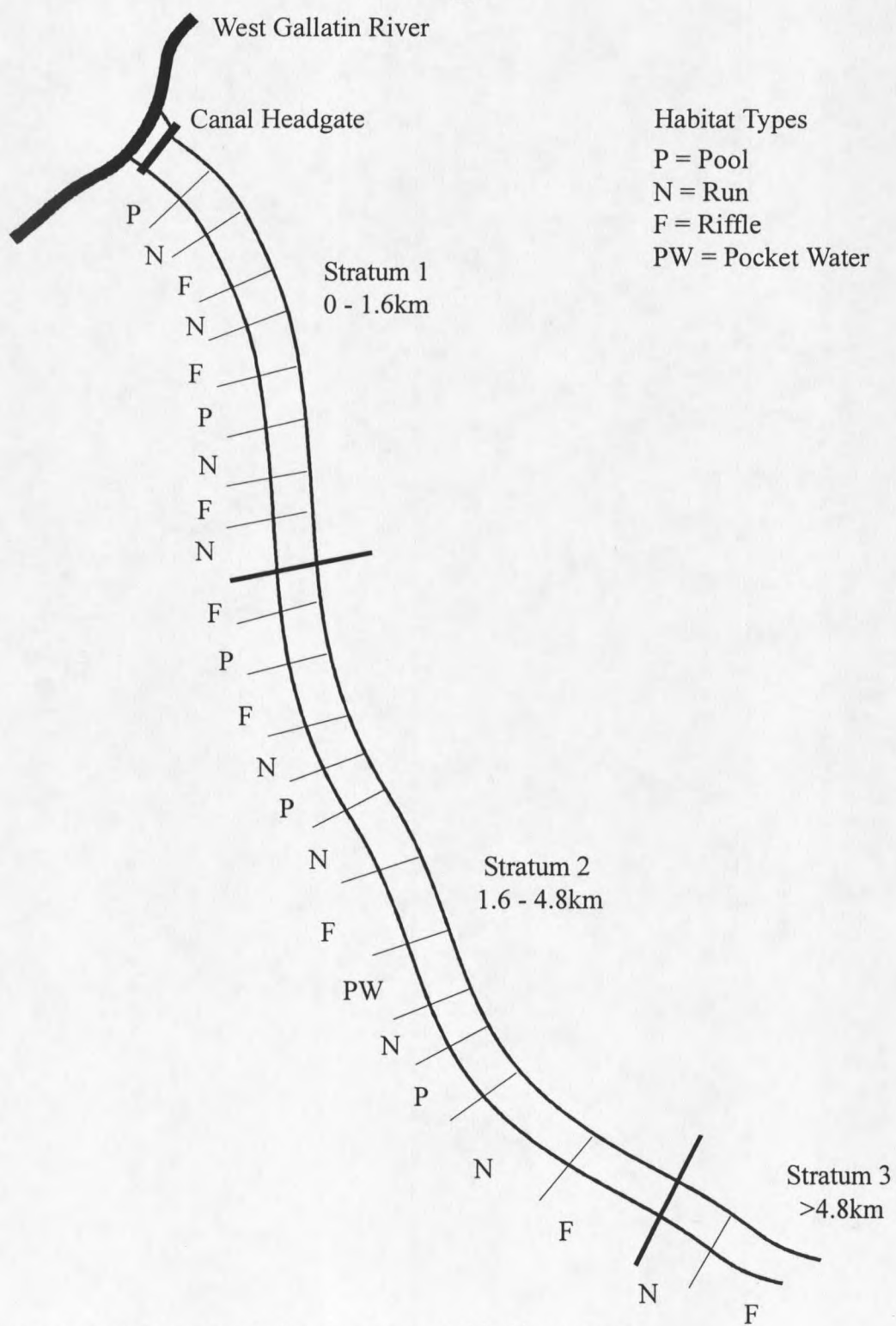


Figure 6. Irrigation canal showing strata and habitat types.

Minimum size restrictions were placed on the habitat units for recording and sampling purposes. Habitat units are individual segments of one habitat type (i.e. - pools, runs or riffles) that are bordered by other habitat types. Pools had to be $\geq 5\text{m}$ in length and encompass the entire width of the canal to be recorded, while runs, riffles and pocketwater habitat units had to be $\geq 30\text{m}$ in length. If the habitat units did not meet these minimum criteria, they were not separated out as individual habitat units and were included in the previous unit's length.

Total lengths of each habitat type were measured, or estimated in each strata by subtracting measured habitat unit lengths from the total length of a reach. All pools were measured in each stratum. Either runs or riffles were measured with the length of the other habitat types estimated. Although this procedure provided the length of each habitat type within each stratum, it could not be used to extract the actual distance from the headgate for each habitat unit.

The procedure for marking and measuring individual habitat units and estimating the length of the other habitat type varied between strata. Habitat units were identified, marked and measured walking down canal beginning at the canal's headgate in strata one and two. In stratum one, all run habitat units were measured and the lengths of riffles between map locations were estimated in all canals except the Valley, Lewis, Moreland and White. In stratum two, all riffle habitat units were measured and the lengths of run habitat types were estimated in all canals, except the Lewis and White canals. The pocketwater habitat unit in stratum two of the Lewis canal was

measured. In all canals except one (Lewis), riffles were measured while runs were estimated for stratum three. The habitat units in stratum three were identified and measured either prior to electrofishing by kayaking the canal or during the electrofishing process.

Habitat units on the West Gallatin, Bush/Ethrington, Valley, Lewis and Moreland canals were remeasured 20-90 d after the original measuring to ascertain the effects of flow alterations on the length and type (pool, run or riffle) of habitat units. Habitat units in strata one and two were remeasured after the electrofishing had been completed. The original habitat unit's identification and length was then compared to the remeasured data. If a canal's habitat influences its trout abundance, then changes in habitat could affect the trout abundances over time.

Electrofishing Site Selection and Density Estimates

The Lewis, Keughan, and West Gallatin canals were the only canals electrofished during fall 1993. In these canals, all pools within 4.8 km of the canal headgate were electrofished. Selection of pool sampling-sites was limited by accessibility during the 1993 field season. Although data were not collected in all canals, data from the 1993 subset allowed me to compare population estimates between years.

In 1994, stratification, habitat typing and electrofishing selection procedures were employed on the study canals. The electrofished habitat unit, or portion thereof,

was referred to as an electrofishing reach. All accessible pool habitat units that were possible to sample within the limitations of backpack electrofishing gear were electrofished to estimate trout population abundances. A systematic sampling procedure was used to select the run and riffle habitat units for electrofishing (Hankin 1986; Hankin and Reeves 1988; Scheaffer et al. 1990; Thompson 1992). Run and riffle habitat units were consecutively numbered within each strata and a one-in-three systematic sampling schematic was used to select the individual habitat units for electrofishing (Figures 6 and 7). In strata one and three a random starting point of one was selected, while in stratum two a random starting point of two was selected. Runs and riffles used the same starting point in each stratum. An individual starting point should have been selected for each habitat type. Without a randomly selected, individual starting point for each habitat type (pools, runs and riffles), the habitat types lacked independence.

Some sections of the study canals were inaccessible for sampling and the habitat units within these regions were not electrofished. Although attempts were made to secure trespass rights on the property abutting study canals, some landowners did not permit access. Other canal sections were inaccessible due to physical constraints (i.e.- tunnels, siphons, depth, etc.). In regions that were inaccessible, sampling was stopped and then resumed immediately after this region. Inaccessible units were located in stratum three of the West Gallatin, Highline, Lowline and Moreland canals.

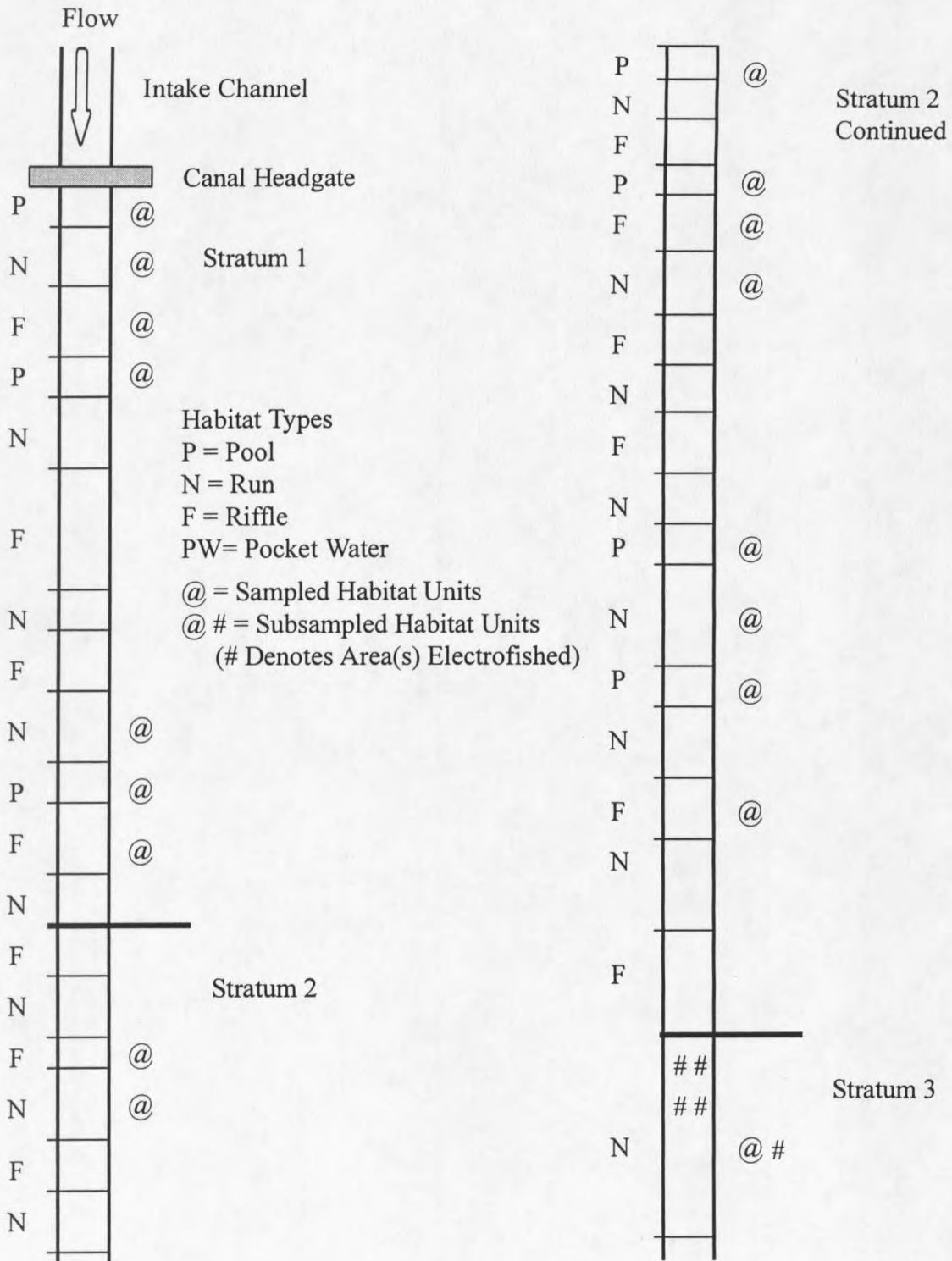


Figure 7. Diagram of an irrigation canal showing strata, habitat types and individual habitat units, and the sampled habitat units.

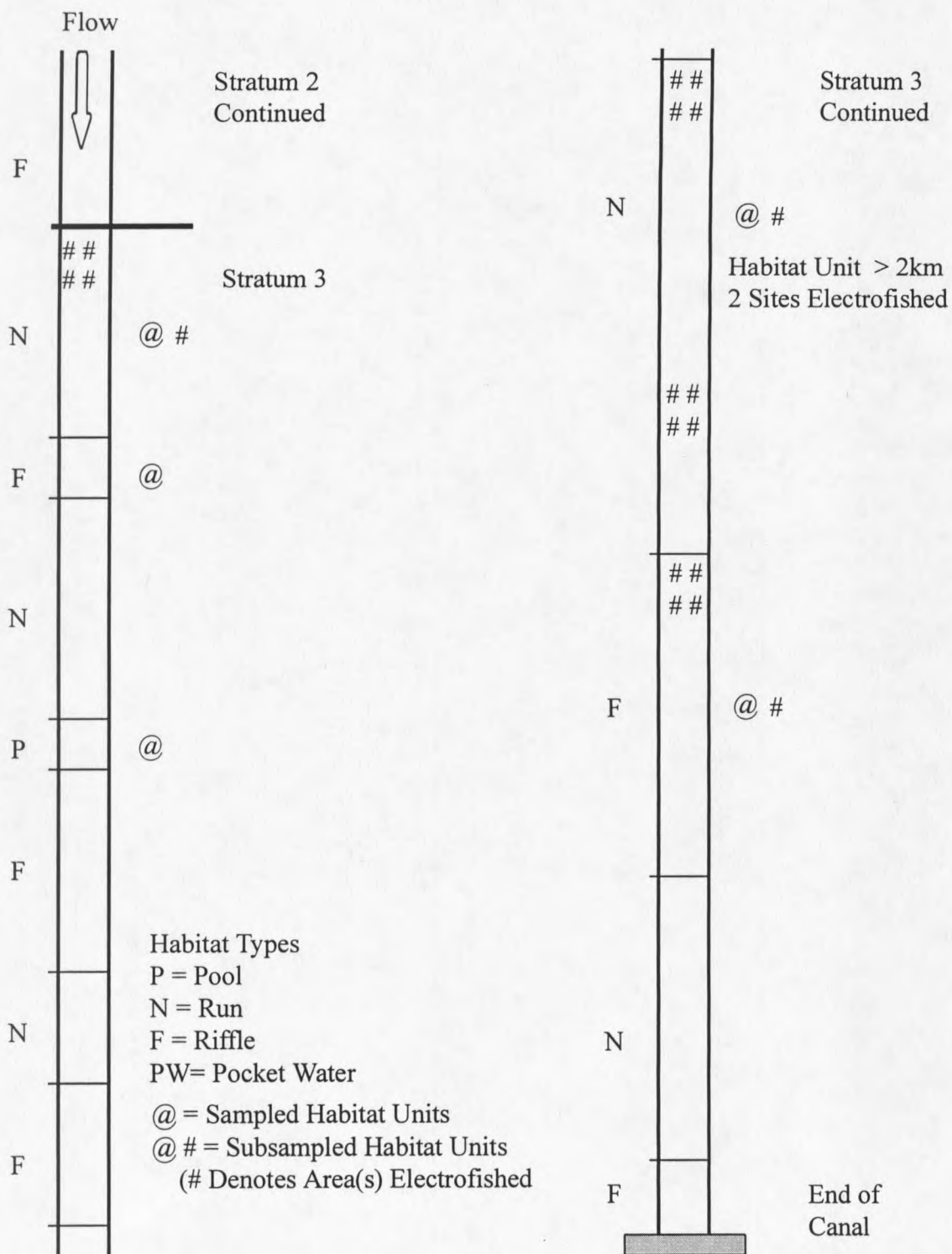


Figure 7. Continued.

Electrofishing reaches ranged from 5 - 250m in length depending on habitat unit length. Run and riffle habitat units exceeding 250m in length were subsampled. If the habitat units were between 251m and 2,000m, then a 250m electrofishing reach was sampled at the beginning of the habitat unit. If the unit exceeded 2 km then additional 250m-long electrofishing reaches were sampled every 2 - 4 km. These additional electrofishing reaches were placed where the canal could be accessed by vehicle.

Electrofishing continued until at least five consecutive habitat units were sampled without capturing a trout ≥ 150 mm. Any combination of habitat types or subsampled electrofishing reaches were used in obtaining the five reach limit. The remainder of the canal was assumed to have no trout ≥ 150 mm and was not used in calculating canal trout population abundances. In six canals, the five electrofishing reach limitation was attained and sampling was discontinued (Table 3).

Additional information collected during electrofishing included: set-up time, electrofishing time per pass, power settings, time between passes, time required to record fish data, time to measure each transect, break-down time, the number of netters and shockers, and any comments on electrofishing difficulties. This information was used to assess the advantages of additional electrofishing passes within a reach or electrofishing additional reaches in order to maximize the accuracy of population estimates.

Table 3. Number of reaches electrofished during the 1993-94 field season. The reach locations sampled in fall 1993 and spring 1994 were sampled again in fall 1994 enabling comparison between and within sampling seasons.

Canal	Sampling period		
	Fall 1993	Summer 1994	Fall 1994 ¹
West Gallatin	8	5	26*
Gilmore/Todd			12
Bush/Ethrington			13
Highline			12*
Lowline			24*
Keughan	5	5	19
Valley			36*
Lewis	8	8	34
Moreland			27*
White			20*

¹ - An asterisk "*" indicates canals in which at least five reaches were sampled without capturing any salmonids ≥ 150 mm. Sampling was discontinued and the population beyond that point was considered negligible.

Five equally spaced, cross-sectional transects were used to gather width/depth information for density estimates on each electrofishing reach. Five depth recordings were taken at each cross-sectional transect. No zero bank depth was recorded because of the U-shaped cross-section of the canals. Reach length and width information, was used to determine the electrofished area. Total lengths and surface areas were used in estimating trout densities.

Relating Fish Abundances to Canal Characteristics

I collected canal, headgate and adjacent river measurements to examine the relation between canal characteristics and population estimates. The canal headgate characteristics included headgate opening width and depth, construction materials and the method used to open or control the headgate. The headgate opening width and depth were recorded as the maximum possible capacity of each headgate. The construction materials were recorded as the primary material used to form the headgate and support the headgate opening mechanisms. As concrete headgates require more excavation, they usually had deeper and larger pools preceding the headgate than wood or metal headgates. The methods used to control flows on all of the study area canals were either lift type gates or wood slats (boards).

The habitat variables measured were cover, habitat type and substrate adjacent to the headgates and the river's habitat type at the mouth of the canal. Cover was

described as high, medium or low ($\geq 66\%$, $65\% - 33\%$ and $< 33\%$, respectively).

Cover was defined as any structure (wood, rock, metal, etc.) in the intake's bank full channel within 15m of the canal headgate. Depth was not considered cover. The modified Wentworth scale was used to visually estimate substrate sizes (Welch 1948). Habitat types were described as pool, run or riffle (Bisson et al. 1982; Dolloff et al. 1983). The amount of pool habitat in the canal's upper 1.6 km was recorded on canals examined in 1994.

Flow variables included decreed flow and flow ratio. Flow ratios were obtained using the following formula (Spindler 1955; Chow 1959; Evarts et al. 1991):

$$\text{Flow Ratio} = \frac{\text{ditch flow (cfs)}}{\text{river flow (cfs)}} \times 100.$$

This ratio gives the percentage of river discharge that is extracted by the diversion.

Flow ratios were calculated using the average West Gallatin River discharge for the irrigation season (1 May - 31 October) and the canal's decreed flow. It was not possible to obtain quantity of water withdrawn from all canals within the study area on a daily basis, and therefore decreed flow was used. Using the river's average discharge underestimates the flow ratio early in the irrigation season and overestimates it late in the season, and so the flow ratios were not an accurate measurement of the percentage of the river's flow withdrawn by a canal. No downstream adjustments were made to the average West Gallatin River flows to account for upstream irrigation withdrawals. The downstream adjustments would have been extremely complicated because seven

tributaries without USGS gauging stations enter the West Gallatin River within the study area boundaries.

There are problems associated with using decreed flow to represent a canal's withdrawal. First, decreed flows can underestimate a canal's actual flow early in the irrigation season. Consequently, canals with primarily senior water rights (e.g.- Lewis canal) would only be slightly underestimated by the decreed flow, while canals with primarily junior rights (e.g.- Highline canal) could be severely underestimated. Also prior to the water commissioner regulating water withdrawal, larger canals (e.g.- Highline, Lowline, etc.) can withdraw more water. Canals with large intake channels (West Gallatin, Lowline, etc.) can withdraw a larger proportion of the West Gallatin River's discharge, returning excess water to the river. However, decreed flow was considered the best estimate of canal flow given the lack of actual estimates of canal withdrawal.

Intake channel measurements included the intake's width at the canal's headgate, total length of intake and its angle in relation to the river's thalweg. If the canal did not have an intake channel, the intake's width and length were recorded as zero. The angle of the river relative to the intake's position was recorded by designating a 50m and 300m point at the river's bankfull discharge mark upstream and downstream of the canal's water withdrawal structure. A surveyors transit was used to calculate the river's angle from the downstream side of the intake channel or canal headgate.

The measured canal, headgate and adjacent river characteristics were compared to the 1994 canal trout abundances to determine if the measured variables had any effect on the numbers of trout in the canals. The variables that affected canal trout population abundances were used to develop a predictive model, which could be used in predicting fish loss.

Fish Response to Canal Drawdown Procedures

To assess the response of fish in canals to drawdown procedures at the end of the irrigation season, I examined staged (30%) and rapid (90%) canal closures. Staged reductions consisted of three equal reductions in canal flow for 7 d. The rapid canal closure consisted of a single reduction of approximately 90% of canal flow on day 1, followed by canal closure 24 - $\geq$ 48 h later. Staged drawdown were tested on the Lewis (1993) and Moreland (1994) canals, and rapid reduction procedure on the West Gallatin, Highline, Lowline, Valley and Lewis (1994) canals. The West Gallatin and Highline canals were shut off within 24 h of the initial rapid reduction of 90%, while > 48 h lapsed before the Lowline, Valley and Lewis canals were completely closed. The irrigators and the water commissioner controlled which drawdown procedure could be tested on each canal, thus the drawdown method for a given canal was not random.

Trout movement information was obtained from each test canal by electrofishing strata one and two and recording the locations of tagged salmonids

before and after drawdowns. The distances between points of marking and recapture were used to determine movement (Ireland 1993). Recovery operations also verified the population estimates conducted during the canal population abundance estimates.

West Gallatin River Trout Population Estimates

To compare trout population demographics of irrigation canals to the West Gallatin River, I used electrofishing data collected by Montana Department of Fish, Wildlife and Parks (MDFWP) in 1990. I used these 1990 trout population estimates and length/weight data for comparisons to my 1994 canal trout data. Although MDFWP had anticipated sampling the West Gallatin River in 1994, the sampling was omitted due to time constraints. Therefore, despite the fact that the West Gallatin River's trout population densities, age structure or condition factors may have changed from 1990 to 1994, the 1990 estimates were the best data available.

The MDFWP estimates were conducted at two locations. The upper site was located at the Williams Bridge river access, and the lower site was located at the Shedd's Bridge river access (elevations - 1,539m and 1,427m, respectively) (Figure 2, Appendix B). The Williams Bridge sampling site was 1.9km (1.21 miles) long and the Shedd's Bridge site, 1.7km (1.09 miles) long. The MDFWP population estimates were conducted in the spring and fall at both sites in the main channel and on all major side channels. Electrofishing was conducted using a mobile electrode system from an

electrofishing drift boat. The mark-recapture procedure used one or two recapture runs, depending on efficiency.

Data Analysis

Only trout $\geq 150\text{mm}$ were used to develop and test models except for the canal drawdown procedures, where all tagged salmonids $\geq 150\text{mm}$ (trout and whitefish) were used. In all statistical analyses, a P-value ≤ 0.05 was considered statistically significant, unless noted otherwise. Normality tests were conducted with Shapiro-Wilk test of normality (Zar 1984; Daniel 1990). The model assumptions of homoscedasticity were tested using a Cochran test for homogeneity of variances ($\alpha = 0.10$) (Zar 1984).

Statistical Analysis Systems (SAS) and Statistica computer programs were used to perform statistical computations and graph the data (SAS Institute 1987; StatSoft 1994). Power and beta analyses were conducted with Statistical Power Analysis (Borenstein and Cohen 1988).

Fish Loss Estimates - Trapping

Trapping was used to provide an estimate of the number of fish entering the canals and an understanding of when most fish entered the canals by recording the number of captured in each trap on a daily basis. A recovery of $\geq 80\%$ of the hatchery trout was required for trap efficiency data, which provided an estimate of the number of

fish that could bypass or escape the traps. Trout had the opportunity to enter the canals prior to trap installation, and therefore electrofishing was used to verify trapping estimates, determine if fish had entered the canals prior to trap placement and evaluate changes in electrofishing densities over time.

Fish Loss Estimates - Electrofishing

The electrofishing reach trout population estimates were obtained using the generalized removal estimator in program CAPTURE (Otis et al. 1978; White et al. 1982). Program CAPTURE assumes that at least 20 fish are captured for each electrofishing reach when using the generalized removal estimator (Otis et al. 1978; White et al. 1982). Separation of age-classes and species avoids related heterogeneity which could alter capture probabilities (White et al. 1982; Riley and Fausch 1992), yet due to the small numbers of trout captured in most of the irrigation canal electrofishing reaches, separating estimates by species or age-classes could not be accomplished. All species of trout $\geq 150\text{mm}$ were combined in the reach population estimates. Program CAPTURE calculated standard errors for the trout population estimates.

Electrofishing reach densities were determined by dividing each reach's trout population estimate by its total length and surface area. Estimates were averaged (weighted by area) for each habitat type within each stratum. The average densities were then extrapolated over the amount of habitat type per stratum to estimate the numbers of trout in each stratum. The trout abundances within each stratum were

summed to estimate the total canal trout population abundances (Dolloff et al. 1993). Standard errors were also weighted by area and were calculated for the trout population estimates per habitat type, strata and each canal's total trout abundance.

Fish Loss Estimates - Population and Habitat Comparisons

The canal trout abundances were calculated with and without using habitat units assumed to have no trout (those units following the continuous reaches without capturing a trout), because the effects of not averaging trout densities for the additional habitat units could significantly alter abundance estimates. Comparing these population estimates with a Wilcoxon matched pairs test determined whether or not elimination of the habitat units significantly altered the trout population abundance estimates (Zar 1984; Daniel 1990).

Habitat lengths that were remeasured after population sampling were compared to previous measurements with a Wilcoxon matched pairs test (Zar 1984; Daniel 1990). No remeasured habitat types needed to be reclassified as a different habitat type. This procedure evaluated the effects of flow fluctuations on habitat availability.

Differences in trout population densities by habitat type and differences in trout population densities between strata were evaluated using a Kruskal-Wallis test (Zar 1984; Daniel 1990). These tests evaluated the relationship between habitat and trout abundances. If canal habitat influences trout abundances then altering the physical shape of a canal could reduce the numbers of trout in a canal.

A Wilcoxon matched pairs test was used to address the changes in trout population densities between summer and fall sampling (Zar 1984; Daniel 1990). Examination of the trapping information contributed to estimating when the fish entered the canals. Evaluating the changes in the electrofishing trout population densities both within and between years yielded information pertaining to variability that has been reported in canal trout abundances.

Relating Fish Abundances to Canal Characteristics

To assess canal, intake channel and river parameters that could be affecting the number of trout entering the irrigation canals, I conducted an exploratory analysis by regressing those variables (predictor variable) with the canal trout abundances (response variable). Significant slopes ($P\text{-value} \leq 0.10$) were used to determine if the measured physical parameter influenced the number of trout in the canals.

Physical characteristics of the canals and their headgates, habitat parameters and intake characteristics (predictor variables) were used to develop a model to predict the canal trout abundances (response variable) in the unsampled West Gallatin River canals. Categorical variables were analyzed using a Mann-Whitney U test or Kruskal-Wallis test depending on the number of variables (Zar 1984; Daniel 1990). Variables were considered further if a $P\text{-value} \leq 0.20$. This method of variable reduction does not account for potential variable interactions.

The remaining predictor variables (physical characteristics of canals) were plotted with the response variable (trout population abundances), and assumptions were tested. Predictor variables that did not meet test assumptions (homoscedasticity and normality of residuals) or were not linear were transformed to attempt to satisfy these requirements. The original and transformed variables were evaluated for collinearity using a correlation matrix. Collinearly related variables were removed from the multiple regression analysis by testing their correlation with the response variable. The variables with the highest correlation were retained (Kleinbaum et al. 1988).

A best subsets multiple regression was used to build a predictive model. Mallow's C_p was used to select the model (Kleinbaum et al. 1988; Manly 1995; Rencher 1995). The multivariate model was regressed and variables with nonsignificant slopes were removed (P -values ≥ 0.10) (Kleinbaum et al. 1988). Model assumptions and outliers (Cook's distance) were tested. No outliers were removed unless biological reasoning could be provided. The multivariate model was tested for predictive bias using a delete-one jackknife procedure (Wu 1986).

Fish Response to Canal Drawdowns

The number of trout originally tagged in a reach were compared to the number of recaptured trout that were tagged down canal during the salvage operations using a chi-squared goodness-of-fit test (fish movements) (Daniel 1990). It was assumed that the tagged fish did not relocate and that there were no significant differences in

mortality between the tagged fish and the untagged fish. Tags returned by anglers on the West Gallatin River were used to determine fish passage through the headgates. If the numbers of fish stranded in the canal at the end of the irrigation season could be significantly reduced, it would lessen the effects of fish loss to canals on the West Gallatin River trout fishery.

Comparing River and Canal Trout Population Demographics

Length frequency histograms were constructed for brown and rainbow trout populations in the West Gallatin River and for each canal. The canals were also subdivided by their proximity to the MDFWP sampling sites (Williams Bridge and Shedd's Bridge). The study canals associated with the Williams Bridge sampling location were the West Gallatin, Gilmore/Todd, Bush/Ethrington and Highline canals. These canals are within the West Gallatin River's B channel type region. The study canals associated with the Shedd's Bridge sampling location (braided D channel) were the Lowline, Keughan, Valley, Lewis, Moreland and White canals. All comparisons were made using the fall West Gallatin River population data.

Length - weight regressions were constructed for brown and rainbow trout in the West Gallatin River and the study canals associated with the Williams Bridge and Shedd's Bridge sampling locations. An analysis of covariance was used to evaluate the differences between the regressions' slopes and intercepts (Zar 1984). Cone (1989)

recommends this procedure over comparing population condition factors to avoid interactions masking potentially different population conditions.

Characteristics of the trout populations in the canals and the West Gallatin River were examined to determine if the canals were "capturing" a representative segment of the river's population. Each trout population's median length and length frequency distributions were compared using a Mann-Whitney U test (median location) and a Wald-Wolfowitz runs test (distribution) (Zar 1984; Daniel 1990). Although some of the populations were normally distributed, nonparametric analyses were employed.

West Gallatin River Population Estimates

West Gallatin River trout population were estimated by MDFWP using the modified Peterson estimator in the computer program Mark/Recapture Version 4.0 - A Software Package for Fishery Population Estimates (MDFWP 1994). No standard errors were provided for their data. Population estimates were not separated by species or age classes. Reach densities for the Williams Bridge and Shedd's Bridge sampling sites were calculated by dividing the trout population estimate of each reach by its total length and surface area. The West Gallatin River densities were calculated for trout $\geq$ 203mm (8 inches).

RESULTS

Trapping and electrofishing provided data on the numbers of trout lost to irrigation canals, when fish entered the canals, and how trout densities changed over time. In 1993, I trapped seven canals and electrofished 21 reaches in three canals. In 1994, I electrofished 10 canals. A total of 223 reaches was electrofished over the 2 years of the study.

Fish Loss Estimates

Trapping

The traps captured 135 trout entering the canals and 126 trout leaving the canals during the irrigation season (Table 4). Six whitefish were trapped entering the canals and 26 whitefish were captured leaving the canals. Of the trout leaving, 69% were trapped in two canals (Noble and Lewis) during the canal-closure procedures. No tagged trout were captured leaving the canals. The low numbers of trout captured entering the canals and the lack of tagged trout exiting the canals indicated either that trout entered the canals prior to trap installation, or that trap efficiency was poor.

Trap efficiency tests were conducted in the West Gallatin canal, where 63% (38) of the hatchery rainbow trout were captured by the trap while moving downcanal

Table 4. Trapping and electrofishing data for West Gallatin River irrigation canals sampled in 1993. The number trapped, population estimates and densities are based on salmonids $\geq 150\text{mm}$.

Canal	Number of trout trapped ¹		Electrofishing population estimates		
	Entering	Leaving	Density ²	Estimate ³	Standard Error
West Gallatin	59	11	0.063	16	0.45
Bush/Ethrington	4	5	---	---	---
Gilmore/Todd	10	5	---	---	---
Noble	21	25	---	---	---
Lower Middle Creek	17	17	---	---	---
Keughan	10	1	0.167	34	0.83
Lewis	14	62	0.355	157	3.20

¹ - "Entering" refers to salmonids captured during down-canal movement and "leaving" refers to salmonids captured during up-canal movement. The salmonids recorded as "leaving" may not have passed through the canal headgate.

² - Salmonid densities were recorded in fish/m.

³ - Salmonid population estimates were calculated by summing the sampled pool reaches.

and only 5% (3) were unaccounted for after the 16 d test period. No fish were found below the trap and only one fish escaped the trap. In the Lewis canal, 73% (44) were captured by the trap and 3% (2) were recovered below the trap. No fish escaped the Lewis canal trap and only 3% (2) were not recovered at the time of removal. The efficiency of the traps in terms of capturing the hatchery rainbow trout provides evidence that fish were not bypassing the traps, and most fish entered the canals prior to trap installation in 1993.

Electrofishing - 1993

In 1993, I collected a total of 207 trout $\geq 150\text{mm}$ in the West Gallatin, Keughan and Lewis canals. I estimated a total abundance of 2,808 trout in the upper 4.8 km of these canals (West Gallatin = 302, Keughan = 802 and Lewis = 1,704) (Table 4). The large numbers of trout estimated to be in the upper 4.8 km of these canals could have been influenced by the fact that only pools were electrofished, and the higher pool densities were extrapolated over the remainder of the unsampled canal area. The 1993 trout population estimates revealed that fish had entered the canals prior to the trap installation and that there were large numbers of trout in the electrofished canals. The canals are closed during the winter and it is unlikely that salmonids could have overwintered.

Although the traps were efficient at capturing trout, the number of trout trapped comprised a small fraction of the percentage of trout estimated to be in the upper 4.8

km of the canals. The West Gallatin canal trap captured 19.5% of its total trout abundance with the Keughan trap capturing 1.3% and the Lewis 0.8% (overall 3.0%). The high trap efficiency and small percentage of the total trout abundance captured in the traps supports the assumption that most fish entered the canals prior to trap installation.

Electrofishing - 1994

The estimated canal trout abundances ranged from < 1 in the Gilmore/Todd canal to 1,905 in the Lewis canal (Tables 5 and 6). The average canal trout abundance was 505 (SD 698). The West Gallatin and Lewis canals had almost three times the number of trout than in the next highest canal (Moreland). If the estimated populations had not been truncated by the zero fish reaches, the West Gallatin, Highline, Lowline, Valley, Lewis and Moreland canal estimates would have increased by 154, 553, 275, 124, 165 and 306 fish, respectively. However, no significant difference was found when comparing the truncated trout abundances to the unadjusted population abundances (Wilcoxon matched pairs, P -value = 0.028). The variability in trout abundances between canals indicates that using the average abundance would not be appropriate to estimate canal populations, and therefore all canals would need to be sampled to predict their trout abundances.

The pool population densities ranged from 0 - 2.081 fish/m, with runs ranging

Table 5. Population estimates by section and habitat type for the sampled irrigation canals on the West Gallatin River, in 1994. The densities and population estimates are based on salmonids ≥ 150 mm.

Canal	Section	Habitat type	Trout densities		Population estimates	Standard errors
			Fish/m	Fish/m ²		
West Gallatin	1	Pools	0.122	0.017	7	0.27
		Runs	0.070	0.010	109	0.45
	2	Pools	0.136	0.018	7	0.48
		Runs	0.084	0.012	266	0.68
	3	Pools	2.081	0.313	119	0.08
		Runs	0.048	0.009	1,138	1.00
		Riffles	0.128	0.021	9	0.10
Gilmore/Todd	1	Pools	0.017	0.007	0	<0.01
		Runs	0	0	0	<0.01
		Riffles	0	0	0	<0.01
	2	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01
		Riffles	0	0	0	<0.01
Bush/Ethrington	1	Pools	0.254	0.078	8	<0.01
		Runs	0.006	0.014	18	0.56
		Riffles	0	0	0	<0.01
	2	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01
		Riffles	0	0	0	<0.01

Table 5. Continued.

Canal	Section	Habitat type	Trout densities		Population estimates	Standard errors
			Fish/m	Fish/m ²		
Highline	1	Pools	0.037	0.004	3	<0.01
		Runs	0.016	0.003	25	<0.01
	2	Pools	0.138	0.020	2	<0.01
		Runs	0.012	0.002	38	<0.01
	3	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01
Lowline	1	Pools	0.053	0.009	1	<0.01
		Runs	0.053	0.007	81	0.44
		Riffles	0.027	0.008	2	<0.01
	2	Runs	0.025	0.004	79	0.39
		Riffles	0	0	0	<0.01
	3	Pools	0.046	0.006	7	<0.01
		Runs	0.009	0.002	171	<0.01
	Kueghan	Pools	0.121	0.018	3	0.54
		Runs	0.026	0.005	38	0.10
		Riffles	0.325	0.050	41	<0.01
	2	Pools	0.202	0.033	26	<0.01
		Runs	0.013	0.003	38	0.33
		Riffles	0.077	0.014	4	0.33
	3	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01

Table 5. Continued.

Canal	Section	Habitat type	Trout densities		Population estimates	Standard errors
			Fish/m	Fish/m ²		
Valley	1	Pools	0.575	0.117	53	0.10
		Runs	0.129	0.028	87	<0.01
		Riffles	0.044	0.009	37	0.60
	2	Pools	0.389	0.062	7	0.48
		Runs	0.035	0.007	69	<0.01
		Riffles	0.031	0.007	38	<0.01
	3	Pools	0	0	0	<0.01
		Runs	0.008	0.002	49	<0.01
		Riffles	0	0	0	<0.01
Lewis	1	Pools	0.823	0.115	63	2.07
		Runs	0.351	0.057	278	0.69
		Riffles	0.187	0.027	139	0.18
	2	Pools	0.498	0.080	130	1.29
		Runs	0.385	0.062	149	0.99
		Riffles	0.168	0.027	417	0.85
		Pocket Water	0.472	0.076	44	1.88
	3	Pools	0.305	0.073	17	<0.01
		Runs	0.035	0.016	4	<0.01
		Riffles	0.087	0.025	664	0.56

Table 5. Continued.

Canal	Section	Habitat type	Trout densities		Population estimates	Standard errors
			Fish/m	Fish/m ²		
Moreland	1	Pools	0.983	0.144	52	0.99
		Runs	0.382	0.053	265	0.50
		Riffles	0.025	0.004	22	0.17
	2	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01
		Riffles	0.018	0.003	23	0.50
	3	Pools	0	0	0	<0.01
		Runs	0.024	0.005	225	0.12
		Riffles	0	0	0	<0.01
White	1	Pools	0.134	0.023	8	<0.01
		Runs	0.040	0.010	14	<0.01
		Riffles	0.011	0.003	14	<0.01
	2	Pools	0	0	0	<0.01
		Runs	0	0	0	<0.01
		Riffles	0	0	0	<0.01
	3	Runs	0	0	0	<0.01

Table 6. Population estimates for irrigation canals on the West Gallatin River, Montana. The salmonid densities and population estimates are based on the 1994 electrofishing data and were calculated using salmonids $\geq 150\text{mm}$.

Canal	Section	Trout densities		Population estimates	Standard errors
		Fish/m	Fish/m ²		
West Gallatin	1	0.072	0.011	116	0.52
	2	0.085	0.012	273	0.83
	3	0.052	0.009	1,266	1.00
	totals	0.057	0.009	1,654	1.40
Gilmore/Todd	1	<0.001	<0.001	<1	<0.01
	2	0	0	0	<0.01
	totals	<0.001	<0.001	<1	<0.01
Bush/Ethrington	1	0.016	0.007	26	0.56
	2	0	0	0	<0.01
	totals	0.007	0.003	26	0.56
Highline	1	0.017	0.003	28	<0.01
	2	0.013	0.002	40	<0.01
	3	0	0	0	<0.01
	totals	<0.001	<0.001	68	<0.01
Lowline	1	0.052	0.007	84	0.44
	2	0.025	0.004	79	0.39
	3	0.009	0.002	178	<0.01
	totals	0.011	0.002	341	0.59
Keughan	1	0.051	0.010	82	0.55
	2	0.021	0.005	68	0.49
	3	0	0	0	<0.01
	totals	0.009	0.002	150	0.74
Valley	1	0.110	0.024	177	0.60
	2	0.035	0.007	114	0.48
	3	0.008	0.002	49	<0.01
	totals	0.021	0.005	280	0.77

Table 6. Continued.

Canal	Section	Salmonid densities		Population estimates	Standard errors
		Fish/m	Fish/m ²		
Lewis	1	0.298	0.046	480	2.17
	2	0.230	0.037	740	2.62
	3	0.107	0.025	685	0.56
	totals	0.162	0.030	1,905	3.45
Moreland	1	0.211	0.032	339	1.12
	2	0.007	0.001	23	0.50
	3	0.022	0.005	225	0.12
	totals	0.031	0.006	587	1.23
White	1	0.022	0.005	36	<0.01
	2	0	0	0	<0.01
	3	0	0	0	<0.01
	totals	0.002	0.001	36	<0.01
Gallatin River ¹					
Williams Bridge	Spring	1.263	0.023	1,263/km	*
	Fall	2.196	0.039	2,196/km	*
Shedds Bridge	Spring	1.141	0.021	1,141/km	*
	Fall	1.616	0.029	1,616/km	*

¹ - West Gallatin River estimates were collected by MDFWP in 1990. The section refers to the sampling period and population estimates were recorded in fish/km. These estimates were for brown and rainbow trout only.

* - An asterisk "*" indicates that the standard errors for the population estimates were unavailable.

from 0 - 0.385 fish/m, and riffles from 0 - 0.325 fish/m (Table 5). However, no significant differences were found between canals when densities were compared by habitat type (pools P-value = 0.178; runs P-value = 0.117; and riffles P-value = 0.905). The highest densities were recorded in stratum 2 of the West Gallatin canal and stratum 3 of the Moreland canal. The variability between population estimates can be attributed to the electrofishing reach variability and the percent of available habitat units in that stratum.

Although it appeared that trout densities decreased as distance increased from the headgate on most canals, significant differences between decreasing strata population densities and increasing distances from the headgate were only detected in the Moreland and White canals (Kruskal-Wallis, P-values < 0.025) (Appendix C). The combined Moreland canal trout densities and trout densities in riffles showed an inverse relationship between densities and distance from the headgate. The White canal pool habitat followed this same pattern. The West Gallatin and Lewis canals had significant differences within habitat types (pools and runs, respectively) but densities did not decrease downcanal.

Electrofishing reaches surrounding the tributaries that cross the West Gallatin canal contained primarily brook trout, elevating the average trout densities in runs (0.084 fish/m in stratum 2 and 0.048 fish/m in stratum 3). These increased densities, coupled with the length of run habitat available (23,708 m in stratum 3), influenced the pattern of trout abundance in the West Gallatin canal's trout abundance estimate (266

fish in stratum 2 and 1,138 fish in stratum 3). Large numbers of brook trout were also sampled in the electrofishing reaches near the springs on the Moreland canal. The Lewis canal also has tributaries entering the canal, but no elevated trout densities were found in the surrounding electrofishing reaches. Tributaries and springs entering the canals may have increased their estimated trout abundances, but these fish can still be considered lost recruitment to the West Gallatin River.

The repetitive examining of electrofishing reaches enabled comparing population densities (fish/m) between and within sampling years. Although the same electrofishing reaches were sampled between and within years, density estimates were used for standardization. No significant differences were found between the 1993 and 1994 sampling densities (P -values > 0.26 , Betas > 0.92), indicating that there may be physical factors of a canal which influence the numbers of fish in that canal (Table 7). The lack of differences between years also supports the assumption that canal populations do not fluctuate between years even though the canals do not support overwintering trout populations and these populations are renewed each irrigation season. Also, no significant differences were found between the spring and fall sampling periods (P -values > 0.12 , Betas > 0.83). The consistent population densities between sampling periods suggests that fish were entering the canals prior to the spring sampling, during the peak West Gallatin River and canal flows.

Table 7. Summary statistics for the Wilcoxon matched pairs test comparing population densities between the 1993 and 1994 field season and spring (1994) to fall (1994) sampling periods.

Canal	Sampling periods (Medians) ²	Sample ¹ size	P - value (Beta)
West Gallatin	8/93 vs. 8/94	8	0.31050
	(0.08 vs. 0.05)		(0.94)
	6/94 vs. 8/94	5	0.46521
	(0.04 vs. 0.05)		(0.95)
Keughan	7/93 vs. 9/94	5	0.68583
	(0.13 vs. 0.12)		(0.93)
	6/94 vs. 9/94	5	0.50019
	(0.11 vs. 0.12)		(0.93)
Lewis	7/93 vs. 9/94	8	0.26263
	(0.35 vs. 0.35)		(0.92)
	6/94 vs. 9/94	8	0.12350
	(0.57 vs. 0.51)		(0.83)

¹ - The sample size represents the number of reaches sampled for each sampling period. The exact sampling sites were replicated for each period.

² - The medians used for analyses were densities recorded in fish/m.

Runs were the dominant habitat type in all canals (>84%), except the Lewis canal (>85% riffles), which also had the largest percentage of pool habitat (3.1%) (Table 8). Pools comprised only 0.2 - 1.1% of the habitat in the other canals. When separated by stratum, runs and riffles were still the principal habitat type, with more pools in stratum one. Pools tended to decrease downcanal as the canal diminished in size. Although four canals follow old stream channels, their habitat complexity does not resemble that of a natural stream.

Trout in the West Gallatin, Bush/Ethrington, Highline, Lowline, Keughan, Valley, Moreland and White canals were primarily located in runs (Table 9). Sixty three percent of the Lewis canal's trout population occupied riffles which comprised 85% of the available habitat. The Keughan and White canals also had notable proportions of their populations in riffle habitats (30% and 39%, respectively). Only one salmonid ≥ 150 mm was captured in the Gilmore/Todd canal, and it was recovered from a pool habitat unit.

Although 20-90 d elapsed between the time of habitat measuring and population sampling, no significant differences were recorded in habitat changes (P -values > 0.35) (Table 10). If habitat types or lengths had changed over this period, then the changes in habitat could have affected the numbers of trout in a canal.

Table 8. Percentage of each habitat type per section in the electrofished canals during the 1994 field season.

Canal ¹	Total ² Length (m)	% Habitat - Section 1 ³			% Habitat - Section 2			% Habitat - Section 3		
		Pool	Run	Riffle	Pool	Run	Riffle	Pool	Run	Riffle
WGC	31,949	3.5	96.5	0	1.6	98.4	0	0.2	99.5	0.3
G/T	2,859	1.2	86.8	12.0	0.5	95.4	4.1	---	---	---
B/E	4,009	1.9	83.5	14.6	0.3	98.2	1.5	---	---	---
HL	50,835	4.2	95.8	0	0.5	99.5	0	0.1	99.9	0
LL	56,591	1.6	95.0	3.4	0	99.2	0.8	0.3	99.7	0
KC	16,827	1.6	90.7	8.7	3.9	94.3	1.8	0.2	99.8	0
VC	19,314	5.7	42.1	52.2	0.6	61.7	37.7	0.2	98.7	1.1
LC ⁴	12,754	4.7	49.2	46.1	8.1	12.1	76.9	0.7	3.1	96.2
MC	28,655	3.3	43.2	53.5	1.1	58.6	40.3	0.7	91.9	7.4
WC	20,681	3.7	22.2	74.1	2.0	37.6	60.4	0	100.0	0
Mean (SD)	24,447 (18,020.4)	3.1 (1.5)	70.5 (28.1)	26.8 (27.5)	1.9 (2.5)	75.5 (31.4)	22.4 (29.1)	0.3 (0.3)	86.6 (33.8)	13.1 (33.6)

Table 8. Continued.

Canal ¹	Total ² Length (m)	% Habitat - Total ³		
		Pool	Run	Riffle
WGC	31,949	0.5	99.3	0.2
G/T	2,859	0.9	90.6	8.5
B/E	4,009	0.9	92.3	6.8
HL	50,835	0.2	99.8	0
LL	56,591	0.3	99.6	0.1
KC	16,827	1.1	97.8	1.1
VC	19,314	0.7	87.8	11.5
LC ⁴	12,754	3.1	11.1	85.0
MC	28,655	0.9	85.4	13.7
WC	20,681	0.6	84.2	15.2
Mean (SD)	24,447 (18,020.4)	0.9 (0.89)	84.8 (26.6)	14.2 (25.6)

¹ - Abbreviations for each canal:

WGC - West Gallatin Canal, G/T - Gilmore/Todd, B/E - Bush/Ethrington, HL - Highline Canal, LL - Lowline Canal, KC - Keughan Canal, VC - Valley Canal, LC - Lewis Canal, MC - Moreland Canal, WC - White Canal.

² - Total length was extrapolated from 7.5 minute series topographical maps using a planimeter.

³ - Percent habitat type was calculated from measuring two habitat types and extrapolating the length of the third habitat type between known points on the topographical maps.

⁴ - Pocket water comprised 2.9% of section two's habitat, therefore percentages will not sum to 100%.

Table 9. Percent population in each habitat type based on salmonids ≥ 150 mm using the truncated canal population abundance estimates in 1994.

Canal	Total ³ Population	% Population per habitat type ¹		
		Pools	Runs	Riffles
West Gallatin	1,654	8.0	91.5	0.5
Gilmore/Todd	0	100.0	0.0	0.0
Bush/Ethrington	26	30.8	69.2	0.0
Highline	68	7.4	92.6	0.0
Lowline	341	2.4	97.1	0.5
Keughan	150	19.3	50.7	30.0
Valley	280	21.4	73.2	5.4
Lewis ²	1,905	11.0	22.6	63.0
Moreland	587	8.9	83.5	7.6
White	36	22.2	38.9	38.9
Mean	505	23.1	61.9	14.6
(SD)	(698)	(28.4)	(32.9)	(22.0)

¹ - The Lewis Canal had 3.4% of its total population in pocketwater habitat, which comprised 2.9% of section two's habitat.

² - The total population is the estimated trout abundance estimates.

Table 10. Summary statistics for the Wilcoxon matched pairs test comparing changes in habitat lengths within a canal between the time of measuring and the time of population sampling with an elapsed time of 20-90 d.

Canal	Sampling periods	Medians ¹	Sample ² size	P - values
West Gallatin	6/94	28.0	8	0.83394
	8/94	29.5		
Bush/Ethrington	6/94	41.0	18	0.86577
	7/94	39.5		
Valley	6/94	40.5	22	0.78741
	7/94	41.0		
Lewis	6/94	31.0	33	0.71500
	9/94	31.0		
Moreland	6/94	40.0	16	0.34524
	8/94	44.5		

¹ - The median lengths of the paired habitat units within each canal were compared for changes in lengths between sampling periods.

² - The sample size represents the number of habitat units measured in strata one and two for each sampling period. The exact sampling sites were replicated for each period.

Relating Fish Abundance to Canal Characteristics

Physical Factors Influencing Trout Loss and Model Development

The river's habitat type at the point of intake (pool, run, or riffle) was the only categorical variable found to have a significant influence on canal trout population abundance (Kruskal-Wallis, P-value = 0.00621). No significant differences in canal trout abundances were found when comparing the physical parameters of headgate material, structure or manipulation; the type of habitat at the headgate; or the intake's stream channel position (main or secondary) (Mann-Whitney, P-values > 0.25) (Appendix D). No significant differences were documented between trout populations when comparing substrate size classes or the amount of cover at the canal headgate or intake (Kruskal-Wallis, P-values > 0.24). Higher trout abundances were found in the canals that diverted water from pools on the West Gallatin River. Altering the habitat at a canal headgate could reduce a canal's trout abundance. The Mann-Whitney or Kruskal-Wallis tests do not consider potential variable interactions, but these methods were used to examine variable effects on canal trout abundances and as a preliminary means of reducing the number of model variables used in the multiple regression. A combination of one or more variables may create an environmental condition that could affect canal trout abundances.

Canal trout abundances were only correlated with the predictor variable headgate area ($R^2 = 0.44$, P-value = 0.037); all other predictor variables had



nonsignificant slopes ($P\text{-values} > 0.15$) (Appendix E). Although their slopes were not significant ($P\text{-value} \geq 0.10$), the 50m angle in relation to the river's thalweg, the amount of cover at the headgate, the river habitat type at the point of diversion, and the intake channel's length may have also influenced the number of trout in the canals ($P\text{-values } 0.25 > x_i > 0.15$). Thus, larger canals have the potential of capturing more fish, but if a large canal is located on the outside of a river bend with a short intake channel and its point of diversion is located in a pool with cover, this canal could pose a greater threat to fish loss.

The following transformations were applied to linearize the variables for the analyzing the variables influence on canal trout abundances and for the multiple regression model development: width, depth, decreed flow, flow ratio and intake length were square root transformed ($\sqrt{x_i}$); 50m and 300m river angles and intake width were transformed using an inverse relationship ($1/x_i$); and headgate area was exponentially transformed (e^{x_i}) (Appendix F). In developing the best subsets multiple regression model for predicting canal fish abundances based on canal physical characteristics, the Mallow's C_p stabilized in the four variable model region. The transformed predictor variables selected for further analysis were: area, decreed flow, 50m river angle, and intake length.

Predicting Canal Fish Abundances Based On Canal Characteristics

A three variable model was developed to predict trout abundances in the unstudied canals. An insignificant slope, in the final modeling procedure, eliminated decreed flow from the regression (P-value = 0.87301). The final regression model included the transformed area, 50m river angle, and intake length ($R^2 = 0.87$, P-value = 0.00483). All of the slopes for the predictor variables were significant (P-values = 0.00292 for area, 0.01153 for river angle, and 0.07001 for intake length). The model met all assumptions and was employed to predict populations in the unstudied canals. The equation used for predictions was:

$$\text{Canal populations} = -2429.7 + 0.7246(e^{\text{area}}) + 0.5405(1/50\text{m angle}) - 0.3287(\text{sqrt (intake length)}).$$

The model variables describe canal size (area), the canal's angle in relation to the river's thalweg (50m angle) and an inverse relationship between trout numbers and the distance from the headgate. The 50m angle quantifies the canal's position in relation to the river's flow. A canal located on the outside of a river bend would capture more fish than a canal on a straight section or on the inside of a river bend. Larger canals, located on the outside of river bends with short or no intake channels, capture more fish.

A Cook's distance test for outliers indicated that the West Gallatin (2.93) and Lewis (2.25) canals were beyond the Cook's limit set at one. Although the West Gallatin and Lewis canals were outliers, they were not removed from the analysis for canal selection and sampling procedures did not provide any biological reason for their

removal. Also, removal of the outliers did not increase the predictive capability of the model.

The delete-one jackknife bias estimation procedure yields an unbiased estimator of a model's predictive capability (Wu 1986; Schreuder et al. 1987), and therefore it was used to evaluate the model. This method calculated a predictive $R^2 = 0.25$ (P-value > 0.80). These values indicate that the regression model "overfit" the data and that future predictions using this model may be biased. The low number of canals sampled and the large number of canal physical parameters measured may have affected the model's bias and its predictive capabilities.

Comparisons of actual trout population abundances and predicted abundances also indicated model bias (Table 11). The model predicted that the study area irrigation canals would have a total combined population of 140,353 salmonids, and that the Gilmore/Todd canal would have 400 salmonids. However, electrofishing 12 reaches of the Gilmore/Todd canal only recovered one salmonid. The predicted trout population estimates for the Bush/Ethringen, Highline, Lowline, Valley and White canals were >3.7 times higher than their estimated trout abundances (14.5, 7.0, 4.6, 3.7 and 20.9 times higher, respectively). The West Gallatin, Lewis and Moreland canals contained at least 75% of the predicted trout abundance, with the Lewis canal being the only underestimate (84.9%, 121.8% and 75.6%, respectively). The large errors in prediction and small correlation coefficient from the jackknife model make it unreasonable to use this model to assess the total number of trout in the irrigation canals.

Table 11. Estimated populations via electrofishing for trout in the irrigation canals (trout $\geq 150\text{mm}$) and the West Gallatin River (trout $\geq 203\text{mm}$) and predicted trout populations based on the canal model (trout $\geq 150\text{mm}$). Bolded canals had headgate area variables above the range of data collected on the studied canals.

Canal	Electrofishing ¹ estimate	Prediction ² estimate
West Gallatin	1,654	1,948
Gilmore/Todd	0	400
Bush/Ethrington	26	376
Cockrill	---	217
Williams Bridge ^{3,5}	2,196/km	---
Highline	68	476
Noble	---	675
Farmers	---	83,758
Allison - Lewis	---	662
Lowline	341	1,587
Keughan	150	358
Lower Middle Creek	---	811
Beck & Border	---	143
Shedds Bridge ^{3,5}	1,616/km	---
Spain & Ferris	---	38,312
Mammoth	---	502
Ketterer	---	729
Valley	280	1,041
Bopp M ^c Callough	---	561
Hoffman - Weaver	---	608
Stone - Weaver	---	597
Lewis	1,905	1,564
Durham	---	1,166
Bell - Dunlap	---	1,166
Hoffman	---	1,166
Moreland	587	776
White	36	755

Table 11. Continued.

Canal	Electrofishing ¹ estimate	Prediction ² estimate
Totals ⁴		
Canal Predictions (with bolded outlier canals)	---	140,353
Canal Predictions (without bolded outlier canals)	---	18,283
West Gallatin River Study Area ⁵	34,132	---

¹ - Electrofishing estimates for canals were based on the 1994 data and Williams Bridge and Shedd's Bridge estimates were based on MDFWP 1990 estimates. Canals without estimates were not sampled.

² - Prediction estimates are calculated from the regression model:

$$\text{Canal populations} = -2,429.7 + 0.7246(e^{\text{area}}) + 0.5405(1/50\text{m angle}) - 0.3287(\text{sqrt (intake length)})$$

³ - Williams Bridge and Shedd's Bridge were MDFWP, Gallatin River sampling sites.

⁴ - The total West Gallatin River population was calculated by extrapolating the densities over their representative reaches of the study area. Canal prediction total was calculated by summing the prediction estimates for the canals.

⁵ - MDFWP West Gallatin River estimates are based on trout $\geq 203\text{mm}$ and the canal estimates on trout $\geq 150\text{mm}$.

Several other factors may have influenced the total canal prediction estimate (140,353 trout $\geq 150\text{mm}$), causing it to be a four-fold increase over the number of fish expected to be in the West Gallatin River study area (34,132 trout $\geq 203\text{mm}$). First, several canals had variables (canal characteristics) outside the range of collected predictor variables on the studied canals (Appendix F). The Farmers and Spain & Ferris canals had headgate areas larger than the range of examined headgate areas (range $2.69\text{m}^2 - 7.02\text{m}^2$) with both of these canals having headgate openings $>10.0\text{m}^2$. All other canals had headgate areas either within or below the range.

Second, headgate area was exponentially transformed($e^{x^{(i)}}$) increasing the predicted trout populations in the Farmers and Spain & Ferris canals (83,758 and 38,312, respectively) (Table 11). These two canals account for 87% of the predicted trout populations (140,353 with these canals and 18,283 without these canals). Making predictions with a bias model on canals with variables outside the range of collected data can yield unusable canal trout abundances, especially with the exponentially transformed headgate area.

Third, are the differences in size categories used to estimate trout abundance in canals (trout $\geq 150\text{mm}$) versus the West Gallatin River (trout $\geq 203\text{mm}$) (Appendix G). Trout 150mm - 203mm comprised 45.9% of the total number of trout captured ($\geq 150\text{mm}$) while electrofishing the canals. Consequently, 54.9% of the trout captured in the canals were of a comparable size category to the West Gallatin River trout estimates. The number of West Gallatin River trout captured by MDFWP during the

1990 sampling was inadequate to produce an estimate for trout 150mm - 203mm.

Based on these problems, it would be unreliable to use this model to ascertain the overall affect of irrigation canals on the West Gallatin River trout population.

Fish Response to Canal Drawdowns

Tag Returns

A total of 1,835 trout were tagged over the 2 year study period with 1,768 trout being tagged for the movement study and 888 trout recaptured during the canal drawdown procedures (Table 12). Salmonid movement studies were conducted in two canals in 1993, and in six canals in 1994. The number of tags recovered during movement studies were lowest in the Highline canal (22.2% tags recovered) and highest in the Moreland canal (69.3% tags recovered), with an average tag return of 43.3%. Most of the marked fish were age 1+ brown trout. Thirty-two tagged trout (1.7% of total number tagged) were captured by anglers in the West Gallatin River indicating that fish can escape the canals. The longest recorded distance traveled by a recaptured salmonid in the West Gallatin River was 20.2 km (12.6 miles) (range 0.3 km - 20.2 km, median 2.2 km), with 75% of the these trout traveling ≤ 4 km in the West Gallatin River before being recaptured by anglers. During the 1993 field season, 460 trout were tagged and 83 of those fish were recaptured while electrofishing canals in 1994. The Lewis canal contained 68.7% (57) of the recaptured trout in the canals,

possibly due to the staged drawdown conducted on this canal in 1993. The canal recaptures not only support that fish can escape the canals, but that fish can use the canals as refuges during the irrigation season, returning to the main river to overwinter.

Fish Movement

Rapid drawdown regimes (90%; > 2 d) in the Lewis (1994), Lowline and Valley canals had a significant effect on fish movement upcanal (P-values < 0.005) (Table 13). The West Gallatin and Keughan canal's rapid drawdown regimes (90%; < 1 d) also had significant effects on salmonid repositioning (P-values < 0.020), but the Highline canal's drawdown regime (90%; < 1 d) was ineffective at enticing salmonids to migrate upcanal the distances required to depict significance (P-value > 0.130). No significant differences were found in the staged drawdown procedures (30%, multiple-day) implemented in the Lewis (1993) and Moreland canals (P-values > 0.550 and > 0.070, respectively). A more dramatic reduction was required to entice long distance movements. Although significant upcanal movement was reported in the West Gallatin, Lowline, Keughan, Valley and Lewis (1994) canals, no estimates of the number of fish actually escaping the canals were made. Using a rapid drawdown regime with sufficient escape time may reduce the numbers of trout stranded in canals at the end of the irrigation season.

Table 12. The numbers of salmonids ≥ 150 mm marked with anchor tags in 1993 and 1994 to evaluate fish movement within, and escapement from, the canals.

Canal	Year	Numbers of marked fish	Numbers recaptured ¹		
			Gallatin River	Canals	Salvage
West Gallatin	93	17	1	0	--
	94	216	2	6	57
Gilmore/Todd	94	1	0	0	--
Bush/Ethrington	94	4	0	0	--
Highline	94	9	0	0	2
Lowline	94	46	2	0	17
Keughan	93	27	0	0	--
	94	32	0	2	15
Valley	94	102	0	6	41
Lewis	93	416	14	8	193
	94	833	10	57	484
Moreland	94	114	3	4	79
White	94	18	0	0	--
Totals		1,835	32	83	888

¹ - The number of fish recaptured refers to:

Gallatin River - tag returns reported by anglers on a voluntary basis;

Canal - salmonids that were tagged in 1993 and recaptured in 1994; and

Salvage - tag returns used to test the drawdown procedures.

Table 13. Chi-squared goodness-of-fit analysis summary statistics evaluating the upcanal trout movements by following tagged trout based on different canal drawdown regimes in 1993 and 1994.

Canal	Year	Drawndown regime		Sample size (N)	χ^2	P-Values
		%	Duration			
West Gallatin	94	90	< 1 d	6	15.092	< 0.010
Highline	94	90	< 1 d	5	7.200	> 0.130
Lowline	94	90	> 2 d	5	16.703	< 0.005
Keughan	94	90	< 1 d	4	10.254	< 0.020
Valley	94	90	> 2 d	6	38.070	< 0.001
Lewis	93	30	multiple	7	4.628	> 0.550
	94	90	> 2 d	16	291.378	< 0.001
Moreland	94	30	multiple	5	8.809	> 0.070

Ninety-two percent of the tagged fish in the rapid drawdown regimes were recaptured upcanal of their original marking location, comparatively to only 47% in the staged drawdowns. The Lowline canal had 117 salmonids within 10m of the headgate, of which 6 were tagged downcanal (5%), and the Lewis canal (1994) had 102 salmonids within 10m of the headgate, of which 29 were tagged downcanal (28%). In the staged drawdown canals, the Lewis canal (1993) had 136 salmonids within 10m of the headgate, of which 10 were tagged downcanal (7%), and the Moreland canal had 157 salmonids within 10m of the headgate, of which 14 were tagged downcanal (9%). Of the tagged trout recovered at the headgate in the Moreland canal salvage, 77% were tagged in that location. The known maximum distance traveled by a tagged salmonid was 5.3 km (Valley canal), with the median distance traveled < 1.3 km. It is unknown if the tagged fish repositioned between the time of marking and recapture or if a longer upcanal distance was traveled by an unrecovered tagged fish.

Comparing River and Canal Trout Population Demographics

Significant differences were found between the length - weight regressions for both trout species (P-Values < 0.001) in the Williams Bridge region canals when comparing the trout population of the West Gallatin River indicating that canal trout were in better condition than fish in that reach of river (Appendix H). Trout in the Shedd's Bridge region canals were in worse condition than those in that region of the

West Gallatin River (P-Values < 0.001). This is opposite of the results in the Williams Bridge region canals. All transformed West Gallatin River regressions yielded an $R^2 \geq 0.97$ with the canal regressions $R^2 \geq 0.92$.

The significant differences in the Wald-Wolfowitz distribution analyses when comparing the West Gallatin River and individual canal trout population distributions indicated that in canals with > 17 trout the canal trout populations contained more smaller fish than the river (Appendix I and Appendix J). Sample size is a limitation of the Wald-Wolfowitz runs test and the Mann-Whitney U test (Daniel 1990). Both tests found no significant differences at the smaller sample sizes. The canal trout populations had significantly smaller median lengths and contained a larger proportion of smaller fish when categorizing canal populations into Williams and Shedd's bridge area canals and comparing them to the West Gallatin River trout population. Of the trout captured while electrofishing canals, 45.9% were ≤ 203 mm. The canals also captured more brown trout (57.5%) than rainbow trout (19.1%) even though the West Gallatin River's trout population is dominated by rainbow trout (63.7% - 1990 fall sampling) (Appendix G). The canal trout population demographics did not reflect those of the West Gallatin River in 1990. Conclusions concerning the comparisons of the river and canal trout population demographics are limited by the assumption that the West Gallatin River trout population did not change between 1990 and 1994.

DISCUSSION

Although resident fisheries are an asset to tourism in Montana, agriculture is Montana's principal commodity market (Montana Agricultural Statistics Service 1994). The unity of these markets is essential to Montana's economy and heritage, and therefore cooperation between these industries is necessary. Since 39% of Montana's croplands are irrigated, the burden on its waterways is substantial (Montana Agricultural Statistics Service 1994). Large population variability has been documented in resident fish abundances in canals (Clothier 1953a, 1954; Spindler 1955; Thurow 1980; Evarts et al. 1991). No quantitative assessments have been conducted on time of entry and no predictive capabilities have been made concerning factors influencing fish entry.

Fish Loss Estimates

Although 5,047 trout $\geq 150\text{mm}$ were estimated to be lost to the studied irrigation canals in 1994, this loss is probably not significant to the West Gallatin River fishery. Irrigation withdrawal from the West Gallatin River has occurred since 1865 (Howard 1992), and despite irrigation demands, the West Gallatin River is still considered one of Montana's premier trout fisheries. The West Gallatin River fall

A

population estimate for the Williams Bridge sampling site was 2,196 trout/km and 1,616 trout/km for the Shedd's Bridge site, totaling 34,132 trout $\geq$ 203mm within the study area boundaries (1990 estimate). Not accounting for the size class differences (canals = trout $\geq$ 150mm and rivers = trout $\geq$ 203mm), the studied irrigation canals only captured 14.8% of the West Gallatin River trout population. Forty-six percent of the canal trout population was between 150mm - 203mm, while only 5% or 23% (spring and fall samplings, respectively) of the West Gallatin River trout were within this size range. The increased proportion of trout 150mm - 203mm in the river's fall sampling can be attributed to recruitment of the age 1 rainbow trout and their susceptibility to electrofishing gear. If the West Gallatin River was recruitment limited, then the number of small trout entering canals could prohibit the river from reaching its full fisheries potential. With the threat of whirling disease, additional information should be obtained to determine the limiting factors on the West Gallatin River trout population.

The large differences in canal trout abundances in this and previous studies (Clothier 1953a, 1954; Spindler 1955; Thurow 1980; Evarts et al. 1991) indicates that only a few canals may need to be screened to reduce fish losses. Clothier (1953a) studied 11 canals on the West Gallatin River and found 69% of his estimated canal trout abundance to be in three canals (canal abundance range 16 - 851 trout). Two of my study canals contained 71% of the total canal trout abundance (West Gallatin and Lewis canals). Canals with characteristics similar to the West Gallatin and Lewis



canals should be examined to determine their effect on the fishery (large amount of flow diverted, large headgate, point of diversion at a pool with cover, and/or headgate located on the outside of a meander bend). Prioritizing canals posing the greatest threat to a river's population could reduce costs associated with management activities.

Tributaries entering the West Gallatin canal, as well as springs in the Moreland canal, could have influenced trout abundances. The number of brook trout captured in electrofishing reaches surrounding tributaries in the West Gallatin canal and springs in the Moreland canal comprised 76% of the total number of brook trout captured in all canals. The trout abundances gathered in 1993 by sampling only pools did not incorporate the elevated densities observed in the 1994 electrofishing reaches surrounding the tributaries and springs. Separating the tributary or spring fish from the West Gallatin River fish was not possible, but future canal estimates should evaluate the influence of sampling in these regions.

Although only two canals showed a significant inverse relationship between trout densities and distance from the headgate, this could have been due to the unequal lengths of each stratum (stratum 1 = 1.6 km, stratum 2 ranging from 2.8 to 3.2 km, stratum 3 ranging from 0 to 56.6 km). If the actual distance from the headgate for each electrofishing reach had been recorded and densities not grouped by stratum, the observed decreasing trend in trout densities may have been significant. If significant, developing a regression model to predict reach densities based on the downcanal

distance from the headgate could identify elevated trout densities as unusual data points or outliers enabling them to be eliminated from future analyses.

The 1993 trapping, trap efficiency, and population estimates suggest that trout entered canals prior to trap installation. The trout populations did not change significantly between the 1994 spring and fall sampling periods, supporting movement into canals prior to spring population sampling. Fish appear to be entering the canals during peak West Gallatin River flows, which coincides with peak canal flows. Previous studies have not evaluated when fish enter canals and may have assumed entrance throughout the irrigation season. Assessing the time of entry is necessary because fish protection devices must be designed for the maximum flows they will encounter (Sullivan and Mattice 1986).

Canals may be providing lower velocity microhabitat regions during the West Gallatin River peak flows. Fluctuating flows can alter cover and current velocity which are important variables affecting habitat use by salmonid species (Fausch and White 1981; Fausch 1983; Gatz et al. 1987; Heggenes 1988a and 1988b; Marcus et al. 1990), and these factors may affect fish movement into canals. Extreme fluctuations in cover and velocity variables can affect stream positions selected by salmonids (Heggenes 1988b; Nehring and Anderson 1993), which could explain downstream displacement of salmonids by peak flows (Elwood and Waters 1969; Seegrist and Gard 1972; Hanson and Waters 1974). Downstream displacement of salmonids associated with abrupt increases in stream discharges (Seegrist and Gard 1972; Cowx and Gould 1985 and

1989; Niemela 1989), is inversely related to fish size (Heggenes and Traaen 1988; Bell 1991). My study indicated that trout entered the canals during the West Gallatin River peak flows, a period when trout, especially smaller ones, are being displaced downstream. Clapp et al. (1990) reported that average stream discharge accounted for 68% of their model's variability in explaining downstream movement by adult brown trout. Allen (1951, in Seegrist and Gard 1972) examined a New Zealand stream following a flood and discovered a 25% decrease in all age classes of brown trout. As velocities increase within the base-flow channel, salmonids can be forced to abandon the deeper channel areas in favor of more suitable habitats in shallower regions (Niemela 1989). The West Gallatin River experiences flow fluctuations, typical of unimpeded watersheds (Figures 3, 4 and 5). Modifications in habitat conditions from fluctuating flows (e.g.- increased velocities) may cause shifts in trout habitat use, and therefore contribute to the time salmonids enter irrigation canals. If salmonids are seeking shelter in the canals during peak flows, then any fish protection devices would need to be designed for, and operable during, peak flows.

Relating Fish Abundance to Canal Characteristics

Physical Factors Influencing Trout Loss

My results indicate canal size, intake length, habitat complexity and headgate location in relation to river meander curvature may have influenced trout abundances in

canals. Canal size variables should include point of diversion velocity, maximum flow and width and depth of the headgate opening at maximum flow. Spindler (1955) did not find headgate width, depth, velocity or habitat to have a significant effect on the canal trout abundances, but flow (cfs) was positively correlated and headgate location was negatively correlated with trout abundance. Headgate velocity is probably correlated with habitat at the point of diversion, and velocity can be extrapolated from the flow and area variables. Headgate velocity may provide a better method to assess the effects of the habitat type at the point of diversion. Intake channel characteristics should encompass intake length, the headgate location in relation to river's angle at the point of diversion and intake flow, which may be a more useful estimation of canal size. The Lowline and West Gallatin canals' intake channels convey more water than can be transported. Although there are bypass channels, intake channel discharge could affect canal population abundances. Spindler's study (1955) and my results found that canals with headgates located on the outside of river bends had a better chance of capturing fish than canals with the opposite scenario. The river thalweg is located closest to shore on the outside of a meander, and as fish are displaced downstream they follow the thalweg pattern (Seegrist and Gard 1972; Niemela 1989).

My results also suggest that most fish entered the canals during the peak West Gallatin River flows. The amount and duration of the river's peak flow captured by an open canal could affect a canal's trout population abundance, and therefore river and canal flow variables should be recorded during peak flows. These variables may

provide additional information as to the factors that affect time of entry, enabling additional management options. Although easily stated, this incorporates problems associated with water volume, debris, and visibility. Clothier (1953a, 1954) also experienced difficulties capturing fish due to high flows when he attempted to estimate the number of fish in canals. Trout estimation procedures were ineffective until after the peak West Gallatin River flows had subsided and canals had been restricted to their appropriated water levels. The Highline canal's decreed water right is $4.82 \text{ m}^3/\text{s}$ (170 cfs) (Appendix B). Clothier (1953a) and Spindler (1955) estimated this canal to be carrying two times its decreed flow prior to being restricted by the river's prior appropriation levels.

Predicting Canal Fish Abundance Based On Canal Characteristics

Headgate area, intake length and headgate location in relation to the river meander (50m angle) were used in a model to estimate trout population abundances in the unstudied canals. Spindler (1995) found canal size and headgate location affected canal trout abundances. In my study, headgate area was correlated with canal size and the effect of headgate location was quantified with the 50m angle. Clothier (1953a) found most fish in the upper 1.6 km of the canal, but he did not distinguish an intake channel, which has a bypass channel to the river, from the actual canal, which has no return flows. Although intake length was found to be negatively correlated with trout abundance in my predictive model, most of my study canals did not display a

significant decrease in trout densities as distance increased from the canal headgates.

An intake channel, with a means of returning flow to the river, may imitate a river's side channel acting as a refuge from the river's increased velocities during peak flows.

Intake channels may influence the number of trout in a canal by initially providing refuge from the river flows and then by offering two avenues of escape (up- or downstream).

The jackknife prediction error implied that the model developed to predict trout abundances in unstudied canals would be bias. The model "overfit" the data, thus each data point was found to be driving the model results, common with over-parameterized models. The model may have drastically over-predicted the number of salmonids in two canals, accounting for approximately 87% of the trout predicted to be in the study area canals. These two canals have headgate openings above the range of examined headgates, resulting in large predicted trout populations ($e^{\text{headgate area}(i)}$). With these two canals removed, the predicted canal trout population would be 18,283 fish. The jackknife prediction error and the unstudied canal observations outside the range of studied canal parameters renders the model inadequate for estimating total trout loss to canals in the West Gallatin River study area.

Also, the inconsistent size categories used for estimating populations between the canals and river may have affected the ability to use the predictive model for evaluating the effects of total trout loss on the West Gallatin River fishery. Clothier (1953 and 1954) and Spindler (1955) examined trout $\geq 178\text{mm}$, MDFWP calculated

the West Gallatin River population estimates using trout $\geq 203\text{mm}$ (all size classes of trout captured were recorded), and my study used trout $\geq 150\text{mm}$ in analyses. Gear selectivity could have reduced MDFWP capture efficiencies on smaller trout which occupy shallower stream margins (Reynolds 1996). The low number of marked and recaptured trout 150mm - 203mm in the river did not enable a size class estimate. Since it is easier to reduce electrofishing gear bias in small systems, the canal removal estimates should have been consistent with the size categories used on the river.

Finally, to alleviate the problems of small sample size in the model, less intensive population estimates could provide adequate information and enable sampling more canals. If canal trout population abundances could be estimated by developing a predictive model based on population densities relative to distances from the headgate, then habitat units would need to be linearly recorded downcanal with distance from the headgate measured. The estimated trout abundances would still need to be correlated with the variables of interest.

Fish Response to Canal Drawdowns

Rapid drawdown regimes significantly affected upstream salmonid movement in all canals, except the Highline. Salmonids have been reported to move upstream during flow reductions, following periods of larger discharge (Banks 1969; Seergist and Gard 1972; Cowx and Gould 1985). Elevated light and temperatures have been



found to repress upstream movement (Banks 1969; Sullivan and Mattice 1986; Bell 1991; Bradford et al. 1995), and therefore movement may not occur until dark.

Clothier (1954) found that fish redistributed to areas of cover (brush, trees, undercut banks and pools) during canal drawdowns. The small sample size (9 tagged salmonids), lack of sufficient time for movement, and homogeneous habitat (99.8% runs) may have influenced statistical detection of movement in the Highline canal.

Without ample time for movement, runs may create long stretches of unprotected migration, leaving fish stranded at the closest cover. The West Gallatin and Keughan canals drawdown duration of < 1 d resulted in fewer fish moving upcanal compared to the > 2 d duration drawdowns (Lowline, Valley and Lewis 1994). Bradford et al. (1995) found fewer stranded fish using slow rates of downramping and when reductions occurred at night or over several nights. The < 1 d drawdown regimes may not enable sufficient nighttime flows for migrating the distances needed to escape the canals. Enticing fish to move out of a canal or concentrating them for efficient removal could reduce the numbers of fish lost to a canal.

Incorporating tagging mortality and/or tag loss into the fish movement data in the < 1 d duration may render these short duration periods insignificant. Tag loss and tagging related mortality was not estimated. Mourning et al. (1994) reported a 32% mortality and 11% tag loss in anchor tagged rainbow trout. These authors reported that 28% of the surviving fish had tag induced injuries rated as "moderate to severe." The

insufficient migration time and effects of tag loss and related mortality support using a rapid flow reduction with a > 2 d duration for enticing salmonid movement.

The staged drawdowns I tested had no significant effect on salmonid movement (Lewis 1993 and Moreland canals). Clothier (1953b) recommends using a staged drawdown to reduce the numbers of fish lost to a canal, although he only compared staged drawdowns (33%, 3 d closure) to complete canal closure as a control (100%, < 1 d closure). Irrigators, on the Big Hole River, Montana, reported fewer fish being stranded in irrigation canals using staged drawdowns (Shepard 1990). No estimates of the number of fish escaping the canals were obtained by Clothier (1954) or Shepard (1990). In my study staged reductions may not have enticed fish to move the large distances required to depict significance. In the Moreland canal, springs may have affected movement. Springs, tributaries and habitat refuges may have reduced the need for the long distance migrations required to exit the canals. In my study's staged flow reductions, fish repositioned in the nearest pool becoming trapped when the water gradually receded. A more dramatic reduction was required to entice significant long distance movements.

I did not evaluate the ability of fish to escape the canals at low flows. Low discharge and high temperature have been found to inhibit salmonid movement at barriers (Banks 1969; Winstone et al. 1985; Sullivan and Mattice 1986; Bell 1991). Sufficient discharge and suitable environmental conditions may be needed to entice fish to move through the headgates, otherwise fish will congregate in canal pools. Although

this would benefit salvage operations, most recoveries are not economically feasible.

The drawdown regimes produced useful information for initiating studies on the behavioral aspects of flow-induced movement. Future studies should incorporate escapement to ensure sufficient numbers of fish are bypassing the canal headgates, and the evaluation of legal problems associated with water rights and drawdown regimes. The river's population should be evaluated to determine if the numbers of fish lost to the canals are compensatory or additive sources of mortality to the system. Preventing fish from entering the canals may be a better alternative.

If the West Gallatin River is not recruitment limited, then my study suggests that screening West Gallatin River irrigation canals is not warranted at this time. Fish screens tested on the Keughan and Lowline canals (1950 - 1952) were ineffective, partially due to debris build-up (Clothier 1953a, 1954; Spindler 1955). Present screen designs are competent at preventing juvenile and adult fish from entering diversion structures (Neitzel et al. 1986, 1988, 1990a, 1990b; Abernathy et al. 1989, 1990). Rotary drum screens are the most effective at preventing fish entrance and are capable of passing debris (Schill 1984; Sullivan and Mattice 1986; Bell 1991), but they are expensive to install and maintain. Screen design and operational costs are inversely related to fish size (Sullivan and Mattice 1986). If the West Gallatin River is not recruitment limited, then fish protection devices could be designed for age 1+ and older fish to reduce costs. Although many states use screening programs, this practice is not currently considered economically feasible for most resident fish populations. In



drainages containing species of special concern, threatened and/or endangered species the cost/benefit ratios may be justifiable.

Comparing River and Canal Trout Population Demographics

Trout in Williams Bridge area canals were in better condition and those in the Shedd's Bridge area canals were in poorer condition than the river population in 1990. Condition factors have been used to evaluate differences in environmental factors between study regions (Fay and Pardue 1986; Cada et al. 1987; Bolger and Connolly 1989). The physical conditions in the study canals, either dry or frozen solid during the winter, cannot support overwintering fish or invertebrate populations. Although invertebrates rapidly recolonize new environments (e.g.- a newly opened canal), it is unknown if these new environments can provide better growing conditions than an established system (Allen 1983; Lamberti 1991; Mackay 1992).

Although the canal fish in the Shedd's Bridge region were in poorer condition, it is unknown if canals provide a comparable growing environment to the river. Based on their sampling of invertebrate drift and salmonid densities, Cada et al. (1987) found growth to be limited by an inadequate food supply. Invertebrate sampling procedures have been found to provide biased results (Allen 1983; Needham 1934; Needham and Usinger 1956), and food is not considered to be limiting for trout in lotic systems (McFadden 1969; Shiozawa 1983), although it may influence growth in density

dependent situations. Canal densities are comparable to the West Gallatin River densities, and therefore density should not be a factor in growth unless the food is limited. It is possible that the canals were not capturing a representative segment of the river's trout population.

Canal trout populations were dominated by smaller fish ($\leq$ age two), as evidenced by comparing river population histograms to canal histograms. Larger trout occupy deeper regions of a stream with more cover than do younger individuals (Heggenes 1988a and 1988b; Clapp et al. 1990). Velocities used by trout are inversely related to size (Bell 1991), and smaller fish typically inhabit the shallower stream margins (Heggenes 1988b; Schlosser 1987; Baltz et al. 1991), potentially increasing their probability of being displaced by peak flows causing them to seek shelter in irrigation canals.

Although my results suggest that canal and river trout populations were different, these findings are based on the assumption that the West Gallatin River's population demographics did not change over the 4-year interval between canal and river sampling periods. Positive associations between current velocities and downstream displacement of salmonid fry have been shown in numerous studies (Ottaway and Clarke 1981; Ottaway and Forrest 1983; Heggenes and Traaen 1988; Abernathy et al. 1989, 1990; Bell 1991; etc.). Entire year classes of YOY salmonids can be lost through supercritical flows during egg through fry life stages (Seegrist and Gard 1972; Cowx and Gould 1985; Niemela 1989; Nehring and Anderson 1993). As

size increases, this displacement declines (Heggenes and Traaen 1988; Bell 1991), although adult salmonids have been displaced via unusually rapid or large flow increases (Elwood and Waters 1969; Allen 1951, in Seegrist and Gard 1972; Seegrist and Gard 1972; Hanson and Waters 1974; Clapp et al. 1990). Trout condition factors and population length distributions can be affected by a multitude of environmental variables, as well as the time of sampling. Considering the large discrepancies between West Gallatin River and canal trout populations and the lack of patterns in the data, it would be reasonable to assume the river's population characteristics and/or distributions changed over this period.

Management Implications

Effective management strategies, such as efforts to reduce the number of fish entering canals, may reduce fish loss to canals. In my study, canal size was positively correlated, and intake length negatively correlated, with canal trout abundance. Canals located on the outside of river bends also attracted more fish. Fish were found to have entered the canals during the peak West Gallatin River discharge, possibly trying to escape the increased river velocities. Cover or pools at canal headgates may provide fish with velocity shelters, increasing the probability of fish entering canals. Constructing flow-back channels on canals with sufficient trout populations, and therefore creating an intake channel, may reduce a canal's trout abundance. This would



require locating the headgate and Parshall flumes below the intake region. Altering the intake's point of diversion in relation to the angle of the river would not be feasible, because changing a point of diversion requires an extensive legal process. It is also impractical to alter the size of the canals. Eliminating cover and velocity shelters through habitat manipulating at the point of diversion could reduce fish densities at these headgates, potentially decreasing a canal's trout abundance. Also, working with irrigators to modify the time of canal openings could prevent some fish from entering canals during peak flows which could be the most cost effective measure in reducing losses.

Enticing fish that have entered canals to migrate back to the river may be another cost effective method of reducing the number of fish stranded at the end of an irrigation season. My results indicate that a rapid drawdown regime (90% canal closure) with sufficient nighttime flows for fish movement for a minimum of 2 d induced trout movement towards the headgate. Although I did not estimate the number of trout escaping the canals, my results could be used for subsequent studies examining movement patterns affected by flow reductions. Examining the effects of habitat on flow induced movement also needs to be studied. Habitat may hinder movement by providing either too much cover (large number of pools) or not enough cover (long shallow runs). Habitat could be easily altered by a ditch maintenance crew. Although drawdown regimes may concentrate fish for recovery operations, these salvages are labor intensive and expensive. Ultimately, the variable of interest should be the

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number of fish leaving a canal at the end of an irrigation season. Any management strategies implemented should significantly reduce the number of fish stranded.

Future studies should be designed to better identify factors influencing canal trout abundances, the effects of the river peak flows on trout abundances, and methods to entice fish to leave the canals in order to develop effective management strategies to reduce trout loss to canals. Concentrating efforts on large canals located on the outside of river bends with short or no intake channels could reduce managers costs of arriving at solutions that will be acceptable to the landowners and an agency.



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APPENDICES

APPENDIX A
MONTANA CODE

Table 14. Montana state legislature's code on the screening of irrigation canals.
Reprinted from: Fish and Wildlife. 1993. Montana code annotated. Title 87, Point 1,
Section 222. Page 772.

87-1-222. Construction and maintenance of fish hatcheries and fish ladders.

(1). The department shall furnish plans for, direct, and compel the construction, installation, and repair of fish ladders upon dams and other obstructions in streams. The fish ladders shall be installed and maintained at the expense of the owners of the dam or other obstruction.

(2). The department may purchase and maintain, at the expense of the fish and game fund, suitable fish screens, fish wheels, or other devices to install in irrigating ditches to prevent fish entering said ditches.

(3). The department may locate, lay out, construct, and maintain nurseries and rearing ponds where fry can be planted, propagated, and reared to be distributed in waters of the state. The department may spend from fish and game funds sums necessary for this purpose.

History: En. 26-104.5 by Sec. 6, Ch. 511, L. 1973; and Sec. 13, Ch. 417, L. 1977; R.C.M. 1947, 26-104.5.

Cross References: Propagation and distribution of fry or fingerlings, 87-3-201 and 87-3-202.

APPENDIX B
WEST GALLATIN RIVER
IRRIGATION CANALS

Table 15. The decreed flow, elevation and headgate location for all the canals within the study area on the West Gallatin River, Montana.

Canal ¹	Decreed flow ²		Headgate location	Elevation		Topographical maps ³
	(m ³ /s)	(cfs)		(m)	(ft)	
Upper Study Site Boundary	--	--	T4S R4E S5 SW¼	1570	5150	Ruby Mtn.
West Gallatin	4.28	151	T4S R4E S5 SW¼	1570	5150	Ruby Mtn.
Gilmore/Todd	0.43	15	T4S R4E S4 NW¼	1554	5100	Gallatin Gateway
Bush/Ethrington	0.37	13	T3S R4E S33 NE¼	1545	5070	Gallatin Gateway
Cockrill	0.17	6	T4S R4E S33 NE¼	1542	5060	Gallatin Gateway
Williams Bridge	--	--	T4S R4E S33 NE¼	1539	5050	Gallatin Gateway
Highline	4.82	170	T3S R4E S28 NE¼	1536	5040	Gallatin Gateway
Noble	0.65	23	T3S R4E S22 NW¼	1521	4990	Gallatin Gateway
Farmers	7.93	280	T3S R4E S11NW¼	1494	4900	Gallatin Gateway
Allison Lewis	0.51	18	T3S R4E S2 NW¼	1484	4870	Gallatin Gateway
Lowline	4.82	170	T2S R4E S23 NW¼	1448	4750	Bozeman Hot Springs
Kueghan	2.52	89	T2S R4E S23 NW¼	1445	4750	Bozeman Hot Springs
Lower Middle Creek	2.21	78	T2S R4E S23 NW¼	1445	4750	Bozeman Hot Springs
Beck & Border	1.42	50	T2S R4E S14 SE¼	1442	4730	Bozeman Hot Springs
Shedds Bridge	--	--	T2S R4E S10 SE¼	1427	4680	Bozeman Hot Springs
Spain & Ferris	3.00	106	T2S R4E S11 NW¼	1423	4670	Bozeman Hot Springs
Mammoth	2.10	74	T2S R4E S2 SW¼	1417	4650	Bozeman Hot Springs
Ketterer	2.98	105	T2S R4E S2 SW¼	1417	4650	Bozeman Hot Springs
Valley	2.13	75	T2S R4E S3 NE¼	1412	4635	Bozeman Hot Springs

Table 15. Continued

Canal ¹	Decreed flow ²		Headgate location	Elevation		Topographical maps ³
	(m ³ /s)	(cfs)		(m)	(ft)	
Bopp M ^c Callough	0.34	12	T2S R4E S2 SW¼	1414	4640	Bozeman Hot Springs
Hoffman - Weaver	1.73	61	T1S R4E S34 NW¼	1399	4590	Bozeman Hot Springs
Stone - Weaver	0.85	30	T1S R4E S34 NW¼	1399	4590	Bozeman Hot Springs
Lewis	2.15	76	T1S R4E S27 SW¼	1390	4560	Bozeman Hot Springs
Durham	0.28	10	T1S R4E S22 SW¼	1380	4530	Bozeman Hot Springs
Bell Dunlap	0.51	18	T1S R4E S22 SW¼	1380	4530	Bozeman Hot Springs
Hoffman	0.45	16	T1S R4E S22 NW¼	1380	4530	Bozeman Hot Springs
Moreland	3.45	122	T1S R4E S15 SW¼	1370	4495	Bozeman Hot Springs
White	1.42	50	T1S R4E S16 NE¼	1364	4475	Belgrade
Lower Study Site Boundary	--	--	T1S R4E S33 SW¼	1350	4430	Belgrade

¹ - Williams Bridge and Shedd's Bridge are the Montana Department of Fish, Wildlife and Parks 1990 sampling locations on the West Gallatin River.

² - Decreed flow was based on the West Gallatin River water commissioner's tables for the parshall flumes of each canal. Water rights with an appropriation date prior to January 1, 1900 were used in calculating decreed flows.

³ - The topographical maps are 7.5 series maps printed by the U. S. Geological Service.

APPENDIX C
CHANGES IN TROUT POPULATION
DENSITIES BY STRATA

Table 16. Summary statistics (P - values) for the Kruskal-Wallis test and Mann Whitney U test comparing trout population estimate densities by strata. ANOVA tests were used to determine if there was a significant decline in the trout population estimate densities as distance increased from the canal headgates. Bolded p-values are significant.

Canal	Habitat types ¹			Combined habitat types ¹
	Pools	Runs	Riffles	
	(Sample size per stratum - stratum 1, stratum 2, stratum 3) ²			
West Gallatin	0.01111 (2, 2, 1)	0.79483 (3, 5, 12)	--- (0, 0, 1)	0.79115 (5, 7, 14)
Gilmore/Todd ³	0.66667 (2, 1)	--- (3, 2)	--- (3, 1)	0.50585 (8, 4)
Bush/Ethrington ³	0.66667 (2, 1)	0.38087 (5, 2)	--- (2, 1)	0.47502 (9, 4)
Highline	0.44060 (2, 1, 0)	0.76048 (5, 4, 0)	--- (0, 0, 0)	0.61571 (7, 5, 0)
Lowline	0.82836 (1, 0, 2)	0.05547 (4, 8, 7)	--- (1, 1, 0)	0.09834 (6, 9, 9)
Keughan	0.06717 (3, 3, 1)	0.33590 (3, 6, 1)	--- (1, 1, 0)	0.41394 (7, 10, 2)
Valley	0.69315 (4, 3, 1)	0.06294 (3, 7, 5)	0.34526 (5, 8, 0)	0.45573 (12, 18, 6)

Table 16. Continued.

Canals	Habitat types ¹			Combined habitat types ¹
	Pools	Runs	Riffles	
	(Sample size per stratum - stratum 1, stratum 2, stratum 3) ²			
Lewis	0.35467 (7, 9, 6)	0.44449 (2, 3, 1)	0.70277 (3, 6, 4)	0.16677 (12, 18, 11)
Moreland**	0.28841 (3, 3, 1)	0.10406 (4, 4, 2)	0.02053 (2, 4, 4)	0.01407 (9, 11, 7)
White**	0.02466 (3, 1, 0)	0.41121 (4, 4, 0)	0.20952 (3, 5, 0)	0.21994 (10, 10, 0)

¹ - Dashed lines (---) indicate that either no habitat units of that habitat type existed in that stratum (e.g.- Highline canal 0, 0, 0 = no riffles existed in stratum 3) or no variability existed in the electrofished habitat unit densities (e.g.- Gilmore/Todd canal 3, 2 = 0.0 densities in all sampled units).

² - Zeros indicate that no habitat units of that habitat type were sampled in that stratum (e.g.- White canal 3, 1, 0 = no pools sampled in stratum 3).

³ - The Gilmore/Todd and Bush/Ethrington canals contained no stratum 3.

** - Of the canals having significant p-values, only the Moreland and White canals had significant negative slopes (P - values < 0.05). These were the only canals to display a significant decline in trout population estimate densities as distance increased from the canal headgate.

APPENDIX D
CATEGORICAL VARIABLES

Table 17. Mann-Whitney U test and Kruskal-Wallis test summary statistics for the categorical variables collected on the irrigation canals in 1994.

Variable	Classes	Test ¹	P - value
Headgate Structure	Metal Wood	MW	0.25200
Headgate Habitat	Pool Run	MW	0.90420
River Channel	Main Side	MW	0.41560
Intake Cover	High Medium Low	KW	0.62170
Headgate Cover	High Medium Low	KW	0.24070
Headgate Substrate	Silt/Sand Gravel Cobble Boulder	KW	0.25520
River Habitat	Pool Run Riffle	KW	0.00621

¹ - Mann-Whitney U test was abbreviated MW and The Kruskal-Wallis test was abbreviated KW.

APPENDIX E

**PHYSICAL FACTORS AFFECTING
IRRIGATION CANAL TROUT LOSS**

Table 18. Simple linear regression summary statistics of the physical factors affecting trout abundance in irrigation canals.

Variable	Slope	P - value
Headgate Width	0.365	0.30018
Headgate Depth	-0.015	0.96787
Headgate Area (width X depth)	0.663	0.03677
Intake Channel Width	-0.252	0.48188
Intake Channel Length	-0.399	0.20364
Decreed Flow ¹	0.319	0.36904
Flow Ratio	0.335	0.36904
50 Meter Angle	0.474	0.16630
300 Meter Angle	0.333	0.34757
Headgate Structure	-0.371	0.29089
Headgate Habitat (type of habitat at the canal headgate, in canal)	0.053	0.88488
River Channel	0.253	0.48060

Table 18. Continued.

Variable	Slope	P - value
Intake Cover (amount of cover at the intake channel, in river)	0.243	0.49812
Headgate Cover (amount of cover at the headgate, in river)	0.471	0.16894
Headgate Substrate	0.074	0.83916
River Habitat (type of habitat at the canal, in river)	0.528	0.17351

¹ - Decreed flows were based on the water commissioner's tables for the Parshall flumes of each canal. Water rights with an appropriation date prior to January 1, 1900 were used in calculating the decreed flows.

APPENDIX F
MODEL VARIABLES

Table 19. Canal measurements used in developing the predictive model and for determining unstudied canal population estimates. Study canals are bolded.

Canal	Headgate factors			Intake factors ¹	
	Width	Depth	Area	Width	Length
West Gallatin	5.85	1.20	7.02	5.85	182
Gilmore/Todd	2.05	1.80	3.69	5.80	428
Bush/Ethrington	2.40	1.60	3.84	4.45	0
Cockrill	1.70	0.65	1.11	3.45	0
Highline	5.30	0.95	5.04	5.30	438
Noble	1.55	0.90	1.40	6.50	141
Farmers	7.05	1.55	10.93	11.10	0
Allison Lewis	3.00	0.70	2.10	10.10	15
Lowline	5.25	1.15	6.04	5.25	865
Keughan	4.10	1.15	4.72	4.10	156
Lower Middle Creek	4.30	1.05	4.52	10.85	0
Beck & Border	2.75	0.37	1.02	5.70	0
Spain & Ferris	5.75	1.75	10.06	13.00	0
Mammoth	3.65	0.75	2.74	17.90	0
Ketterer	2.45	1.35	3.31	5.50	98
Valley	2.15	1.25	2.69	17.50	600
Bopp M ^c Callough	2.20	0.56	1.23	7.90	98
Hoffman - Weaver	1.85	0.65	1.20	5.70	406
Stone - Weaver	1.85	0.65	1.20	5.10	0
Lewis	3.90	1.40	5.46	11.90	0
Durham	4.15	0.95	3.94	12.80	93
Bell Dunlap	4.15	0.95	3.94	12.80	93
Hoffman	4.15	0.95	3.94	12.80	93
Moreland	6.15	0.95	5.84	6.15	0
White	4.15	1.10	4.57	18.00	301

Table 19. Continued.

Canal	Flow ²		Canal angle ³	
	Decreed	Ratio	50m	300m
West Gallatin	151	22.11	180	180
Gilmore/Todd	15	2.20	180	190
Bush/Ethrington	13	1.90	169	144
Cockrill	6	0.88	175	165
Highline	170	24.89	187	138
Noble	23	3.37	155	165
Farmers	280	41.00	174	175
Allison Lewis	18	2.64	152	142
Lowline	170	24.89	149	122
Keughan	89	13.03	185	188
Lower Middle Creek	78	11.42	149	156
Beck & Border	50	7.32	180	180
Spain & Ferris	106	15.52	83	81
Mammoth	74	10.83	159	168
Ketterer	105	15.37	153	131
Valley	75	10.98	144	148
Bopp M ^c Callough	12	1.76	160	160
Hoffman - Weaver	61	8.93	163	147
Stone - Weaver	30	4.39	153	153
Lewis	76	11.13	127	115
Durham	10	1.46	135	137
Bell Dunlap	18	2.64	135	137
Hoffman	16	2.34	135	137
Moreland	122	17.86	172	149
White	50	7.32	161	170

¹ - Intake channels precede the headgate and parshall flumes for the canals. They are normally associated with a bypass system that allows excess water to return to the river.

² - Flows were based on the West Gallatin River water commissioner's tables for the parshall flumes of each canal. Water rights with an appropriation date prior to January 1, 1900 were used in calculating decreed flows.

³ - Canal angle refers to the angle of the intake channel in relation to the river's thalweg. A small angle would infer that the canal was located on the outside of a river bend.

Table 20. Range of predictor variables used in the multiple regression model and whether the unstudied canal variables were located above (+), within (0) or below (-) the range of the study canals.

Canal	Range of variable collected on study canals		
	Headgate area	Canal angle 50m ¹	Intake length
	(2.69 - 7.02m)	(127 - 187 ⁰)	(0 - 865m)
West Gallatin	0	0	0
Gilmore/Todd	0	0	0
Bush/Ethrington	0	0	0
Cockrill	-	0	0
Highline	0	0	0
Noble	-	0	0
Farmers	+	0	0
Allison Lewis	0	0	0
Lowline	0	0	0
Keughan	0	0	0
Lower Middle Creek	0	0	0
Beck & Border	-	0	0
Spain & Ferris	+	-	0
Mammoth	0	0	0
Ketterer	0	0	0
Valley	0	0	0
Bopp M ^c Callough	-	0	0
Hoffman - Weaver	-	0	0
Stone - Weaver	-	0	0
Lewis	0	0	0
Durham	0	0	0
Bell Dunlap	0	0	0
Hoffman	0	0	0
Moreland	0	0	0
White	0	0	0

¹ - Canal angle refers to the angle of the intake channel in relation to the river's thalweg. A small angle would infer that the canal was located on the outside of a river bend.

APPENDIX G

**NUMBER AND PERCENTAGES OF TROUT CAPTURED IN
IRRIGATION CANALS AND WEST GALLATIN RIVER**

Table 21. Number and percentages of all sizes of trout captured in the irrigation canals during the 1994 electrofishing field season, divided by length groups.

Length groups	Trout species				Totals
	Brown	Rainbow	Brook	Cutthroat	
Trout < 150mm					
Number captured	432	91	286	0	809
(% of species within length group)	(53.4)	(11.3)	(35.3)	(0.0)	(100)
Trout 150mm - 203mm					
Number captured	303	154	168	0	625
(% of species within length group)	(48.5)	(24.6)	(26.9)	(0.0)	(100)
(% of species $\geq$ 150mm within length group)	(22.3)	(11.3)	(12.3)	(0.0)	(45.9)
Trout > 203mm					
Number captured	480	106	143	8	737
(% of species within length group)	(65.1)	(14.4)	(19.4)	(1.1)	(100)
(% of species $\geq$ 150mm within length group)	(35.2)	(7.8)	(10.5)	(0.6)	(54.1)
Summary of trout used in analyses					
Trout $\geq$ 150mm, number captured	783	260	311	8	1,362
(% of species $\geq$ 150mm)	(57.5)	(19.1)	(22.8)	(0.6)	(100)

Table 22. Number and percentages of all sizes of trout captured by MDFWP in the West Gallatin River combining the Williams Bridge and Shedd's Bridge sampling sites in the 1990 electrofishing field season, divided by length groups.

Length groups	Spring sampling			Fall sampling		
	Brown	Rainbow	Totals	Brown	Rainbow	Totals
Trout < 150mm						
Number captured	10	18	28	0	115	115
Trout 150mm - 203mm						
Number captured	24	52	76	92	443	535
(% of species within length group)	(31.6)	(68.4)	(100)	(17.2)	(82.2)	(100)
Trout > 203mm						
Number captured	694	731	1,425	772	1,076	1,848
(% of species within length group)	(48.7)	(51.3)	(100)	(41.8)	(58.2)	(100)
Total ≥ 150mm	718	783	1,501	864	1,519	2,383
(% of species ≥ 150mm)	(47.8)	(52.2)	(100)	(36.3)	(63.7)	(100)

Table 23. Number and percentages of all sizes of trout captured by MDFWP in the West Gallatin River in the spring 1990 electrofishing field season, divided by length groups.

Length groups	Williams Bridge			Shedds Bridge		
	Brown	Rainbow	Totals	Brown	Rainbow	Totals
Trout < 150mm						
Number captured	0	15	15	10	3	13
Trout 150mm - 203mm						
Number captured	7	46	53	17	6	23
(% of species within length group)	(13.2)	(86.8)	(100)	(73.9)	(26.1)	(100)
Trout > 203mm						
Number captured	258	477	735	436	254	690
(% of species within length group)	(35.1)	(64.9)	(100)	(63.2)	(36.8)	(100)
Total ≥ 150mm	265	523	788	453	260	713
(% of species ≥ 150mm)	(33.6)	(66.3)	(100)	(63.5)	(36.5)	(100)

Table 24. Number and percentages of all sizes of trout captured by MDFWP in the West Gallatin River in the fall 1990 electrofishing field season, divided by length groups.

Length groups	Williams Bridge			Shedds Bridge		
	Brown	Rainbow	Totals	Brown	Rainbow	Totals
Trout < 150mm						
Number captured	0	113	113	0	2	2
Trout 150mm - 203mm						
Number captured	39	298	337	53	145	198
(% of species within length group)	(11.6)	(88.4)	(100)	(26.8)	(73.2)	(100)
Trout > 203mm						
Number captured	286	750	1,036	486	326	812
(% of species within length group)	(27.6)	(72.4)	(100)	(59.9)	(40.1)	(100)
Total $\geq$ 150mm, number captured	325	1,048	1,373	539	471	1,010
(% of species $\geq$ 150mm)	(31.0)	(69.0)	(100)	(53.4)	(46.6)	(100)

APPENDIX H

**LENGTH - WEIGHT REGRESSIONS
AND SUMMARY STATISTICS**

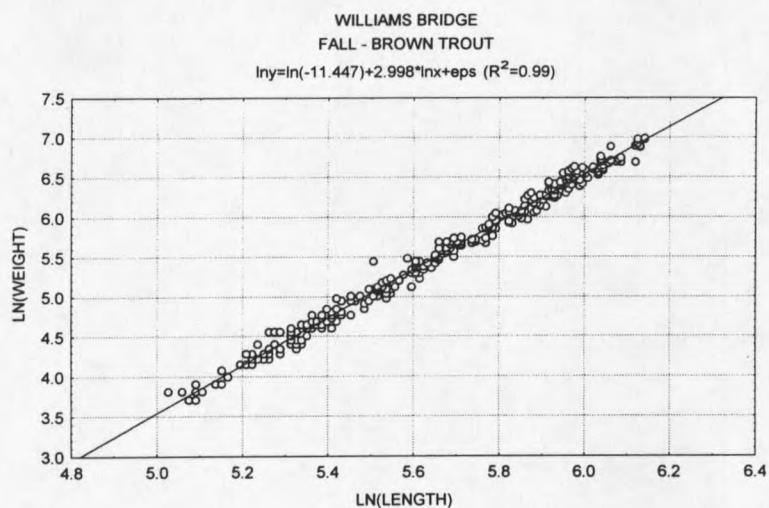


Figure 8. Transformed length - weight regressions for the 1990 fall brown trout sampling at Williams Bridge on the West Gallatin River.

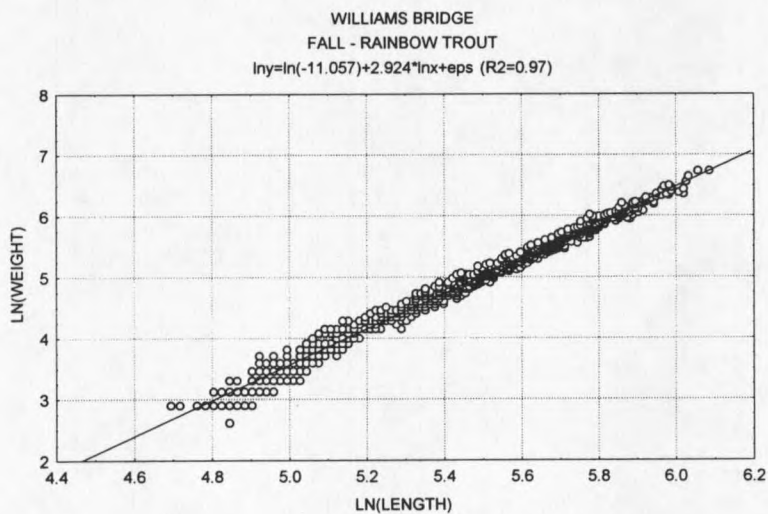


Figure 9. Transformed length - weight regressions for the 1990 fall rainbow trout sampling at Williams Bridge on the West Gallatin River.

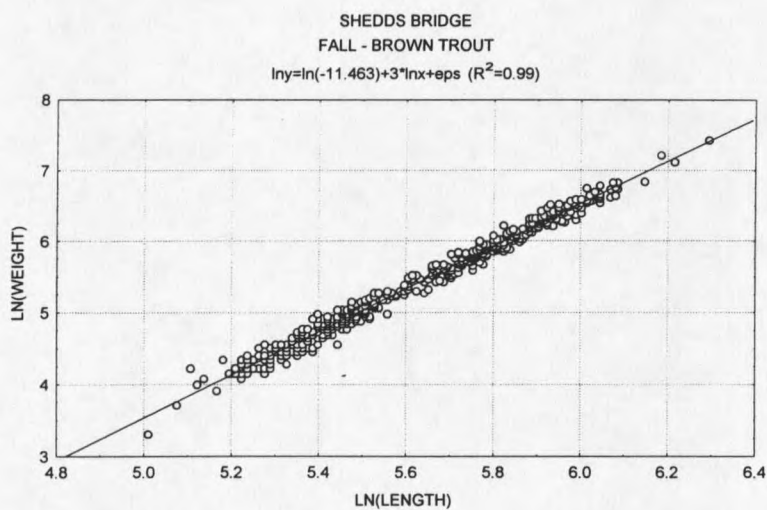


Figure 10. Transformed length - weight regressions for the 1990 fall brown trout sampling at Shedd's Bridge on the West Gallatin River.

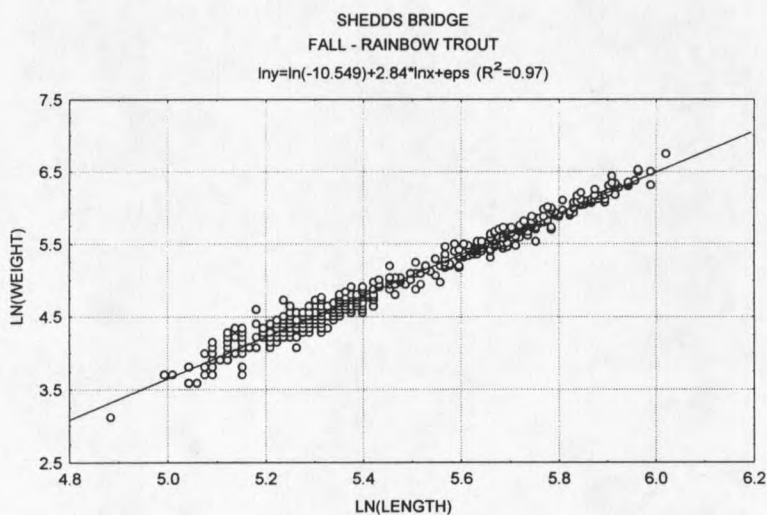


Figure 11. Transformed length - weight regressions for the 1990 fall rainbow trout sampling at Shedd's Bridge on the West Gallatin River.

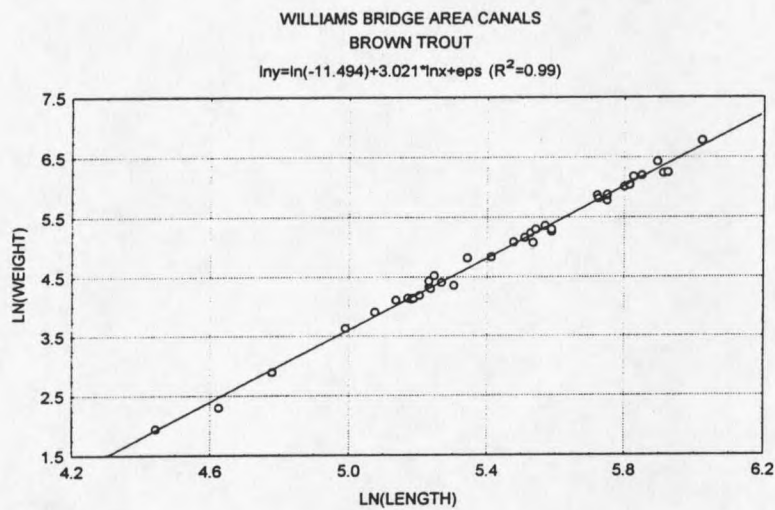


Figure 12. Transformed length - weight regressions for brown trout sampled in the Williams Bridge area irrigation canals in 1994.

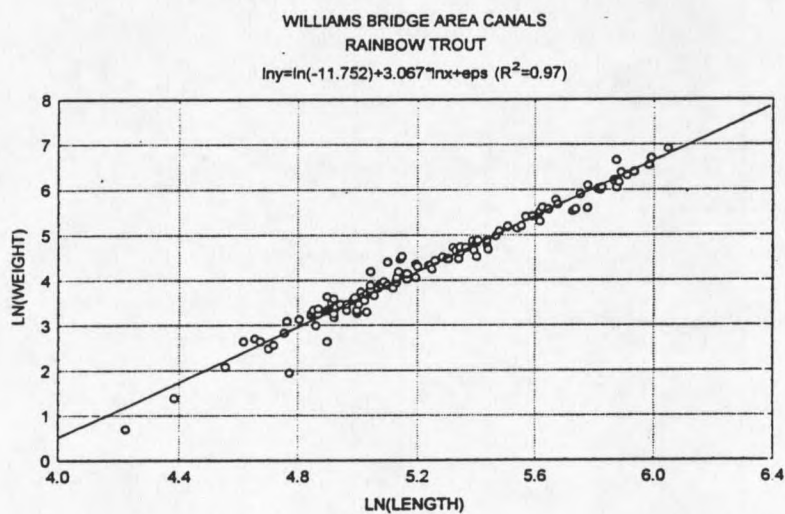


Figure 13. Transformed length - weight regressions for rainbow trout sampled in the Williams Bridge area irrigation canals in 1994.

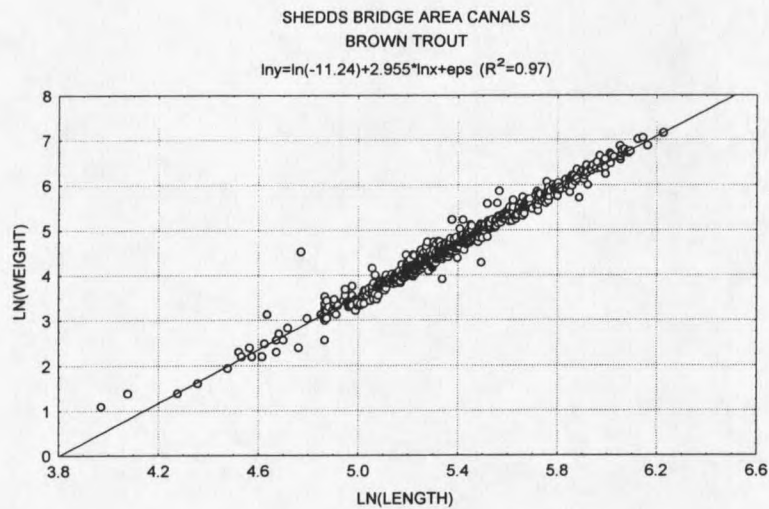


Figure 14. Transformed length - weight regressions for brown trout sampled in the Shedd's Bridge area irrigation canals in 1994.

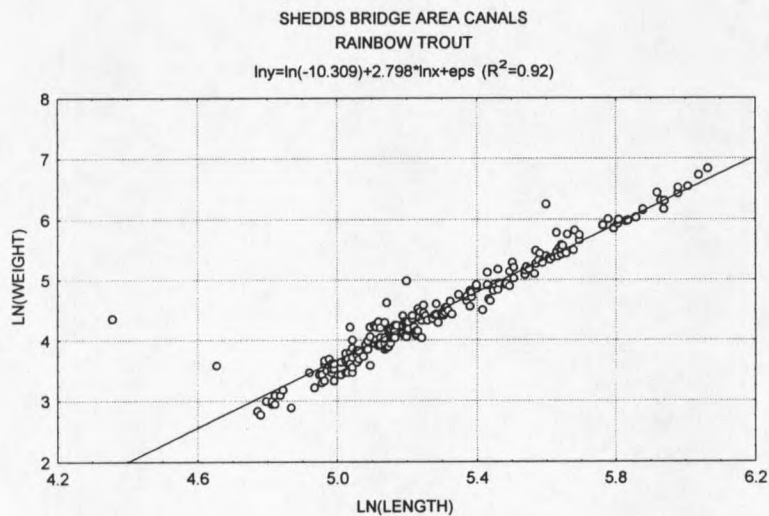


Figure 15. Transformed length - weight regressions for rainbow trout sampled in the Shedd's Bridge area irrigation canals in 1994.

Table 25. Test statistics comparing the 1994 length - weight regression slopes of brown and rainbow trout in the irrigation canals with the 1990 population in the West Gallatin River.

Sampling site ¹	Regression slopes		t - Statistic (df)		Significance ² level
	River (SE)	Canals (SE)			
Williams Bridge ³					
Fall - brown trout	2.9977 (0.02)	3.0207 (0.04)	-8.9	(347)	<0.0001
Fall - rainbow trout	2.9243 (0.01)	3.0665 (0.05)	-69.9	(1,242)	<0.0001
Shedds Bridge ⁴					
Fall - brown trout	2.9997 (0.02)	2.9551 (0.02)	33.7	(1,241)	<0.0001
Fall - rainbow trout	2.8405 (0.02)	2.7976 (0.06)	16.6	(658)	<0.0001

¹ - The Gallatin River sampling information was collected by MDFWP in 1990. Canal length - weight information was collected during the 1994 field season.

² - Significant differences were found using $t_{0.05,2,df}$.

³ - The canals associated with the Williams Bridge sampling site were West Gallatin, Gilmore/Todd, Bush/Ethrington, and Highline.

⁴ - The canals associated with the Shedds Bridge sampling site were Lowline, Keughan, Valley, Lewis, Moreland, and White.

Table 26. Test statistics comparing the 1994 length - weight regression intercepts of brown and rainbow trout in the irrigation canals with the 1990 population in the West Gallatin River.

Sampling Site ¹	Regression intercepts		t - Statistic (df)		Significance ² level
	River (SE)	Canals (SE)			
Williams Bridge ³					
Fall - brown trout	-11.4473 (0.09)	-11.4944 (0.21)	3.7	(347)	<0.001
Fall - rainbow trout	-11.0566 (0.06)	-11.7516 (0.24)	5.0	(1,242)	<0.001
Shedds Bridge ⁴					
Fall - brown trout	-11.4631 (0.09)	-11.2399 (0.10)	14.2	(1,241)	<0.001
Fall - rainbow trout	-10.5494 (0.11)	-10.3086 (0.31)	7.6	(658)	<0.001

¹ - The Gallatin River sampling information was collected by MDFWP in 1990. Canal length - weight information was collected during the 1994 field season.

² - Significant differences were found using $t_{0.05,2,df}$.

³ - The canals associated with the Williams Bridge sampling site were West Gallatin, Gilmore/Todd, Bush/Ethrington, and Highline.

⁴ - The canals associated with the Shedds Bridge sampling site were Lowline, Keughan, Valley, Lewis, Moreland, and White.

APPENDIX I

**WEST GALLATIN RIVER AND IRRIGATION CANAL
POPULATION COMPARISONS
AND SUMMARY STATISTICS**

Table 27. West Gallatin River population estimates conducted by MDFWP in 1990. Estimates were calculated for rainbow and brown trout ≥ 150 mm. No standard errors were available.

Sampling section	Sampling ¹ date	Brown trout		Rainbow trout		Totals	
		#'s/km	(mile)	#'s/km	(mile)	#'s/km	(mile)
Williams Bridge	Spring 1990	426	(266)	837	(523)	1,263	(789)
Williams Bridge	Fall 1990	520	(325)	1,676	(1,048)	2,196	(1,373)
Shedds Bridge	Spring 1990	725	(453)	416	(260)	1,141	(713)
Shedds Bridge	Fall 1990	862	(539)	754	(471)	1,616	(1,010)

¹ - Spring estimates were conducted in March and fall estimates in September.

Table 28. The numbers of brown and rainbow trout $\geq 150\text{mm}$ captured by MDFWP in their 1990 West Gallatin River estimates and the numbers captured in each canal during the 1994 electrofishing field season. Sample sizes of $n \geq 5$ were used in the Mann-Whitney and Wald-Wolfowitz tests.

Site	Species	Sample size (Fish $\geq 150\text{mm}$)	Median length (Fish $\geq 150\text{mm}$)
Williams Bridge Gallatin River	Brown trout	312	295
	Rainbow trout	1,005	236
Shedds Bridge Gallatin River	Brown trout	506	274
	Rainbow trout	450	226
Williams Bridge Area Canals ¹	Brown trout	37	253
	Rainbow trout	94	222
Shedds Bridge Area Canals ²	Brown trout	744	213
	Rainbow trout	203	192
West Gallatin Canal	Brown trout	30	250
	Rainbow trout	82	225.5
Gilmore/Todd Canal	Brown trout	1	---
	Rainbow trout	0	---
Bush/Ethrington Canal	Brown trout	0	---
	Rainbow trout	5	169
Highline Canal	Brown trout	7	339
	Rainbow trout	7	323
Lowline Canal	Brown trout	17	270
	Rainbow trout	28	282
Keughan Canal	Brown trout	15	292
	Rainbow trout	28	228.5

Table 28. Continued.

Site	Species	Sample Size (Fish $\geq$ 150mm)	Median Length (Fish $\geq$ 150mm)
Valley Canal	Brown trout	61	281
	Rainbow trout	11	170
Lewis Canal	Brown trout	569	210
	Rainbow trout	115	181
Moreland Canal	Brown trout	70	228
	Rainbow trout	21	179
White Canal	Brown trout	12	254
	Rainbow trout	2	---

¹ - The canals associated with the Williams Bridge sampling site are West Gallatin, Gilmore/Todd, Bush/Ethrington, and Highline.

² - The canals associated with the Shedd's Bridge sampling site are Lowline, Keughan, Valley, Lewis, Moreland, and White.

Table 29. Summary statistics for the Mann-Whitney U test (length median location) and the Wald-Wolfowitz runs test (length frequency distribution) comparing West Gallatin River population parameters to the canals associated with the Williams Bridge sampling location. Samples were based on brown and rainbow trout ≥ 150 mm.

Sampling location ¹		Species	Mann-Whitney U P - value	Wald-Wolfowitz P - value
River	Canal ²			
Williams Bridge	West Gallatin	Brown trout	0.00070	0.00293
		Rainbow trout	0.52085	< 0.0001
Williams Bridge	Bush/Ethrington	Rainbow trout	0.01379	0.86766
Williams Bridge	Highline	Brown trout	0.94384	0.67774
		Rainbow trout	0.08288	0.81818

¹ - The West Gallatin River population length data was collected by MDFWP in 1990. Canal population information was collected during the 1994 field season.

² - The canals associated with the Williams Bridge sampling site were West Gallatin, Gilmore/Todd, Bush/Ethrington, and Highline. The Gilmore/Todd canal and Bush/Ethrington brown trout were not included due to the small sample sizes ($n < 5$).

Table 30. Summary statistics for the Mann-Whitney U test (length median location) and the Wald-Wolfowitz runs test (length frequency distribution) comparing West Gallatin River population parameters to the canals associated with the Shedd's Bridge sampling location. Samples were based on brown and rainbow trout ≥ 150 mm.

Sampling location ¹		Species	Mann-Whitney U P - value	Wald-Wolfowitz P - value
River	Canal ²			
Shedd's Bridge	Lowline	Brown trout	0.64655	0.93974
		Rainbow trout	0.00124	0.00124
Shedd's Bridge	Keughan	Brown trout	0.32496	0.08941
		Rainbow trout	0.75962	< 0.0001
Shedd's Bridge	Valley	Brown trout	0.64461	< 0.0001
		Rainbow trout	0.01775	0.00038
Shedd's Bridge	Lewis	Brown trout	< 0.0001	< 0.0001
		Rainbow trout	< 0.0001	< 0.0001

Table 30. Continued.

Sampling location ¹		Species	Mann-Whitney U P - value	Wald-Wolfowitz P - value
River	Canal ²			
Shedds Bridge	Moreland	Brown trout	< 0.0001	< 0.0001
		Rainbow trout	0.00009	0.00080
Shedds Bridge	White	Brown trout	0.22141	0.59361

¹ - The West Gallatin River population length data was collected by MDFWP in 1990. Canal population information was collected during the 1994 field season.

2- The canals associated with the Shedds Bridge sampling site were Lowline, Keughan, Valley, Lewis, and Moreland. Rainbow trout in the White canal were not included due to the small sample size ($n < 5$).

Table 31. Summary statistics for the Mann-Whitney U test (length median location) and Wald-Wolfowitz runs test (length frequency distribution) comparing West Gallatin River population parameters to the canals located in that region. Samples were based on brown and rainbow trout ≥ 150 mm.

River ¹	Sampling location Canal ²	Species	Mann-Whitney U P - value	Wald-Wolfowitz P - value
Williams Bridge	Williams Bridge Area Canals	Brown trout	0.00278	0.02050
		Rainbow trout	0.49223	< 0.0001
Shedds Bridge	Shedds Bridge Area Canals	Brown trout	< 0.0001	< 0.0001
		Rainbow trout	< 0.0001	< 0.0001

¹ - The West Gallatin River population length data was collected by MDFWP in 1990. Canal population information was collected during the 1994 field season.

² - The canals associated with the Williams Bridge sampling site were West Gallatin, Gilmore/Todd, Bush/Ethrington, and Highline. The canals associated with the Shedds Bridge sampling site were Lowline, Keughan, Valley, Lewis, Moreland, and White.

APPENDIX J

**WEST GALLATIN RIVER
TROUT POPULATION CHARACTERISTICS
LENGTH FREQUENCY HISTOGRAMS**

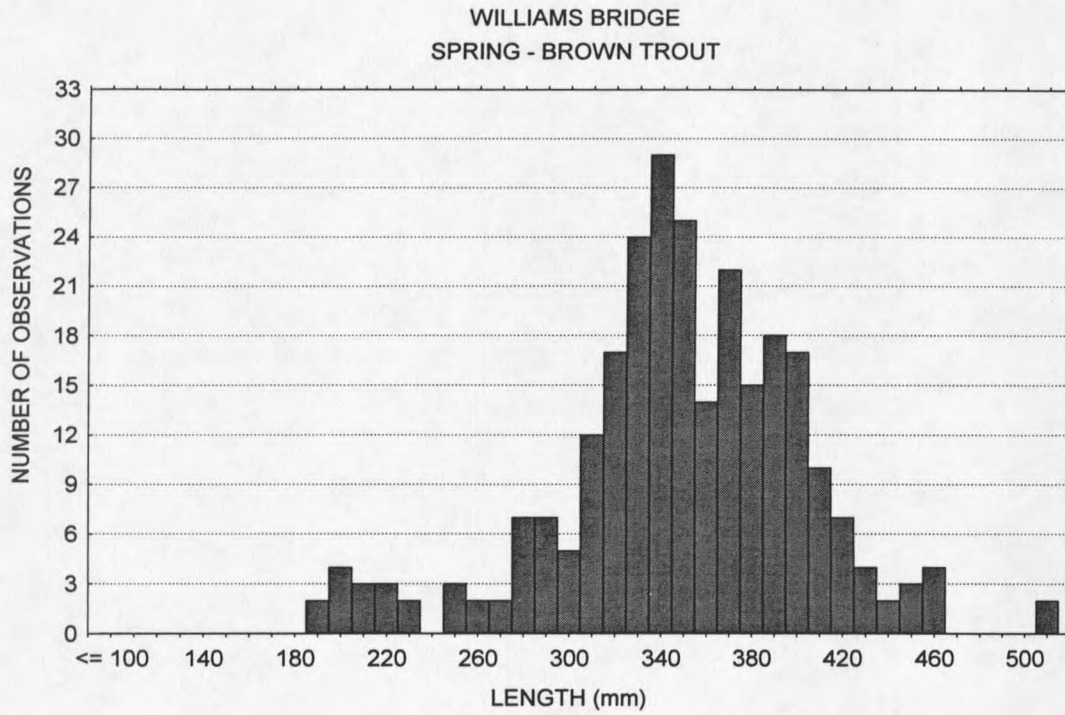


Figure 16. Length frequency histogram for Williams Bridge brown trout. The population data was collected by MDFWP in spring 1990.

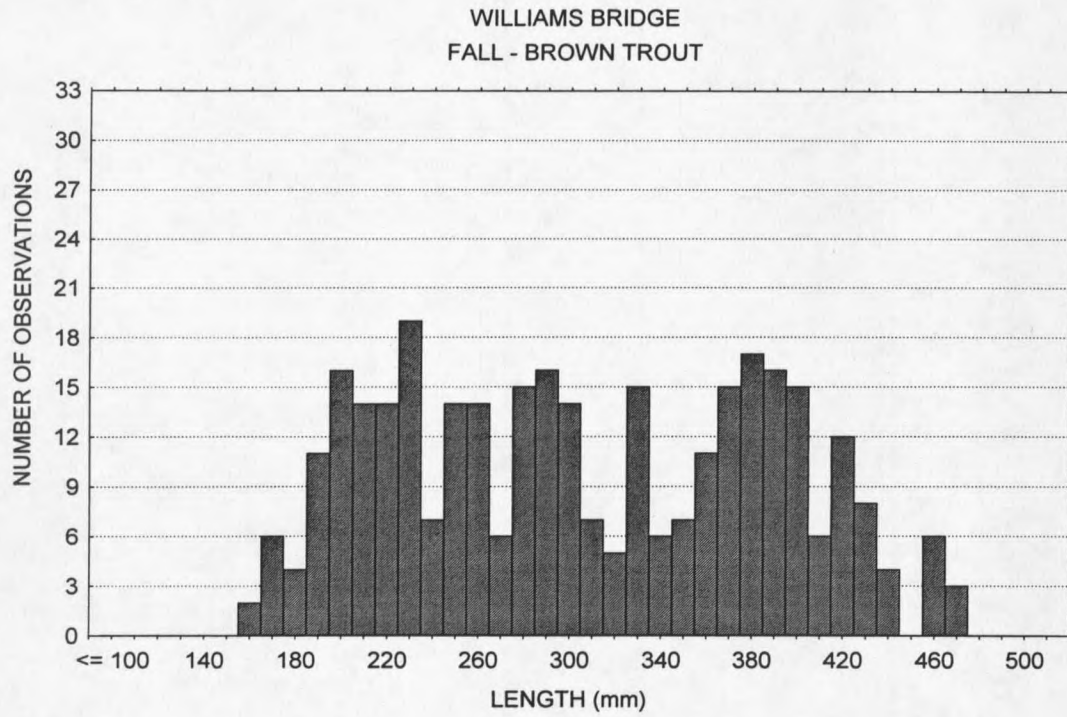


Figure 17. Length frequency histogram for Williams Bridge brown trout. The population data was collected by MDFWP in fall 1990.

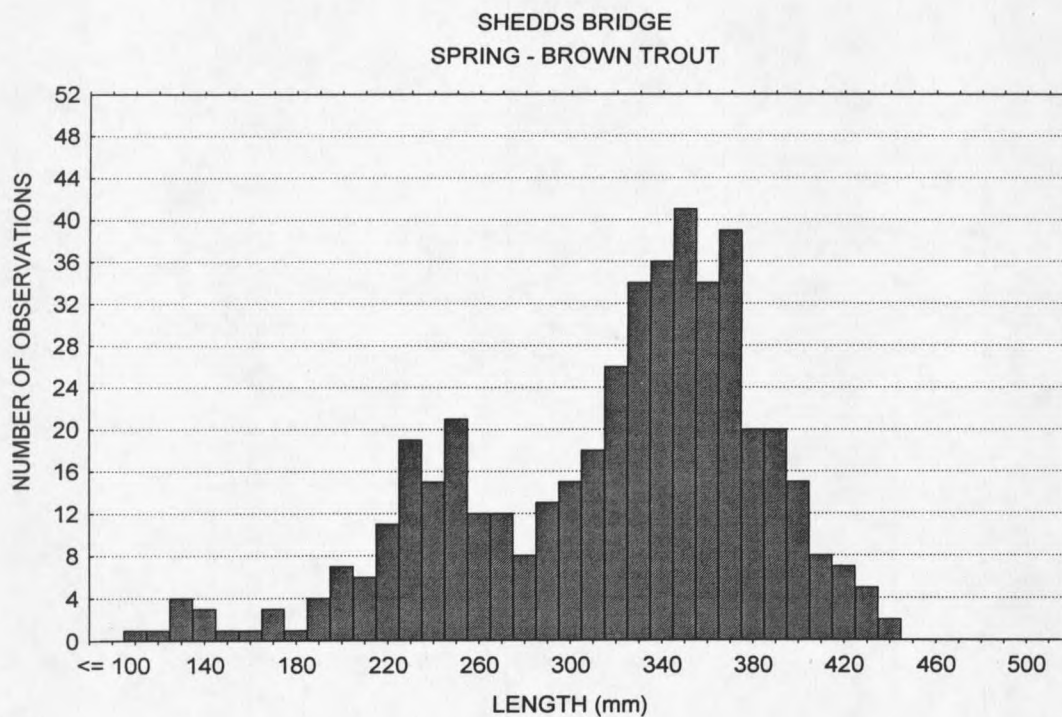


Figure 18. Length frequency histogram for Shedd's Bridge brown trout. The population data was collected by MDFWP in spring 1990.

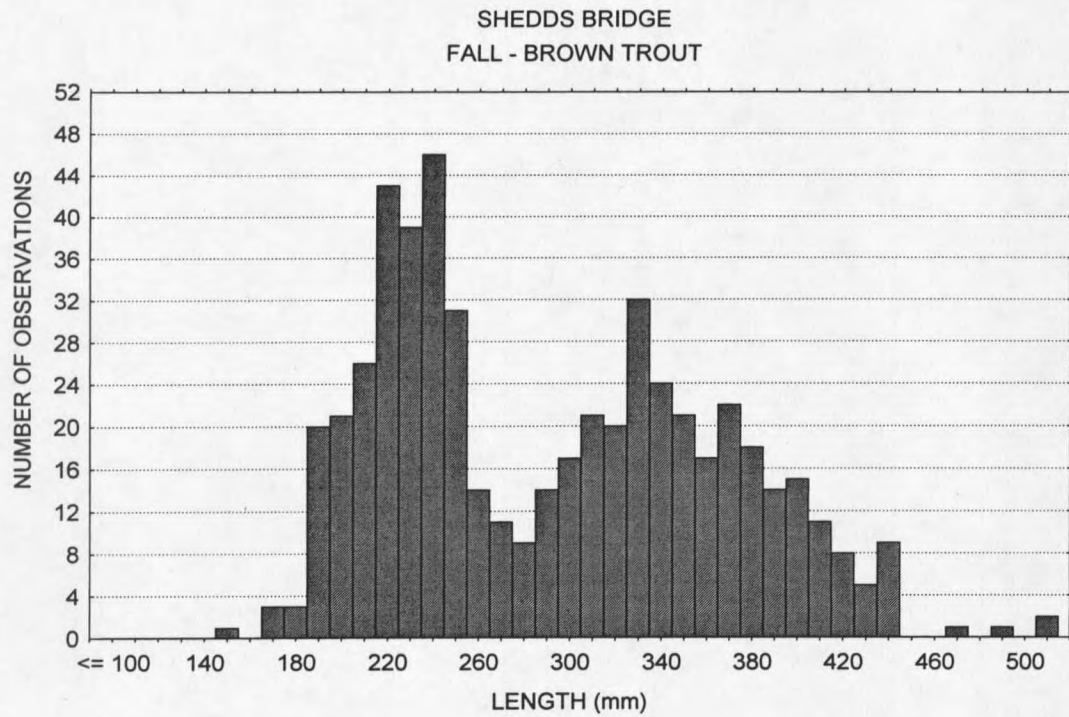


Figure 19. Length frequency histogram for Shedd's Bridge brown trout. The population data was collected by MDFWP in fall 1990.

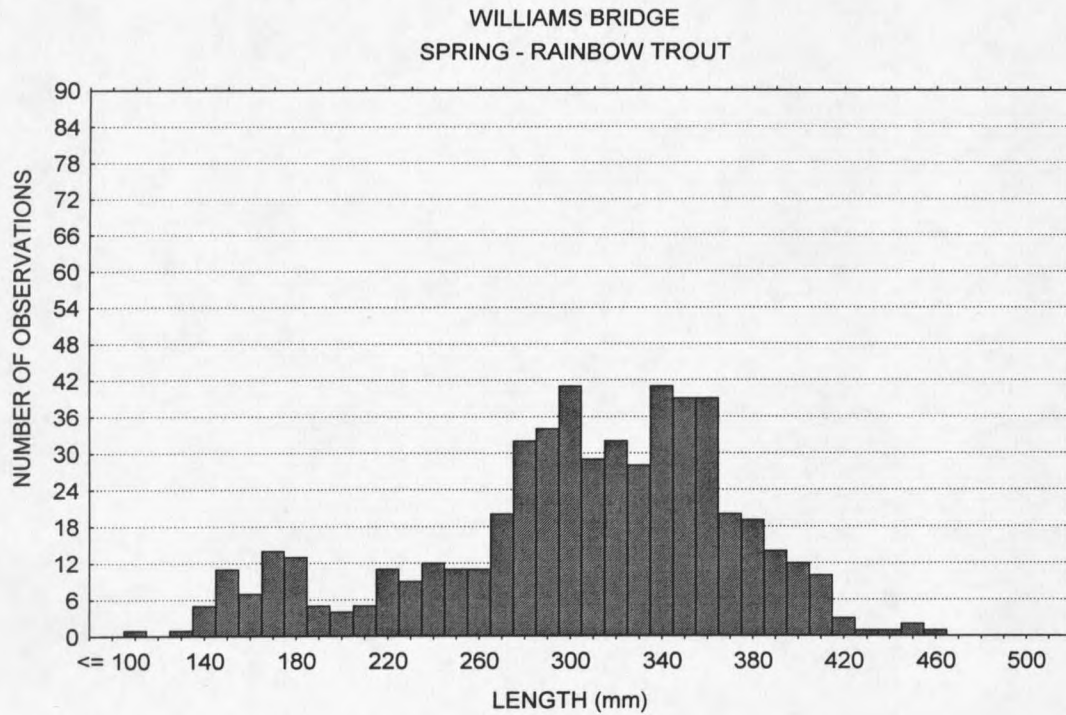


Figure 20. Length frequency histogram for Williams Bridge rainbow trout. The population data was collected by MDFWP in spring 1990.

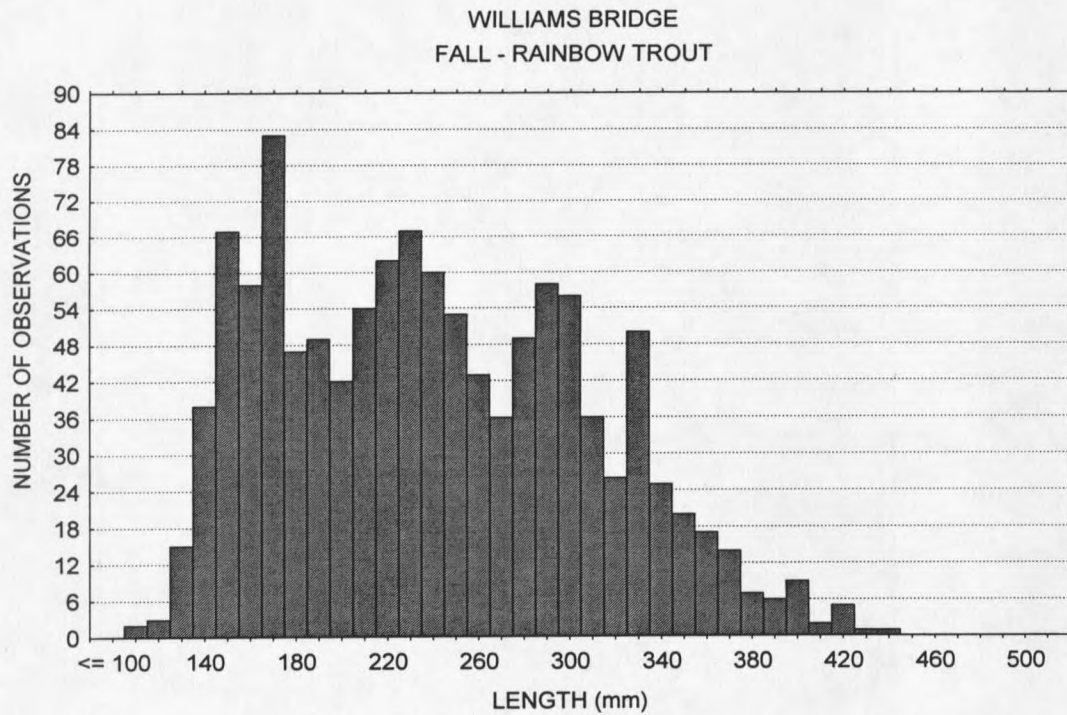


Figure 21. Length frequency histogram for Williams Bridge rainbow trout. The population data was collected by MDFWP in fall 1990.

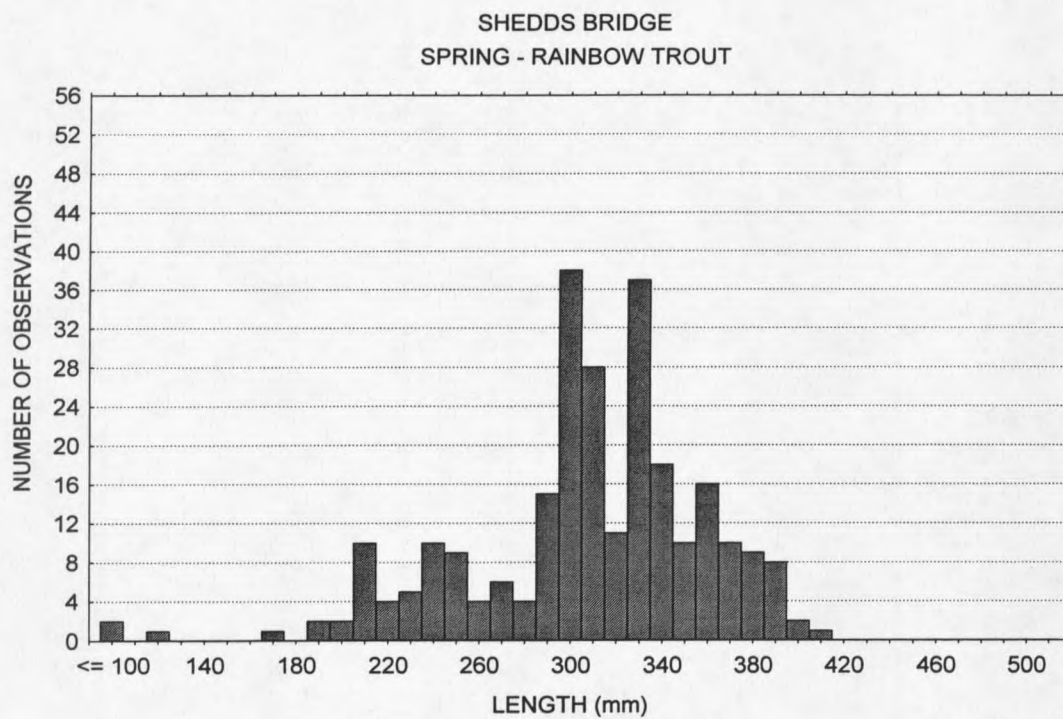


Figure 22. Length frequency histogram for Shedd's Bridge rainbow trout. The population data was collected by MDFWP in spring 1990.

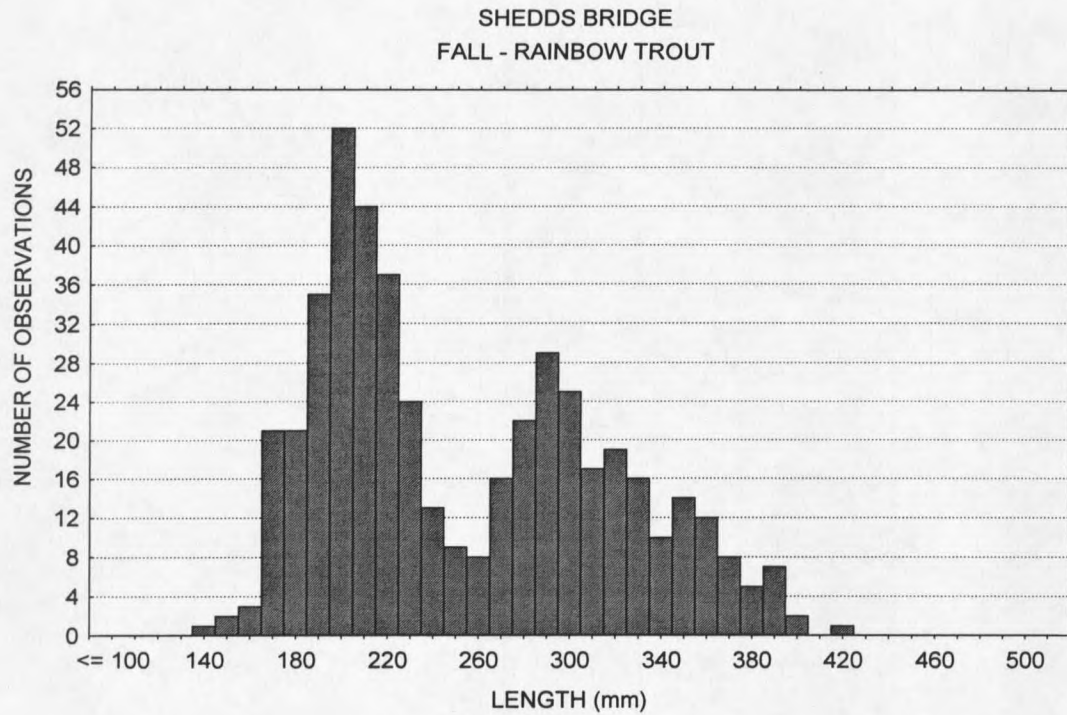


Figure 23. Length frequency histogram for Shedd's Bridge rainbow trout. The population data was collected by MDFWP in fall 1990.

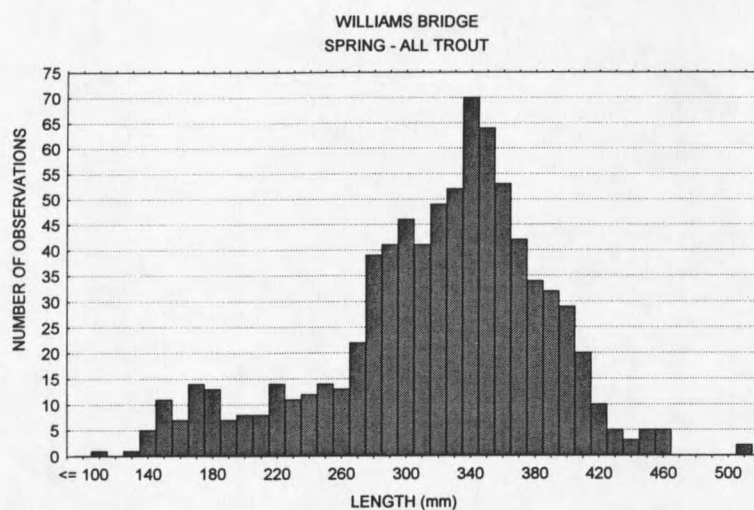


Figure 24. Length - frequency histograms for the 1990 spring sampling at Williams Bridge on the West Gallatin River.

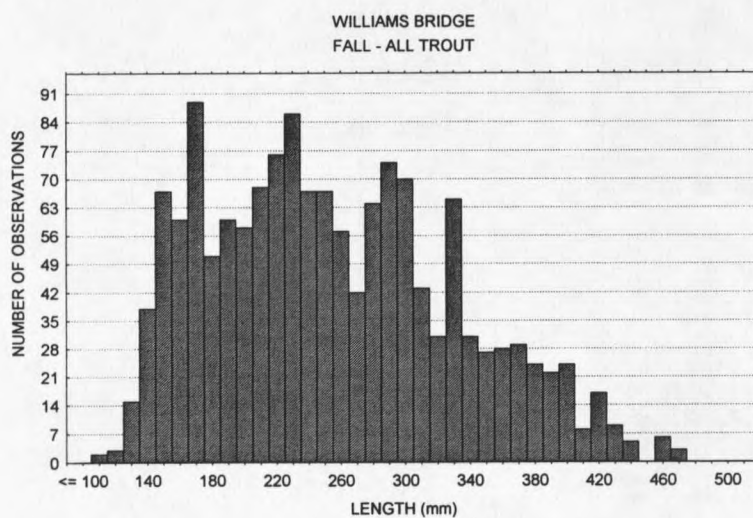


Figure 25. Length - frequency histograms for the 1990 fall sampling at Williams Bridge on the West Gallatin River.

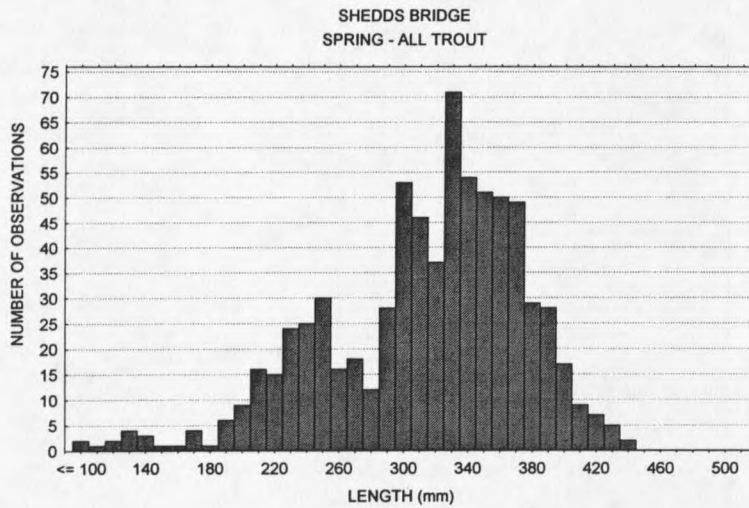


Figure 26. Length - frequency histograms for the 1990 spring sampling at Shedd's Bridge on the West Gallatin River.

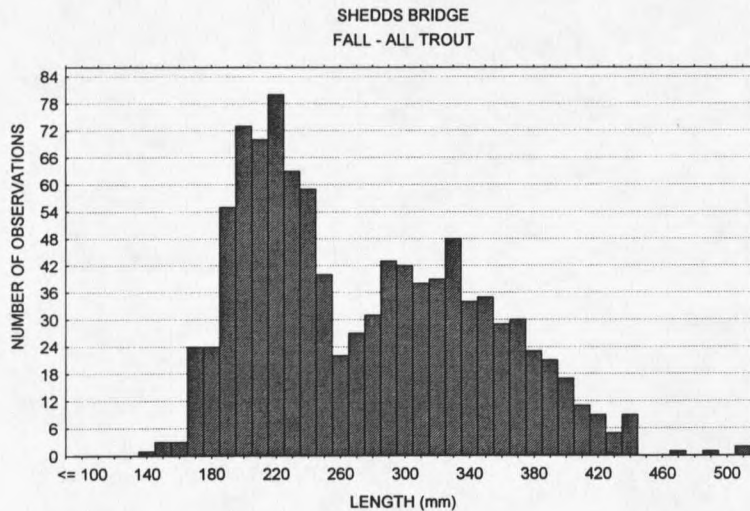


Figure 27. Length - frequency histograms for the 1990 fall sampling at Shedd's Bridge on the West Gallatin River.

APPENDIX K
IRRIGATION CANAL
TROUT POPULATION CHARACTERISTICS
LENGTH FREQUENCY HISTOGRAMS

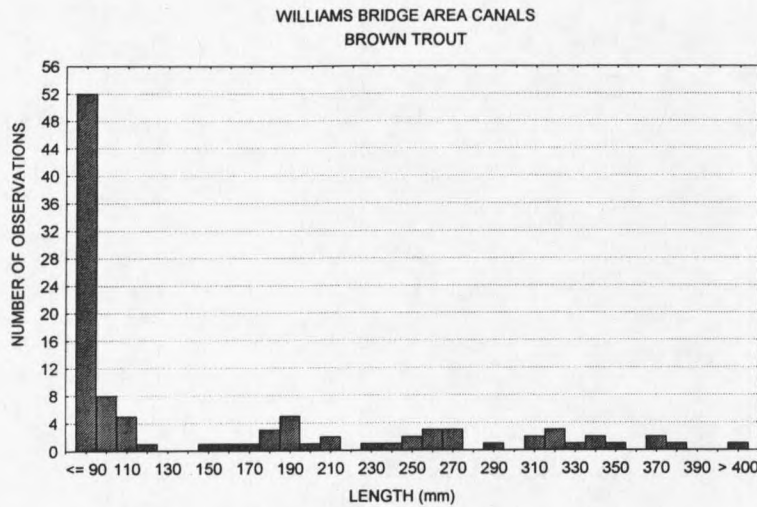


Figure 28. Length frequency histogram for brown trout sampled in the Williams Bridge area irrigation canals in 1994.

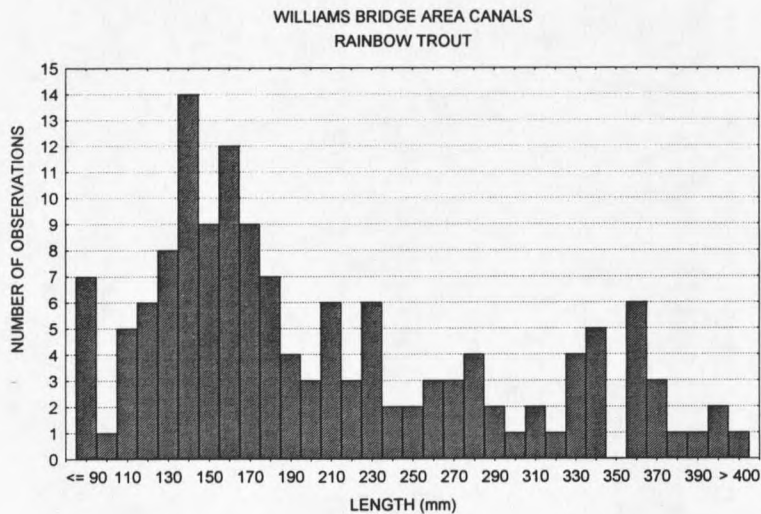


Figure 29. Length frequency histogram for rainbow trout sampled in the Williams Bridge area irrigation canals in 1994.

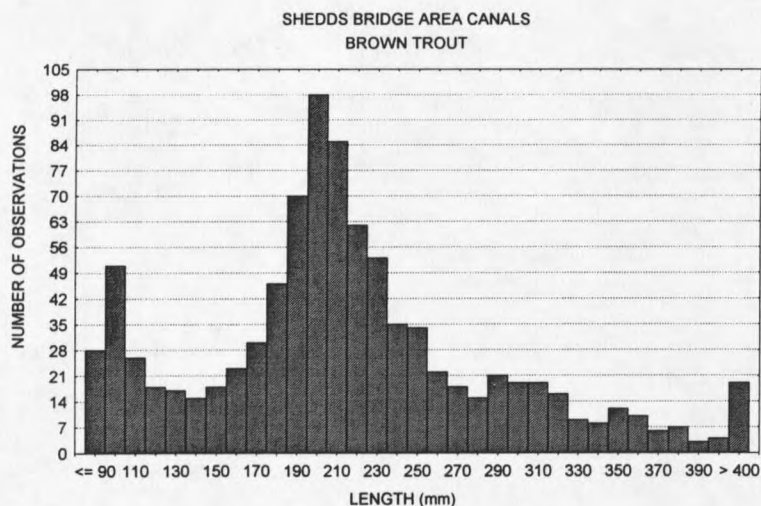


Figure 30. Length frequency histogram for brown trout sampled in the Shedd's Bridge area irrigation canals in 1994.

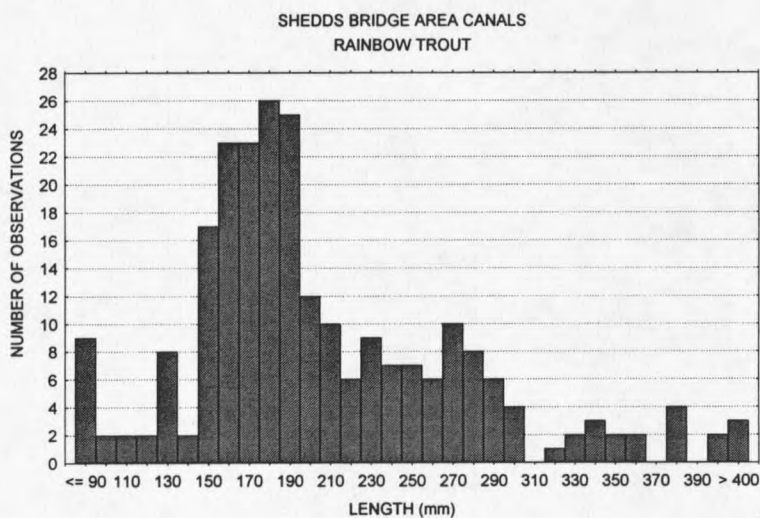


Figure 31. Length frequency histogram for rainbow trout sampled in the Shedd's Bridge area irrigation canals in 1994.

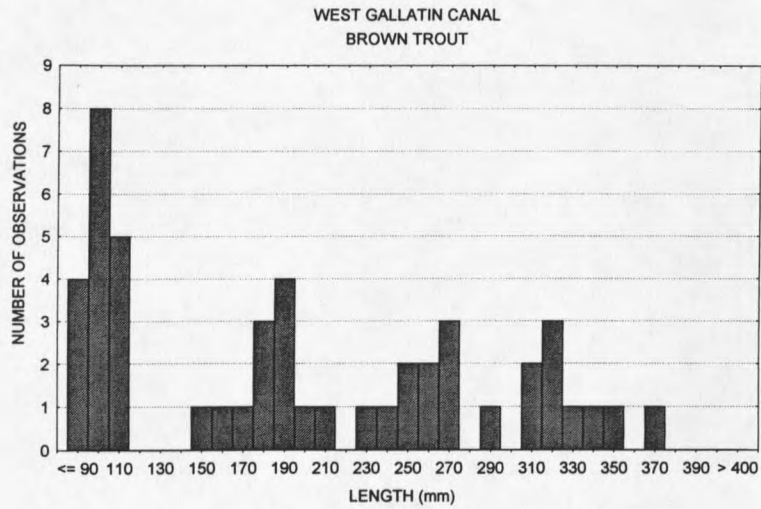


Figure 32. Length frequency histogram for brown trout sampled in the West Gallatin canal in 1994.

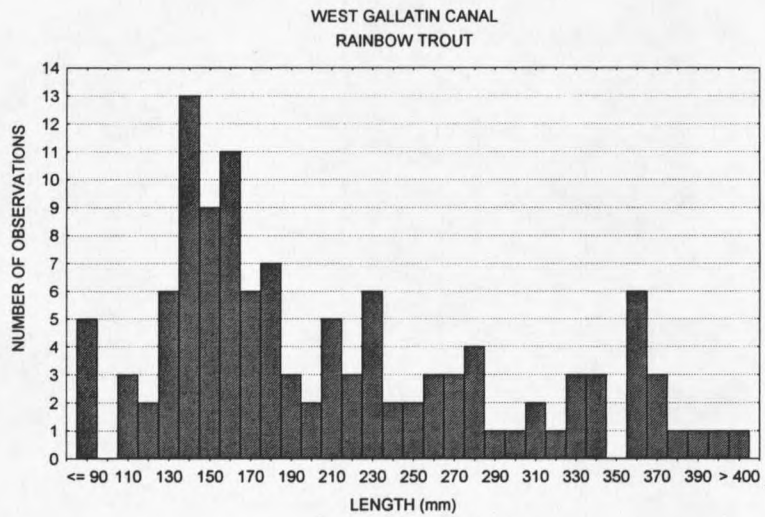


Figure 33. Length frequency histogram for rainbow trout sampled in the West Gallatin canal in 1994.

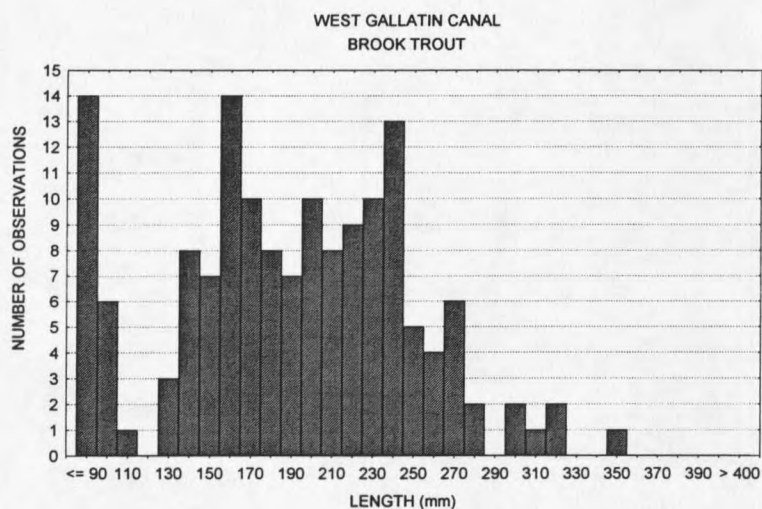


Figure 34. Length frequency histogram for brook trout sampled in the West Gallatin canal in 1994.

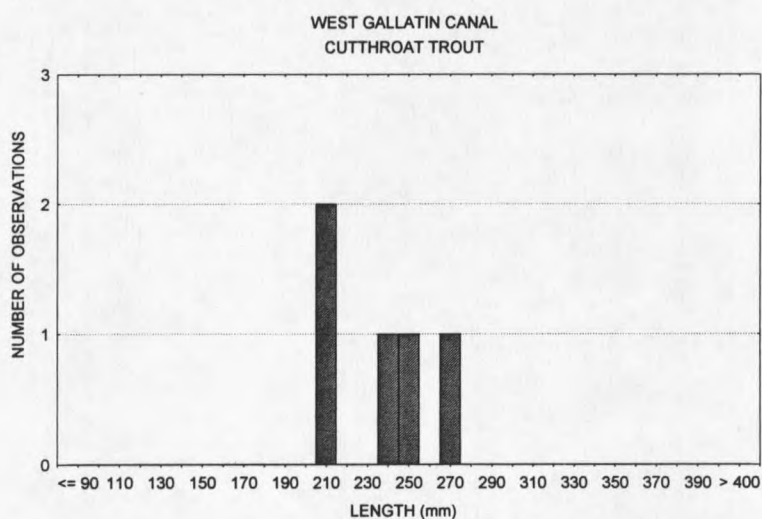


Figure 35. Length frequency histogram for cutthroat trout sampled in the West Gallatin canal in 1994.

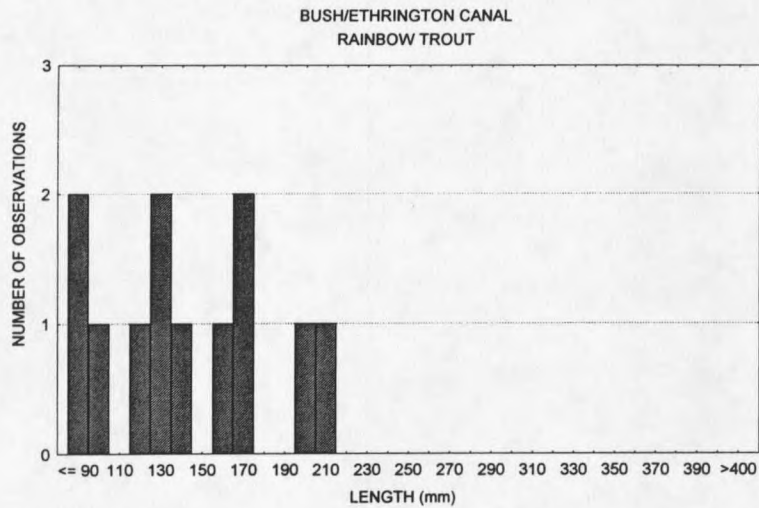


Figure 36. Length frequency histogram for rainbow trout sampled in the Bush/Ethlington canal in 1994.

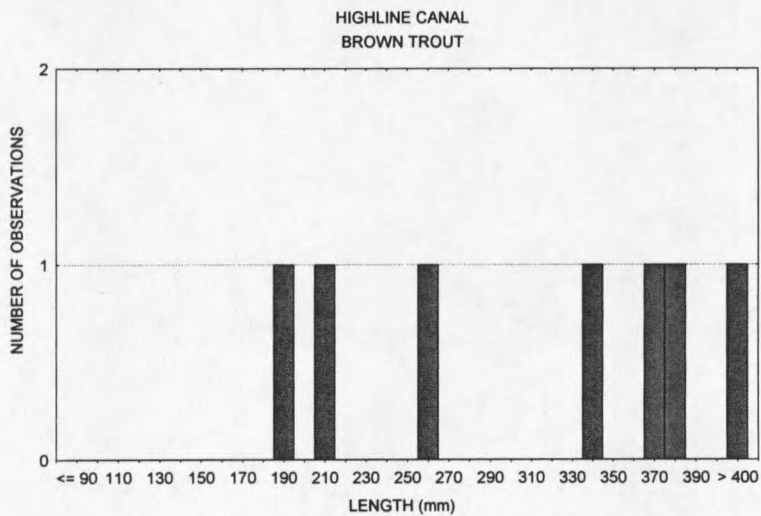


Figure 37. Length frequency histogram for brown trout sampled in the Highline canal in 1994.

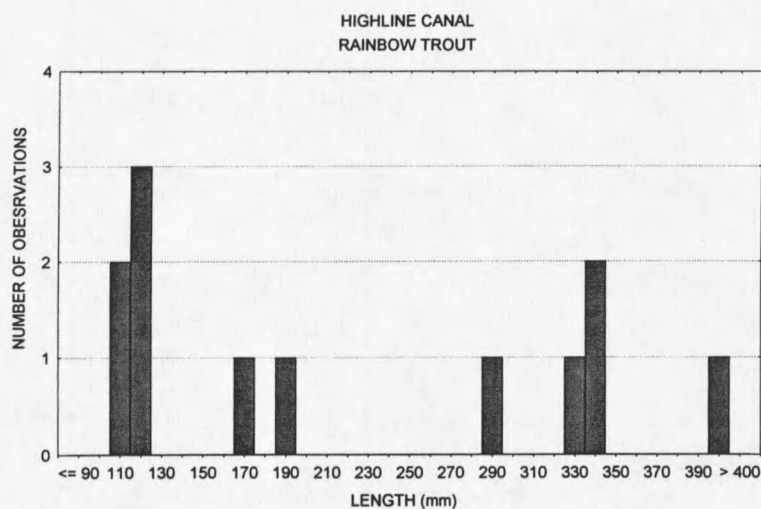


Figure 38. Length frequency histogram for brown trout sampled in the Highline canal in 1994.

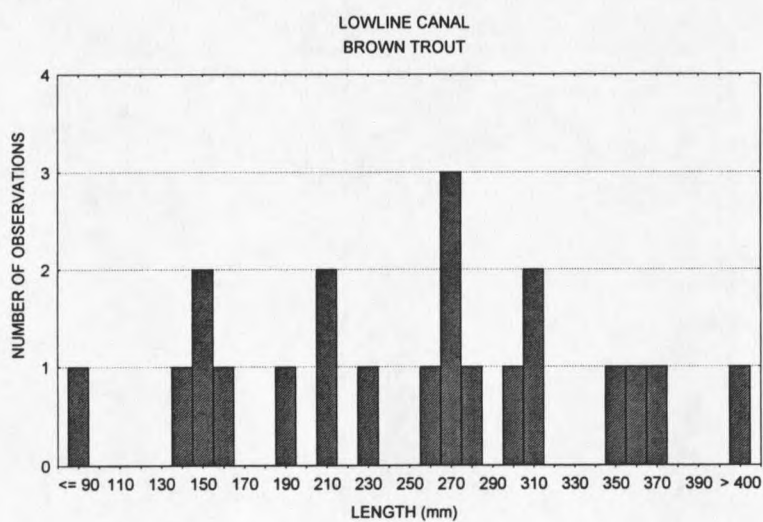


Figure 39. Length frequency histogram for brown trout sampled in the Lowline canal in 1994.

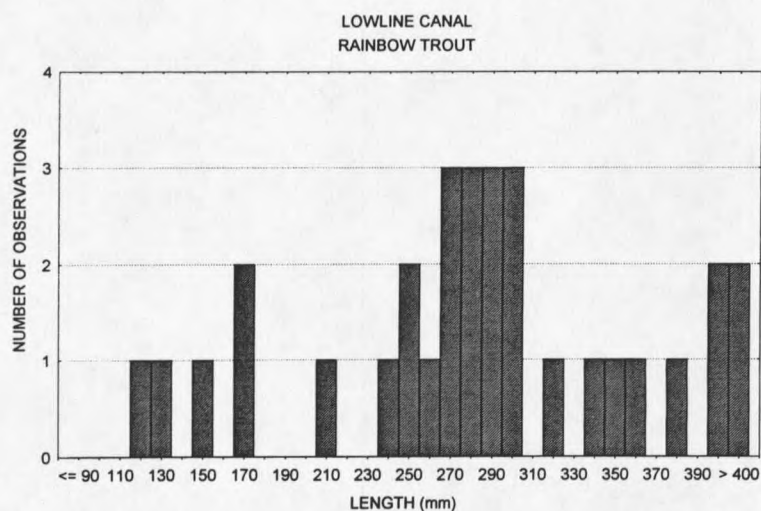


Figure 40. Length frequency histogram for rainbow trout sampled in the Lowline canal in 1994.

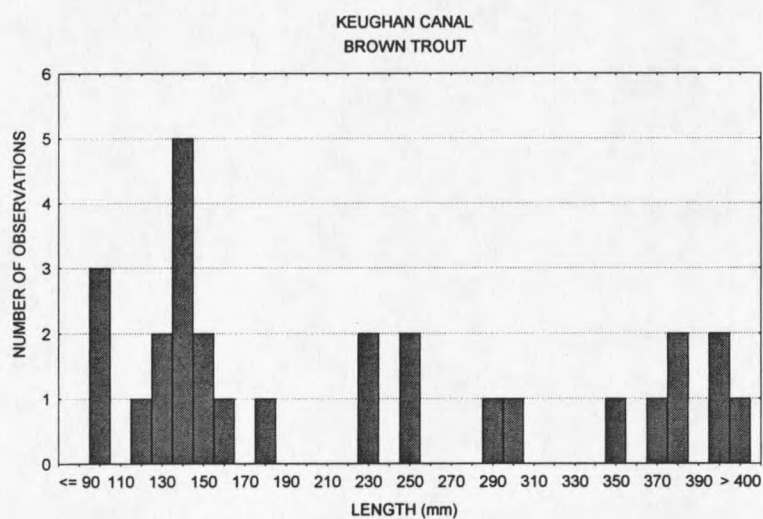


Figure 41. Length frequency histogram for brown trout sampled in the Keughan canal in 1994.

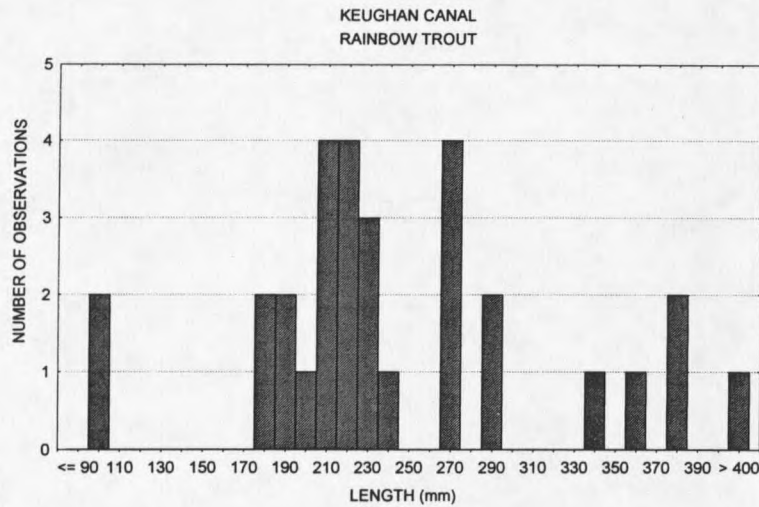


Figure 42. Length frequency histogram for rainbow trout sampled in the Keughan canal in 1994.

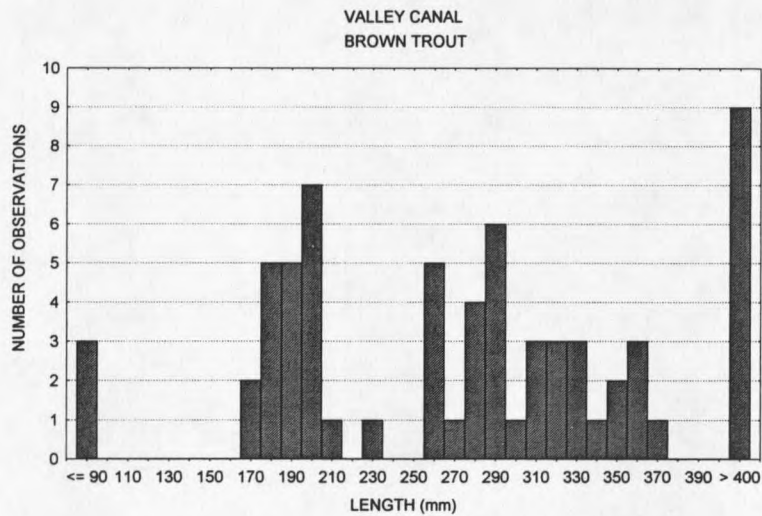


Figure 43. Length - frequency histogram for brown trout sampled in the Valley canal in 1994.

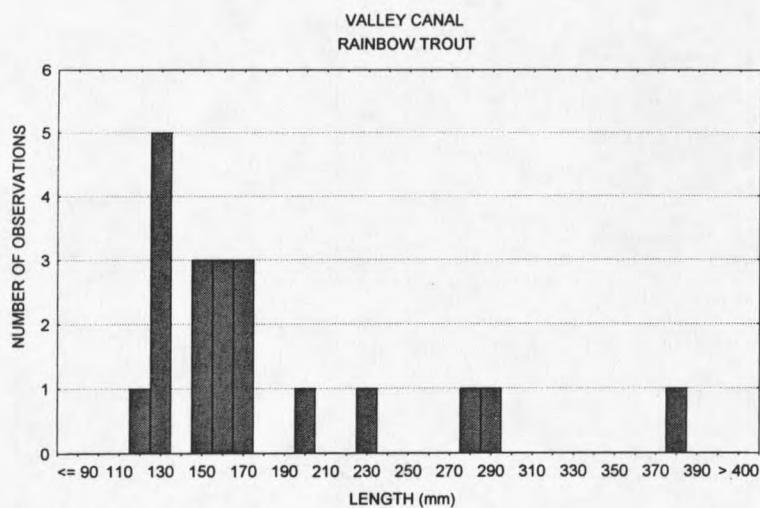


Figure 44. Length frequency histogram for rainbow trout sampled in the Valley canal in 1994.

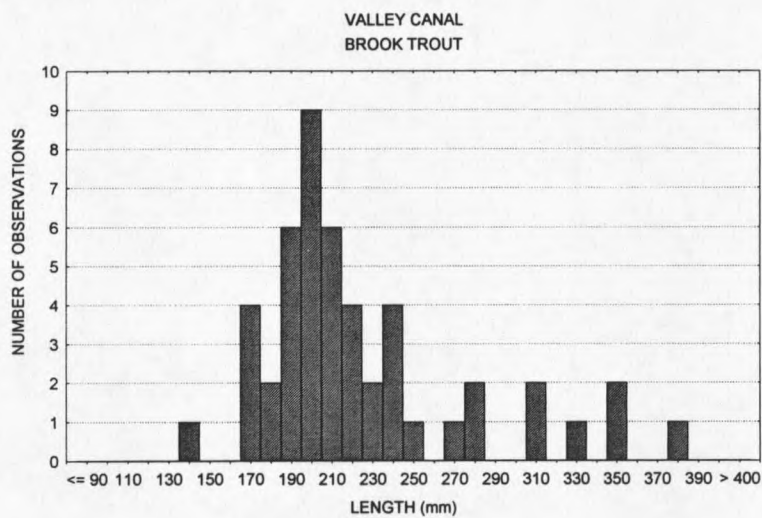


Figure 45. Length frequency histogram for brook trout sampled in the Valley canal in 1994.

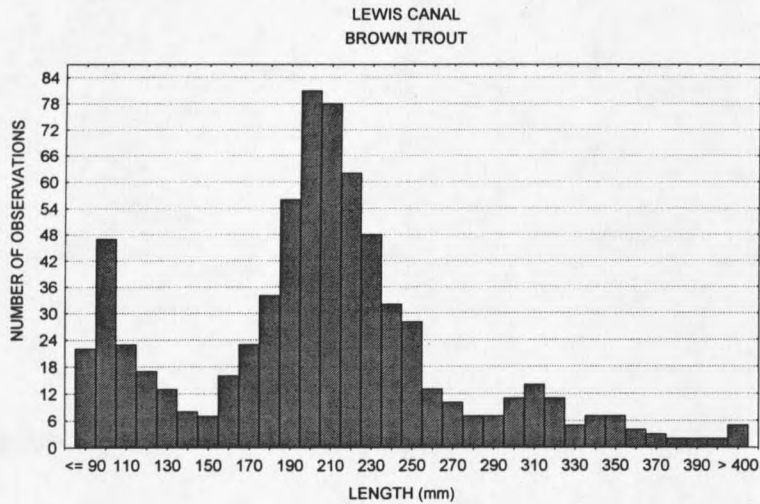


Figure 46. Length frequency histogram for brown trout sampled in the Lewis canal in 1994.

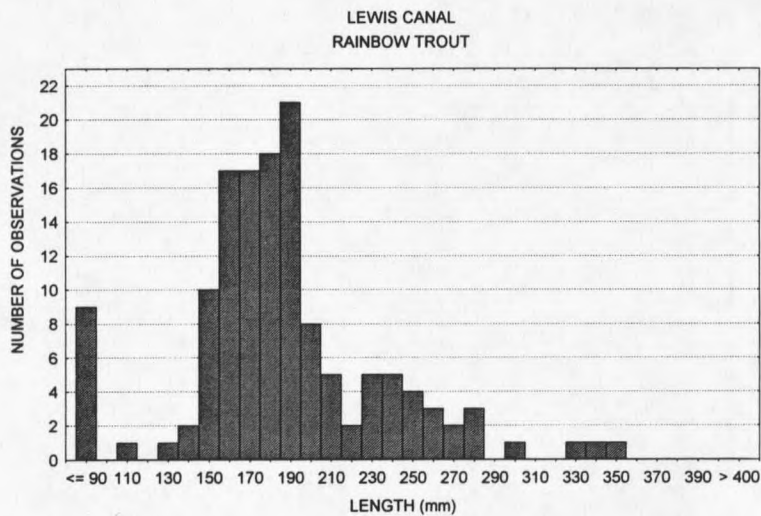


Figure 47. Length frequency histogram for rainbow trout sampled in the Lewis canal in 1994.

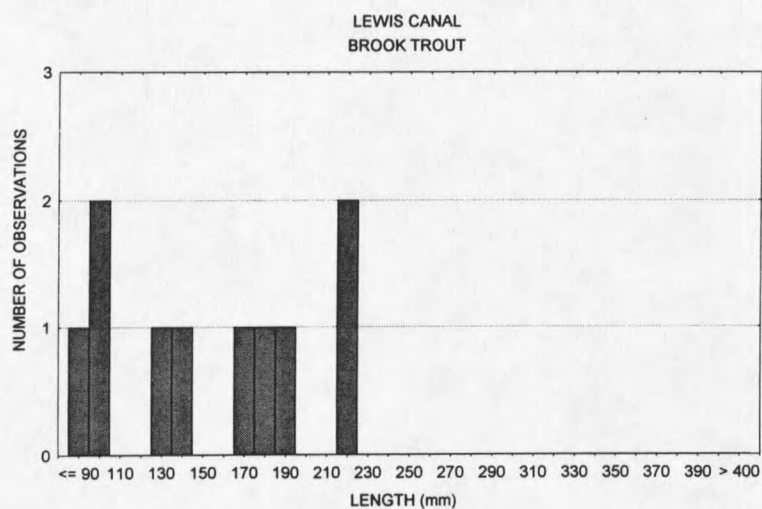


Figure 48. Length frequency histogram for brook trout sampled in the Lewis canal in 1994.

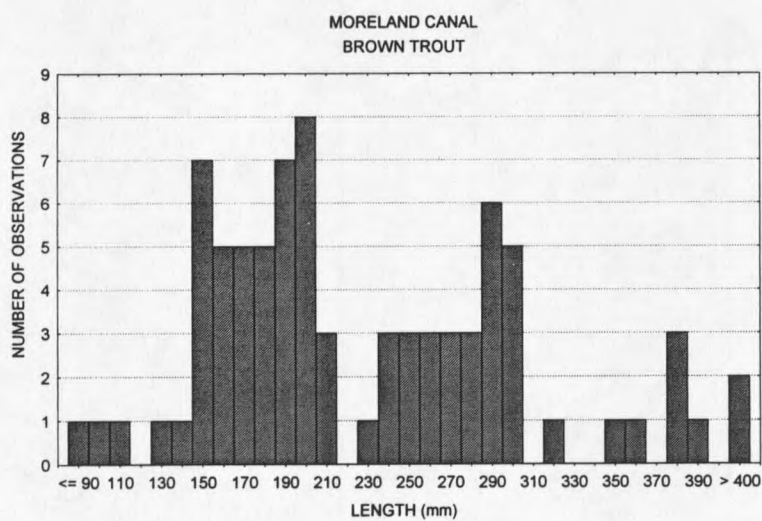


Figure 49. Length frequency histogram for brown trout sampled in the Moreland canal in 1994.

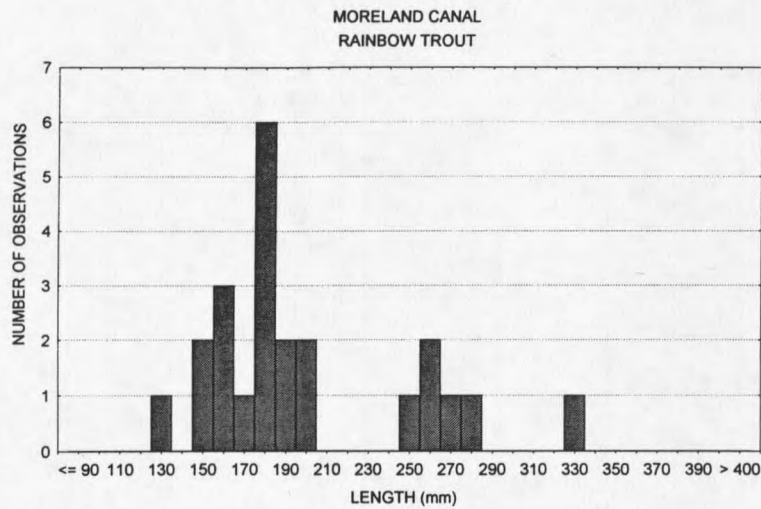


Figure 50. Length frequency histogram for rainbow trout sampled in the Moreland canal in 1994.

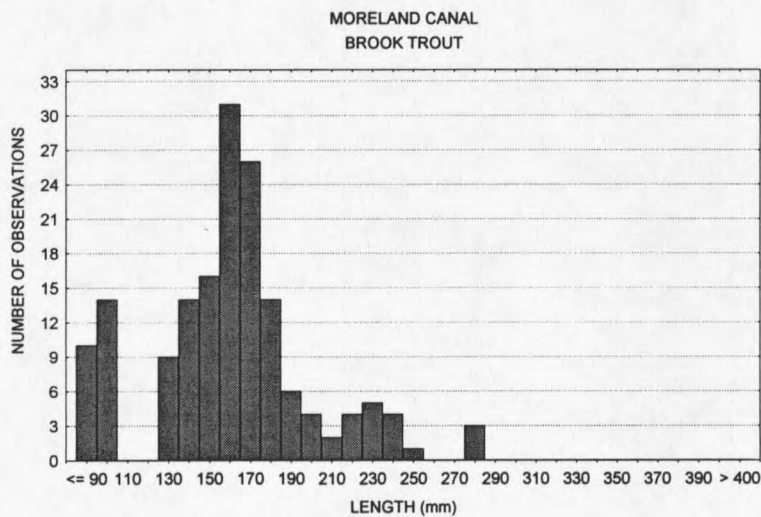


Figure 51. Length frequency histogram for brook trout sampled in the Moreland canal in 1994.

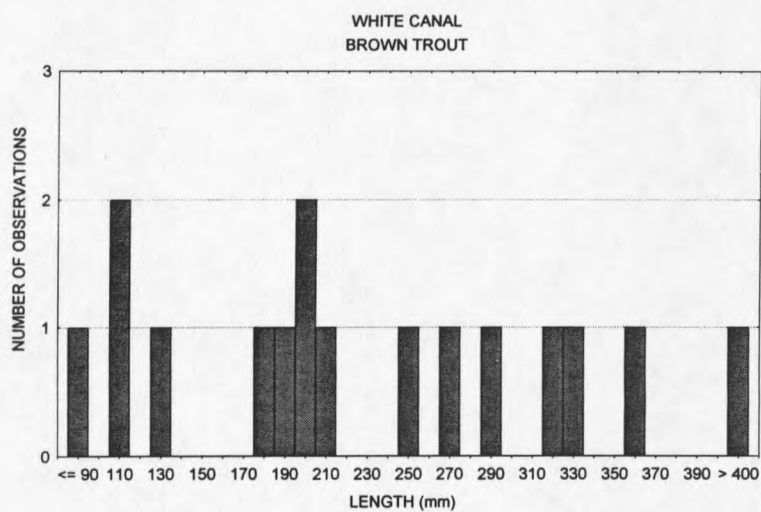


Figure 52. Length frequency histogram for brown trout sampled in the White canal in 1994. Only one rainbow (150mm) was captured therefore no histogram was created.

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