AN ASSESSMENT OF LOSSES OF NATIVE FISH TO IRRIGATION DIVERSIONS ON SELECTED TRIBUTARIES OF THE BITTERROOT RIVER, MONTANA

by

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

of

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ABSTRACT

Withdrawals of surface water for irrigation and stock water leave the Bitterroot River and its tributaries chronically dewatered during the irrigation season. These water withdrawals affect local trout populations by entraining migratory trout into irrigation diversion canals at multiple life stages, and through the loss and degradation of available habitat for aquatic species. Irrigation losses may be responsible in part for the low abundances and restricted distributions of migratory native westslope cutthroat trout *Onchorhyncus clarkii lewisi* and bull trout *Salvelinus confluentus* in this system. My objectives were to quantify entrainment of fish into irrigation diversions on Lost Horse and Tin Cup Creeks, two tributaries of the Bitterroot River used by migratory adult westslope cutthroat trout for spawning, and to identify characteristics of these diversions that correlate with entrainment. I sampled fish species by snorkeling, electrofishing, fry trapping, and reconnaissance at 60 sites in 2005 and 54 sites in 2006. Annual entrainment estimates for age-0 salmonids were 18,061 and 8,972 in 2005 and 2006 in Lost Horse Creek diversions. Concurrent entrainment estimates for Tin Cup Creek were 2,995 and 2,312. Annual entrainment estimates for juvenile and adult trout (>40 mm TL) were 7,947 and 7,877 in 2005 and 2006 in Lost Horse Creek diversions. Concurrent entrainment estimates for Tin Cup Creek were 2,554 and 1,691. The species composition of trout entrained in Lost Horse Creek was dominated by brook trout, whereas on Tin Cup Creek, the species composition of entrained trout was dominated by westslope cutthroat trout. Entrainment of juvenile and adult trout was significantly associated with discharge, upstream gradient, discharge ratio, length of irrigation season, temperature, diversion dam height, and angle with downstream thalweg. A model containing discharge and upstream gradient was the best model selected using the Akaike Information Criterion for small sample sizes (AICc). Several diversions on Lost Horse and Tin Cup Creeks are responsible for the majority of entrainment occurring on these streams, and should be considered for potential screening projects. In addition, a model containing discharge and upstream gradient may help managers identify candidate diversions that could benefit from fish screens to reduce native trout losses.

INTRODUCTION

Water diversions divert water from streams and rivers in Montana for crop irrigation, livestock watering, flood control, hydroelectric power, drinking water and other beneficial uses. Unfortunately, these diversions also commonly entrain fish into pumps, pipes, irrigation canals and agricultural fields, resulting in mortalities that may affect fish populations. Entrainment is especially prevalent among migratory native salmonid species, which can enter diversions as post-spawn adults migrating downstream or as juveniles emigrating from nursery tributaries. The westslope cutthroat trout, *Oncorhynchus clarkii lewisi*, and bull trout, *Salvelinus confluentus*, are two native fish species in western Montana that have experienced declines in their historic range because of a suite of anthropogenic threats common to many native species throughout the West including habitat degradation, non-native species, and altered hydrologic regimes (Richter et al. 1997). Water withdrawals for agricultural activities in Montana exemplify anthropogenic challenges to these species; in addition to entraining fish, they reduce instream flows, degrade habitat, and act as barriers to migration. In tributaries of the Bitterroot River, where irrigation diversions were first developed in 1842, irrigation losses may be responsible in part for low abundances and restricted distributions of these species in the Bitterroot watershed.

Westslope cutthroat trout are a subspecies of interior cutthroat trout

whose native range includes major drainages in Montana and Idaho, and several small drainages in Oregon, Washington, British Columbia, Wyoming, and Alberta (Behnke 1992). Westslope inhabit only about 27 to 39% of their former range in Montana (Liknes 1984; Liknes and Graham 1988; Shepard et al. 2003); genetically pure populations are found in 2.5% of this historic range (Liknes 1984; Liknes and Graham 1988). Westslope cutthroat trout are currently a "Species of Special Concern" in Montana (Montana Natural Heritage Program 2004), and were considered for federal listing as an endangered species (U.S. Fish and Wildlife Service 2003).

The four main life history types recognized for westslope cutthroat trout are fluvial, fluvial-adfluvial, lacustrine-adfluvial, and allacustrine (Varley and Gresswell 1988; Northcote 1997). Fluvial or "resident" populations spend their entire life cycle in natal streams or rivers. Fluvial-adfluvial populations use tributaries for spawning and rearing, and larger rivers to grow and mature. Adfluvial populations spawn in tributaries of lakes, and return to lakes or reservoirs to grow and mature. Allacustrine populations spawn in lake outlets and return to lakes or reservoirs to grow and mature. All four of these life history types can occur within a stream or drainage, and the differences among them are thought to be behavioral rather than morphological (Averett and MacPhee 1971).

Fluvial-adfluvial populations of cutthroat trout are more susceptible to loss of connectivity of habitat than fluvial populations because they use more habitat to complete their life cycles (McIntyre and Rieman 1995; Schmetterling 2001).

The spawning migrations of adult fish, outmigration of juvenile fish, and dispersal of age-0 fish all potentially suffer from the loss of connectivity of habitats.

Culverts, dams, and irrigation diversions fragment cutthroat trout habitat and affect fish movement. In addition, altered flow regimes and temperature regimes may act in concert to affect cues for migratory behavior. The fluvial-adfluvial life form of this fish is important for the evolutionary legacy of cutthroat trout because it constitutes a distinct life history type that is adapted to recolonize and disperse into new habitats (Van Eimeren 1996).

Bull trout, a charr native to Montana, have declined throughout their historic range for many of the same reasons as westslope cutthroat trout, including loss and degradation of habitat, overfishing, competition from non-native species, and hybridization (Saffel and Scarnecchia 1995; Swanberg 1997). Bull trout are listed as a “threatened” species under the federal Endangered Species Act (USFWS 1998). Similar to westslope cutthroat trout, bull trout have fluvial, fluvial-adfluvial, lacustrine-adfluvial, and allacustrine life history forms, with migratory bull trout differentially affected by habitat fragmentation and loss (Rieman and McIntyre 1993). Many bull trout populations currently exist as small-bodied fluvial populations in isolated headwater habitats, and their distribution may be limited by thermal tolerances (Fraley and Shepard 1989), low percentage of fine sediment, and pool habitat (Watson and Hillman 1997). As in the case of westslope cutthroat trout, the decline in the historic large-bodied migratory form of bull trout decreases the viability of the remaining

small, isolated populations through the increased threat of local extinctions (Neraas and Spruell 2001).

Both westslope cutthroat trout and bull trout occur in the Bitterroot River drainage of Montana. The Bitterroot River drainage has the longest history of water withdrawals for irrigation purposes in Montana. The first known irrigators in the valley were Jesuit priests, who diverted water for agriculture in 1842 from Burnt Fork Creek, a tributary of the Bitterroot River. Water rights in Montana follow the Doctrine of Prior Appropriation, which allows for the diversion of surface water, regardless of the reduction of water supply in the stream, and allows for use of this water by both riparian and non-riparian landowners (State Engineer's Office 1965).

The Bitterroot Valley has experienced tremendous human population growth since its first settlement by Europeans, with an estimated 480 kilometers of ditches irrigating 44,500 hectares of farms and ranches as a legacy of this growth (Bitterroot Water Forum 2003). Withdrawals of surface water for irrigation and stock water leave the mainstem of the Bitterroot River and its tributaries chronically dewatered during the irrigation season (Spoon 1987). These water withdrawals affect native westslope cutthroat and bull trout populations by entraining fish in irrigation diversions at multiple life stages (Clothier 1953; Hallock and Van Woert 1959) and through the loss and degradation of available habitat for aquatic species. These populations have also experienced declines from historic levels in the Bitterroot drainage as a result of competition with non-

native species and overexploitation. Non-native trout species such rainbow trout, brook trout, and brown trout *Salmo trutta* are common in the mainstem river and exist to varying degrees in tributaries. Tributaries support consistent and widespread populations of westslope cutthroat trout, and fewer populations of bull trout (Clancy 1993). Although 55 of 72 tributary populations of westslope cutthroat trout are pure, most tributary populations draining the Bitterroot Range to the west are introgressed with rainbow trout because rainbow trout were stocked in high mountain lakes in these drainages (Clancy 1998). Displacement by brook trout and bull trout-brook trout hybridization also occurs in some tributaries.

Westslope cutthroat trout populations have increased in the Bitterroot River since the onset of monitoring in 1989, likely because of catch-and-release regulations implemented in 1990 (Clancy 2003). The existing fluvial-adfluvial populations use a diversity of spawning sites in various tributaries throughout the drainage (Javorsky 2000, 2002; Clancy 2003). The fluvial-adfluvial form of bull trout is rare, with most remaining populations existing as small fluvial populations in headwater tributaries (Montana Bull Trout Scientific Group 1995; Jakober et al. 1998).

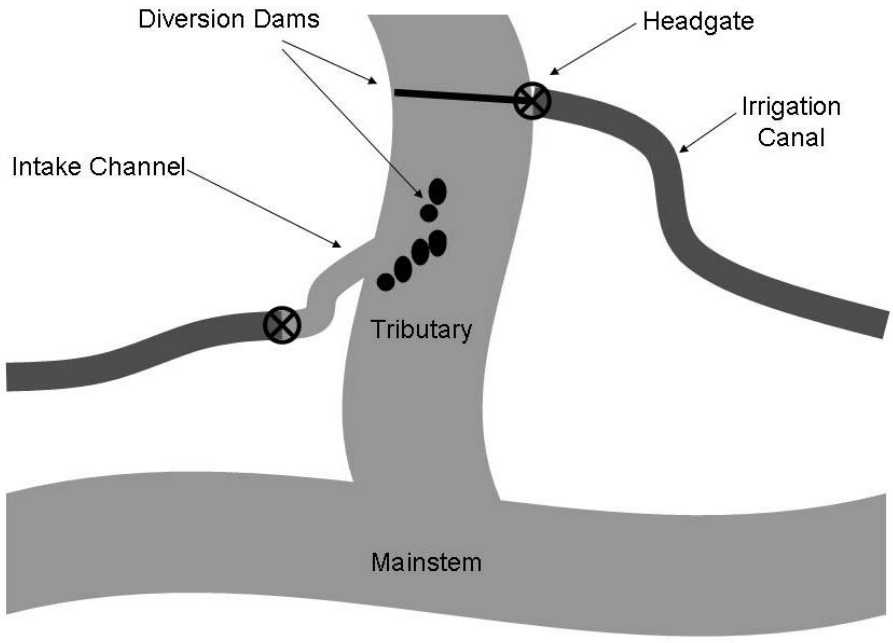

Figure 1. Schematic diagram of a tributary-mainstem system with irrigation diversions, including irrigation canals, diversion dams, intake channels, and headgates. Post-spawning fluvial-adfluvial adult trout, juvenile fluvial-adfluvial trout migrating to mainstem river habitat, and downstream-drifting age-0 trout have opportunities to become entrained in this system. Resident, fluvial trout can also become entrained in their diel or seasonal movements.

Entrainment, the process by which fish are pulled through water diversion or other structures into irrigation canals (Zydlewski and Johnson 2002), is a result of withdrawals of surface water from streams and rivers where fish reside. The problem of fish loss to irrigation ditches in Montana is compounded by the coincident timing of migratory behavior and the irrigation season.

Losses of potadromous fish to irrigation diversions in Montana and throughout the Northern Rockies have been documented and quantified to a lesser degree than for anadromous fish in Idaho, California, and Washington

(Reiland 1997). Previous studies of fish losses to irrigation diversions in Montana, Idaho, and Alberta, Canada, have identified that entrainment occurs, but the magnitude of documented entrainment is often quite variable among canals and streams (Clothier 1953; Spindler 1955; Good and Kronberg 1986; Thurow, 1980, 1981, 1987, 1988; Der Hovanisian 1995, 1997a, 1997b; Der Hovanisian and Megargle 1998; Megargle 1999; Evarts et al. 1991; Reiland 1997; Gale 2005). Two studies have attempted to identify the physical factors that best correlate with entrainment rates, but were either statistically inconclusive (Spindler 1955) or lacked predictive power (Reiland 1997). In addition, the population-level effects of entrainment remain poorly understood, especially with respect to the cumulative effects of all diversions within a single system. Some commonalities of the different studies in this region include observations, either quantitatively or qualitatively, that juvenile fish are entrained at higher rates than adult fish, that larger diversions with high ratios of flow diverted entrain more fish than smaller diversions, and that diversions with headgates that act as barriers to movement back to host streams entrain greater numbers of fish.

Fish screens have been widely implemented and studied for migratory fish passage, with the first known fish screen reported in Caledonia Creek, New York (Leitritz 1952). Fish screens are devices used to prevent fish from entering irrigation diversions and bypass fish back to the stream channel (Reiland 1997). Screening efforts were first widely adopted in western states with declining

anadromous fish stocks, such as California and Idaho. Legislation requiring screens to be placed in irrigation canals from September 1 to March 1 was passed in 1893 in Montana but subsequently revoked because of its impracticality (Clothier 1953). Federal legislation was passed in 1938 to screen diversions on streams with anadromous salmonids in Idaho, Oregon, and Washington, but no such legislation mandates installation of fish screens on ditches in Montana. In the absence of such legislation, most irrigation canals in Montana remain unscreened because of the cost and effort of installing and maintaining screens.

Mitigation by fish screening is a potential strategy for improving the status of fish populations in the Bitterroot River watershed, especially those with the fluvial-adfluvial life history. The federal Fisheries Restoration and Irrigation Mitigation Act of 2000 or FRIMA (Public Law 106-502) is currently addressing the issue of fish losses to irrigation canals by supplying local, state, and tribal programs with funding for fish screening and fish passage projects. For the Bitterroot River, the U.S. Fish and Wildlife Service and Montana Fish, Wildlife, and Parks have agreed to use FRIMA funds for the installation of a fish screens, and for an inventory to aid in the development of mouth-to-headwaters fish passage/screening plans for tributaries of the Bitterroot River. A 2002 survey identified and surveyed a subset of ditches on five tributaries through a convenience sampling approach (Devore and Peck 2005), using electrofishing as the primary sampling technique (Rokosch 2004). This preliminary survey showed

that entrainment occurs in irrigation canals on Bitterroot tributaries, but variability exists in the entrainment rates among diversions as well as in the distribution of entrained fish within diversions.

Development of a sound passage and screening plan for these tributaries requires accurate information about the magnitude of entrainment in ditches. A review of fish screening projects in California's Central Valley, where over 3,000 diversions exist, identified little quantitative basis for screening irrigation diversions (Moyle and Israel 2005). Inquiries regarding entrainment rates into diversions for all life stages and species of fish, evaluation of population-level benefits of fish screens, relationships between entrainment rates and amount of water diverted, benefits of selective screening, potential detrimental effects of screening, and alternatives to screening, have occurred for a relatively small proportion of diversions, screened and unscreened. Moyle and Israel (2005) highlighted a need for more scientific study about factors influencing the entrainment rates of fish into diversions off of riverine systems, and the population-level benefits of fish screens. Some of these questions have been addressed on Skalkaho Creek, a tributary of the Bitterroot River, by Gale (2005), who quantified entrainment rates of westslope cutthroat trout into screened and unscreened canals using radiotelemetry and trapping, before and after installation of three fish screens. Fish screens were effective in bypassing fish, but many telemeterized fish were non-migratory and were therefore less susceptible to entrainment.

The goal of my study was to estimate native fish entrainment in diversions on two tributaries to the Bitterroot River, Lost Horse and Tin Cup creeks, to determine which diversions on these creeks would benefit most from installation of fish screens. In addition, physical, spatial, and temporal characteristics of diversions were quantified and incorporated into a model relating such characteristics to rates of entrainment of migratory fish. A predictive model to identify the physical and spatial characteristics of diversions that correlate with rates of entrainment would facilitate development of screening plans by reducing the need for fish sampling. I used my entrainment abundance estimates and site-specific characteristics to determine if such a model could be successfully developed. In addition, I tested the predictive power of the model by sampling diversions on another tributary of the Bitterroot River, Blodgett Creek.

STUDY AREA

The Bitterroot River drains a 7,409 km^2 basin that is bounded by the Sapphire Mountains to the east and the Bitterroot Mountain Range to the west. The headwaters of the Bitterroot River are located in the southern end of Ravalli County, from which the Bitterroot flows roughly 134 km northward to its confluence with the Clark Fork River near Missoula, Montana (SEO 1965). The drainage consists of 27 tributaries originating from the west and 12 tributaries originating from the east.

My assessments were conducted on diversions on a subset of Bitterroot River tributaries originating from the west (Tin Cup, Lost Horse, and Blodgett creeks; Figure 2) known to support spawning by fluvial fish as previously determined by Montana Fish, Wildlife, and Parks personnel using telemetry (Javorsky 2000, 2002; Clancy 2003). Lost Horse and Tin Cup creeks were selected for sampling in 2005 and 2006 because of access granted by landowners, a similar number of irrigation canals, and similar size of the tributaries and the irrigation systems they support. In 2006, sampling was also conducted on Blodgett Creek.

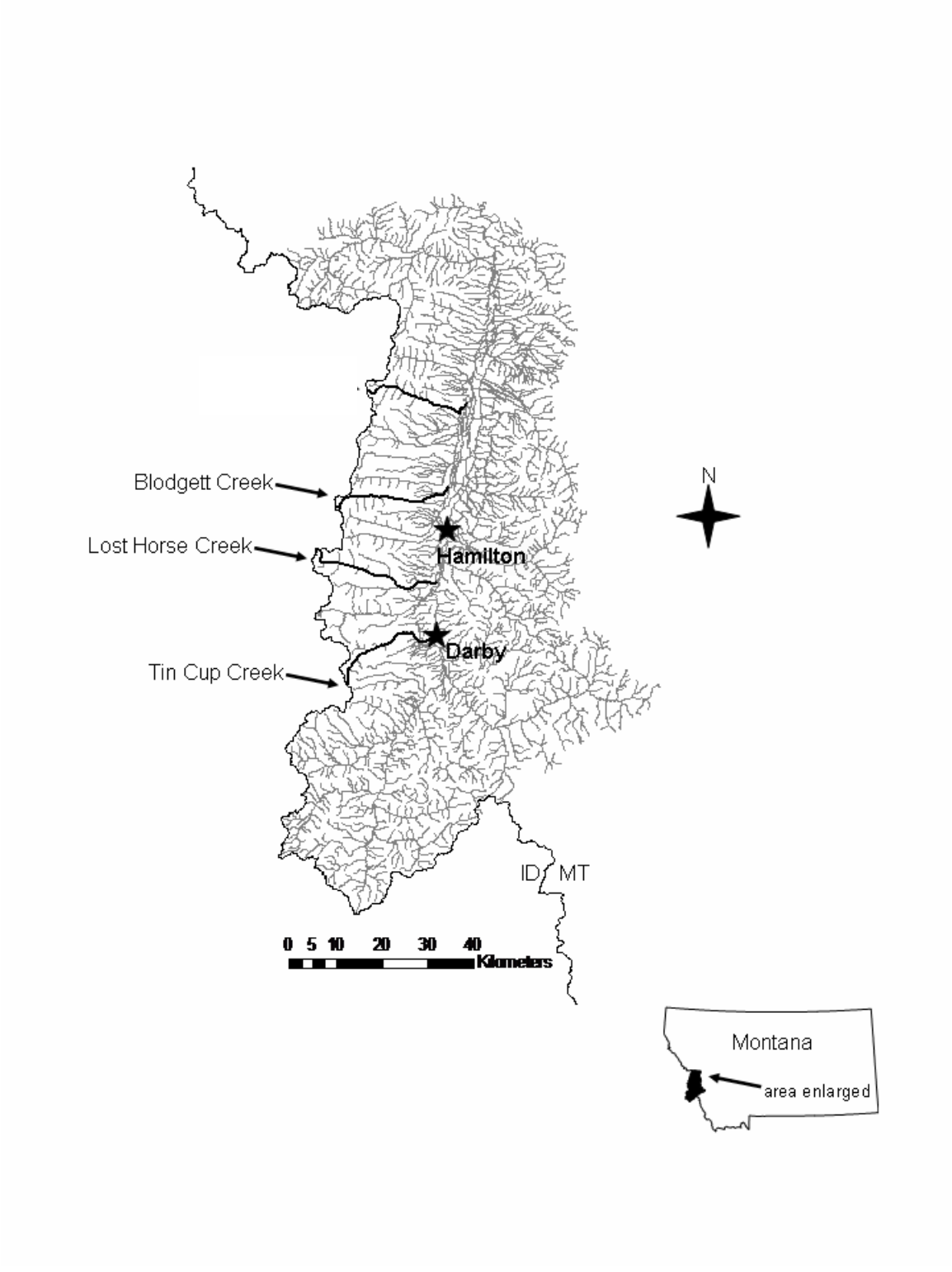

Figure 2. The Bitterroot River drainage, the location of Blodgett, Lost Horse, and Tin Cup creeks, and the location of Hamilton and Darby, Montana.

Lost Horse, Tin Cup, and Blodgett creeks are west-side tributaries of the Bitterroot River that drain the Bitterroot Range near Hamilton and Darby, Montana. The headwaters of Lost Horse Creek are located on the Bitterroot National Forest about 30.5 km west of where Lost Horse joins the Bitterroot mainstem. The upper portion of Lost Horse Creek is divided into three forks: North Lost Horse Creek, South Lost Horse Creek, and Lost Horse Creek. Additional water for irrigation is stored in Twin Lakes, a natural lake that has been augmented for storage purposes, located at the headwaters of Lost Horse Creek. Lost Horse is a fourth-order stream that is primarily on Forest Service land until about 9 km above the mouth, where it enters private land and is dewatered by seven diversions. These are, in descending order from the uppermost diversion, the Bitterroot Irrigation Ditch or BRID Ditch, Highline or Clausin-Kramis Ditch, Clubhouse Ditch, Low Ditch, Point of Diversion 1 or POD 1 Ditch, Point of Diversion 5 or POD 5 Ditch, and the Ward Ditch (Table 1, Figures 3 and 4). The average mean monthly discharge of Lost Horse Creek based on historical data (1938-1982) from a USGS gauge site 8.0 km upstream from the mouth, ranges from 0.91 cms in February to 20.94 cms in June (Rokosch 2005). Instream temperatures vary at sites below diversion dams throughout the study area (Figures 5 and 6), with lower temperatures at upstream sites, higher temperatures at downstream sites, and variable temperatures at intermediate sites. The Lost Horse Creek fish assemblage includes westslope cutthroat trout *Oncorhynchus clarkii lewisi*, bull trout *Salvelinus confluentus*, brook trout

Salvelinus fontinalis, rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*, mountain whitefish *Prosopium williamsoni*, longnose sucker *Catostomus catostomus*, longnose dace *Rhynichthys cataractae*, and slimy sculpin *Cottus cognatus* (Clancy 2005).

Table 1. Properties of Lost Horse Creek diversions, listed from upstream-most to downstream-most order. Total length of diversion, average bankfull width behind headgates, approximate duration of irrigation season, and average water withdrawal from 5/7/2006 to 8/1/2006 are shown.

Diversion (upstream to downstream)	Total length (km)	Bankfull width (m)	Duration of irrigation season	Average water withdrawal (cms)
B.R.I.D.	5.8*	5.0	April-November	0.396
Highline	5.3§	2.6	April- October	0.356
Clubhouse	3.9	1.5	April- October	0.113
Low	2.3	2.0	May-October	0.239
P.O.D. 1	1.8	1.2	May-September	0.106
P.O.D. 5	1.4	1.3	May- August	0.050
Ward	2.7∞	5.8	April-November	0.658

*The B.R.I.D. diversion continues after 5.8 km during spring freshets and carries water underground to the discharge canal (a.k.a. “Big Ditch”) from Lake Como. After spring freshets (early to mid July), the diversion is dammed at 5.8 km for local irrigation purposes.

§The Highline diversion has a main spur diversion known as the Lone Pine Ditch which diverts water from it and eventually connects with the Clubhouse diversion.

∞ The Ward ditch continues after 2.7 km, after which point it crosses and draws water from two drainages to the north, Hayes Creek and Camas Creek. After spring freshets (early to mid July), the Ward ditch diversion dam completely blocks Lost Horse Creek and is supplemented by a canal conveying Bitterroot River water across the dammed Lost Horse Creek.

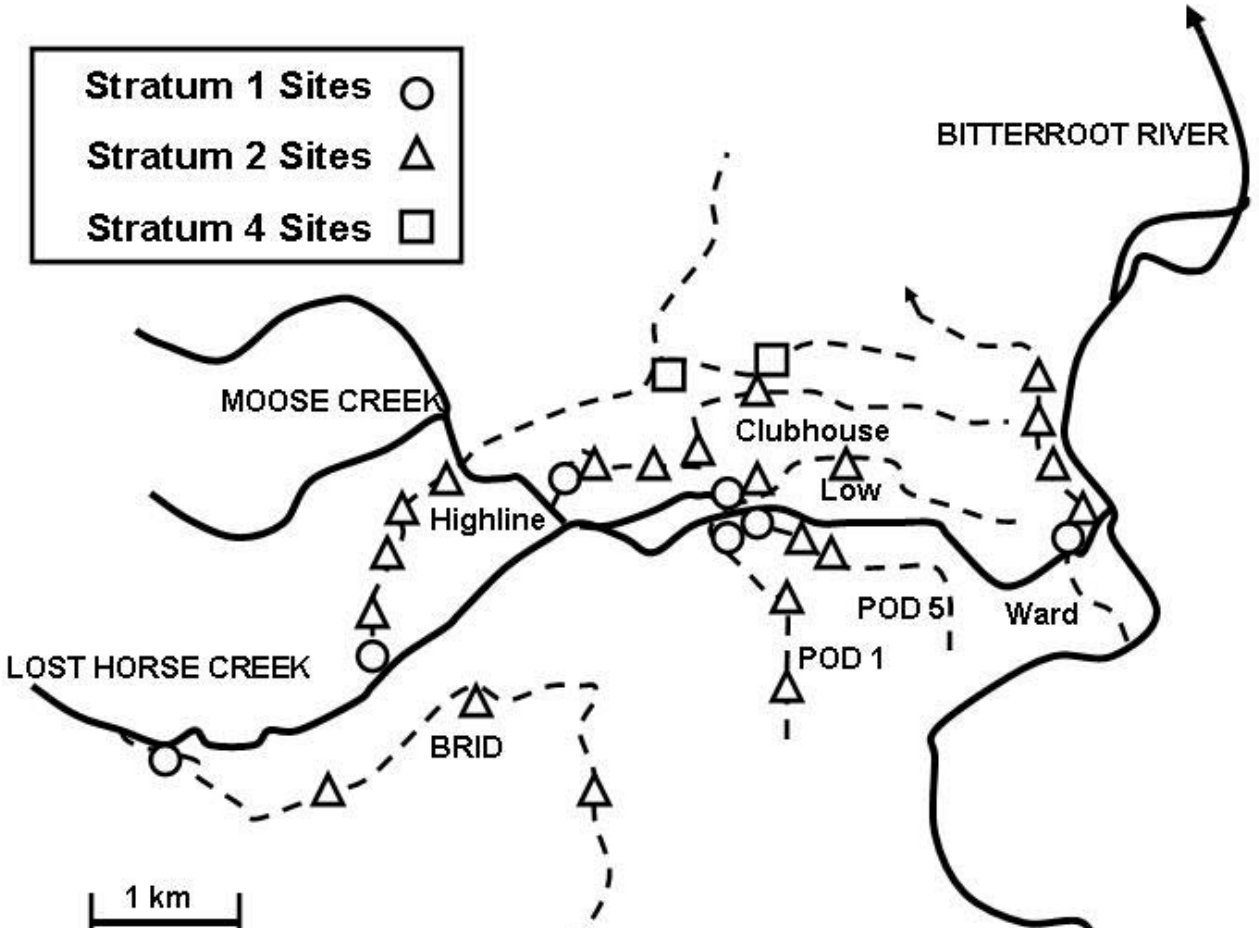

Figure 3. Schematic map of Lost Horse Creek, Montana, showing locations of diversions and sampling sites. Diversions are represented by dotted lines. Arrows indicate those diversions or streams that continue past the scope of the map.

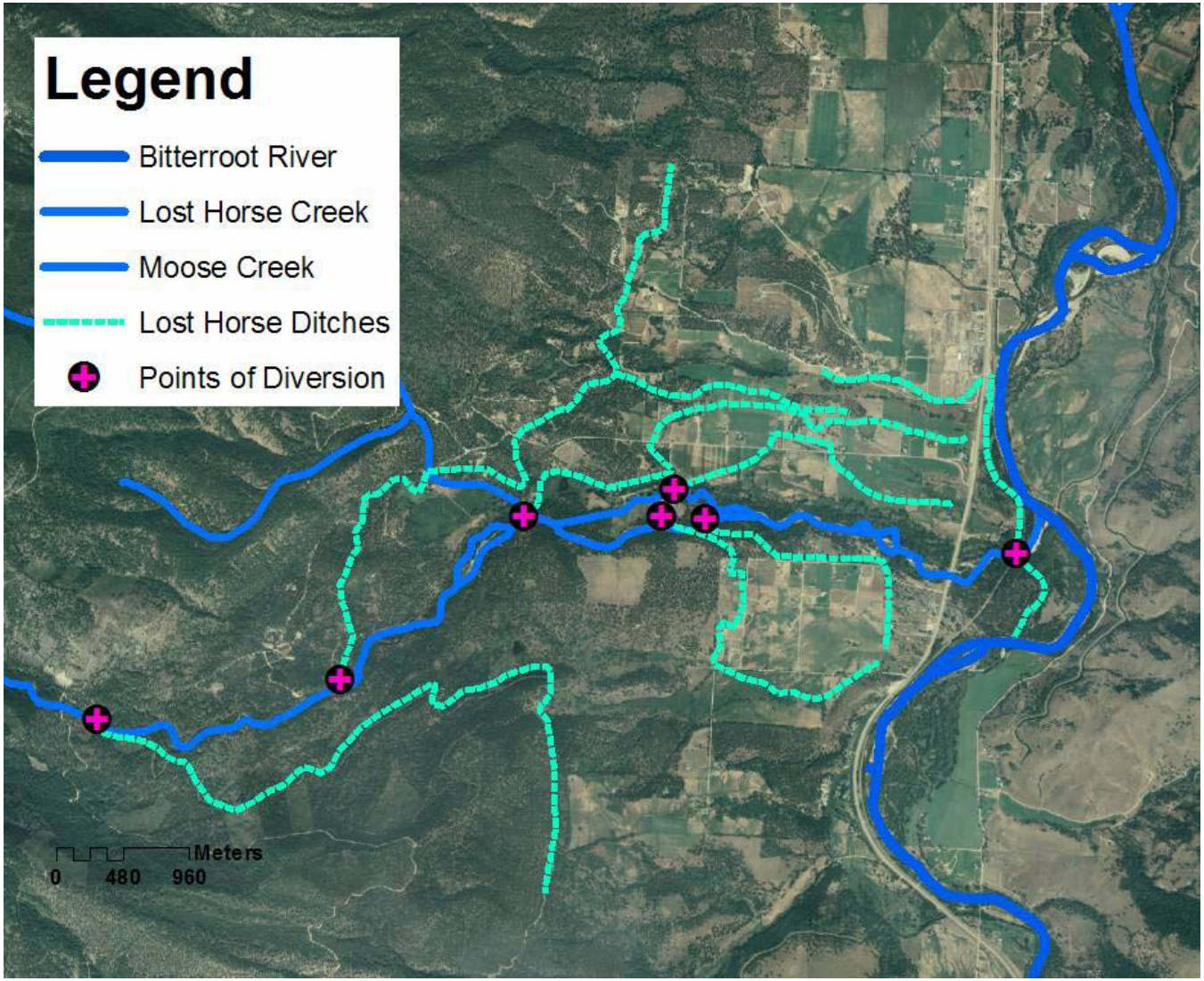

Figure 4. Aerial photograph of the Lost Horse Creek study area, showing the location of Lost Horse Creek, the Bitterroot River, irrigation canals, and points of diversion.

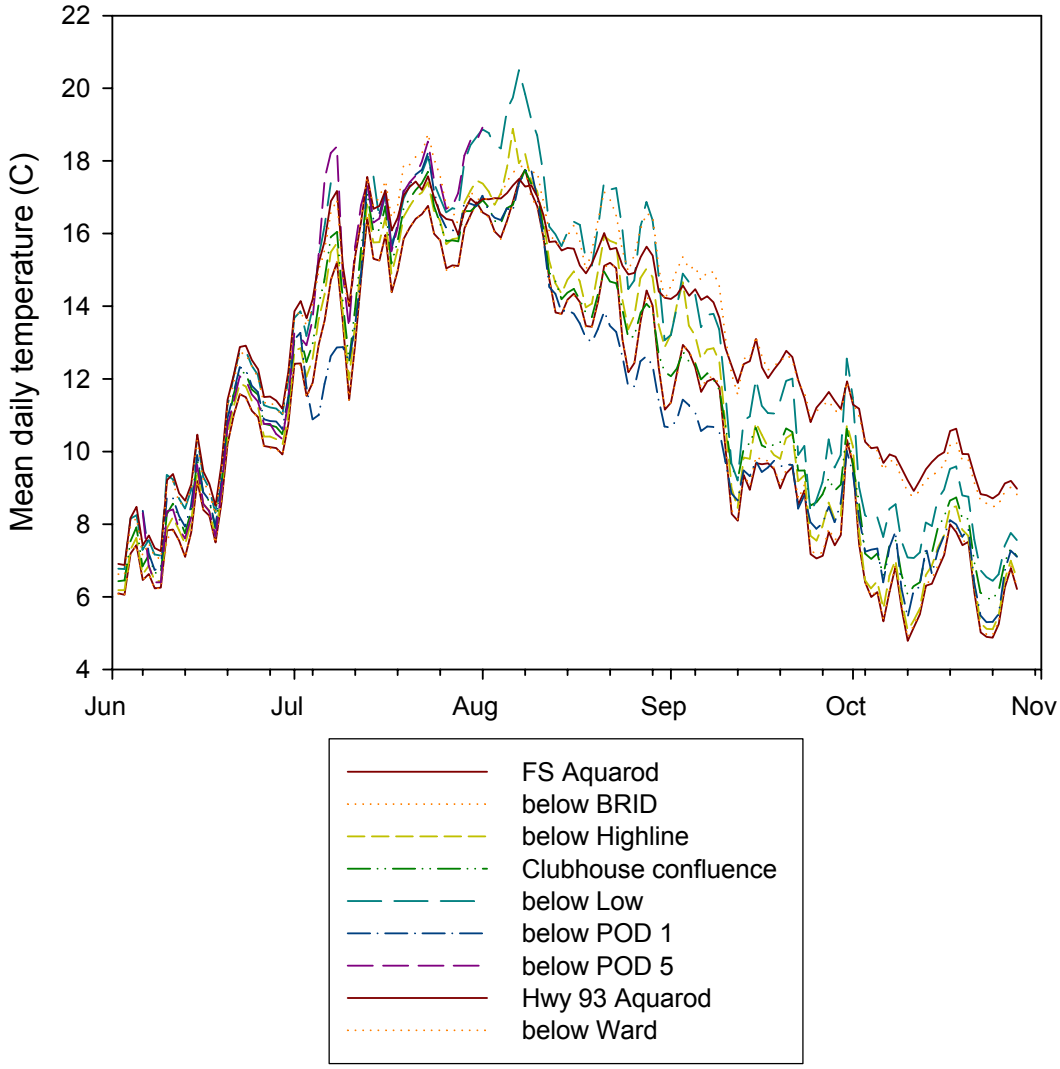

Figure 5. Mean daily water temperatures above and below Lost Horse Creek diversion dams in 2005.

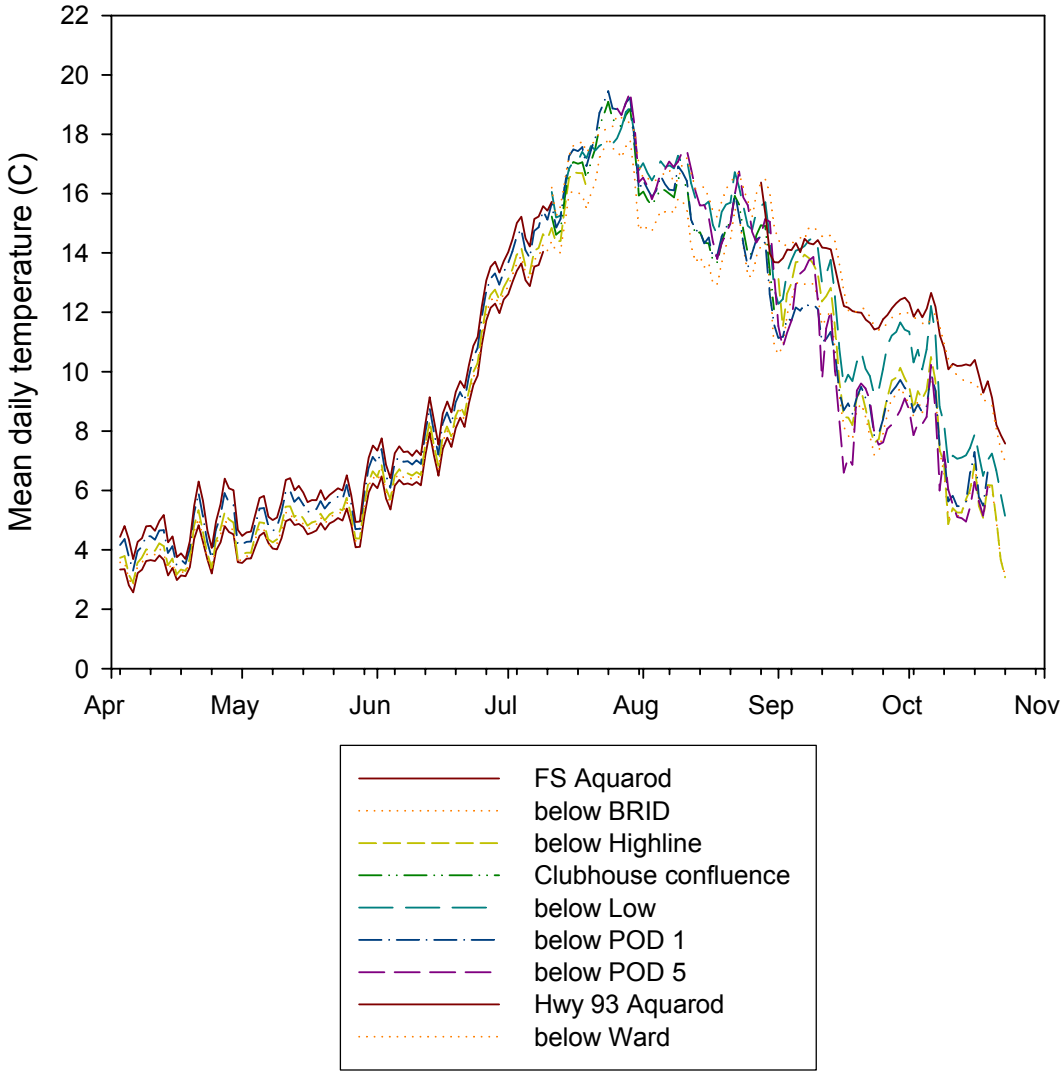

Figure 6. Mean daily temperatures above and below Lost Horse Creek diversion dams in 2006.

Tin Cup Creek is located two drainage systems upstream of Lost Horse Creek. Its headwaters are located on Forest Service land within the boundary of the Selway-Bitterroot Wilderness, about 29 km west of where it joins the Bitterroot mainstem. Tin Cup Lake is a natural lake augmented for water storage purposes located several kilometers below the headwaters. Little Tin Cup Creek, a tributary of Tin Cup Creek, is located to the south of the main Tin Cup Creek, and joins Tin Cup Creek on private land. Tin Cup is a third-order stream that enters private land at about 7 km above its confluence with the mainstem of the Bitterroot River and is dewatered by five diversions. These are, in descending order from the uppermost diversion, the Tin Cup County Water and Sewer District or McIntosh-Morello Ditch, Ford-Hollister Supplemental Ditch, Chaffin-Whinnery Ditch, Click-Matteson Ditch, and Mill Ditch (Table 2, Figures 7 and 8). The main Ford-Hollister Ditch and Frazier-Spoon Ditch take surface water out of Little Tin Cup Creek above its confluence with Tin Cup Creek. The average mean monthly discharge of Tin Cup Creek based on historical data (1938-1982) from a USGS gauge site 6.4 km upstream from the mouth ranges from 0.74 cms in January to 9.28 cms in June (Rokosch 2005). Instream temperatures vary at sites below diversion dams throughout the study area (Figures 9 and 10).The Tin Cup Creek fish assemblage includes westslope cutthroat trout, bull trout, brook trout, rainbow trout, brown trout, mountain whitefish, slimy sculpin, and longnose dace (Kightlinger et al. 2003; Clancy 2005).

Table 2. Properties of Tin Cup Creek diversions, listed from upstream-most to downstream-most order. Total length of diversion, average bankfull width behind headgates, approximate duration of irrigation season, and average water withdrawal from 5/7/2006 to 8/1/2006 are shown.

Diversion (upstream to downstream)	Total length (km)	Bankfull width (m)	Duration of irrigation season	Average water withdrawal (cms)
T.C.C.W.S.D.	8.6	3.7	April-September	0.526
Ford-Hollister	1.4*	2.1	April-September	0.054
Chaffin-Whinnery	4.0	1.9	May- August	0.103
Click-Matteson	3.1	2.3	May- August	0.069
Mill	6.4	3.3	May- October	0.325

*The Ford-Hollister diversion primarily diverts water from Little Tin Cup Creek for 0.1 km, a main tributary of Tin Cup Creek. After spring freshets (early to mid July), this diversion supplements Little Tin Cup Creek water withdrawals with a canal conveying water from Tin Cup Creek.

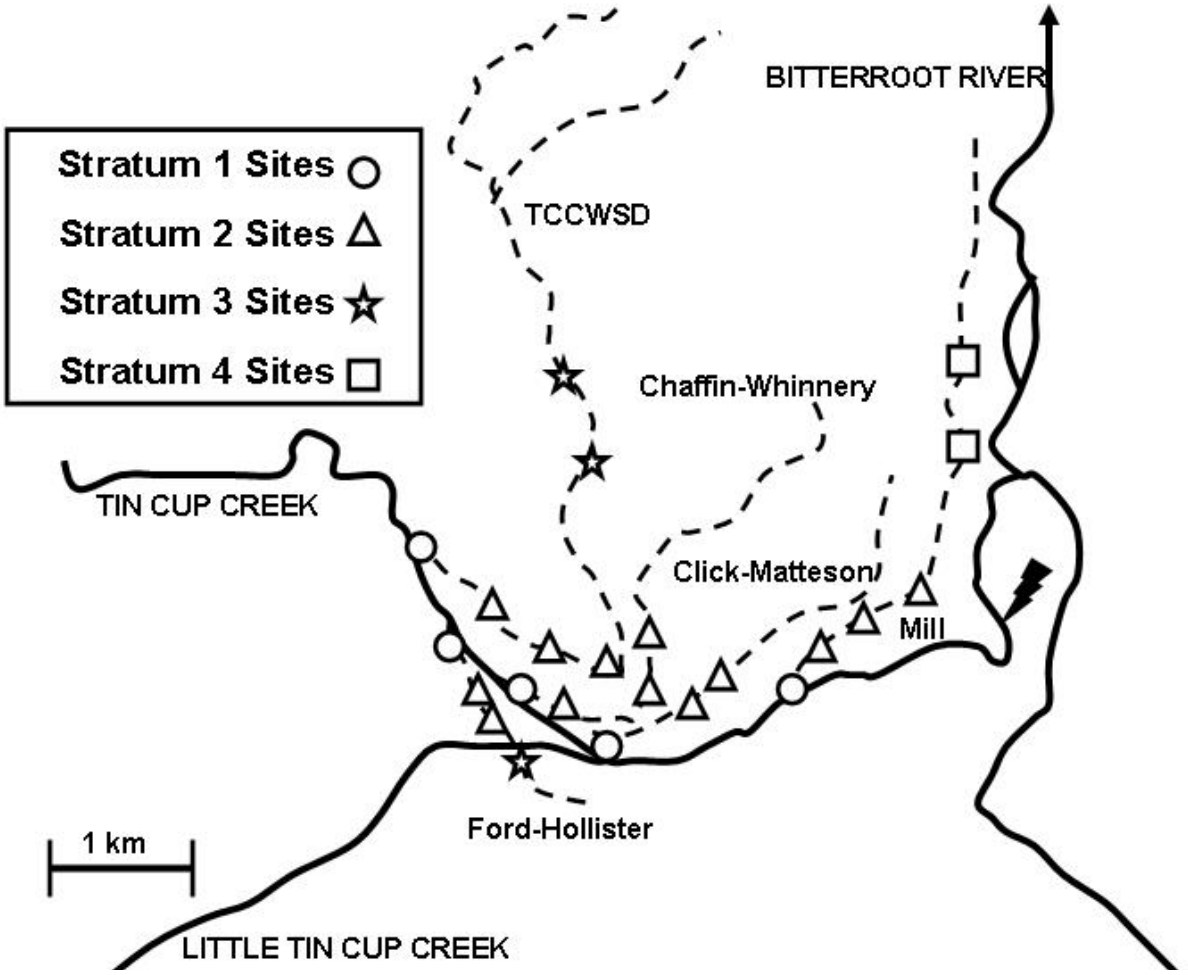

Figure 7. Schematic map of Tin Cup Creek, Montana, showing locations of diversions and sampling sites. Diversions are represented by dotted lines. Arrows indicate those diversions or streams that continue past the scope of the map. Lightning bolt indicates location of instream water right lease for fisheries.

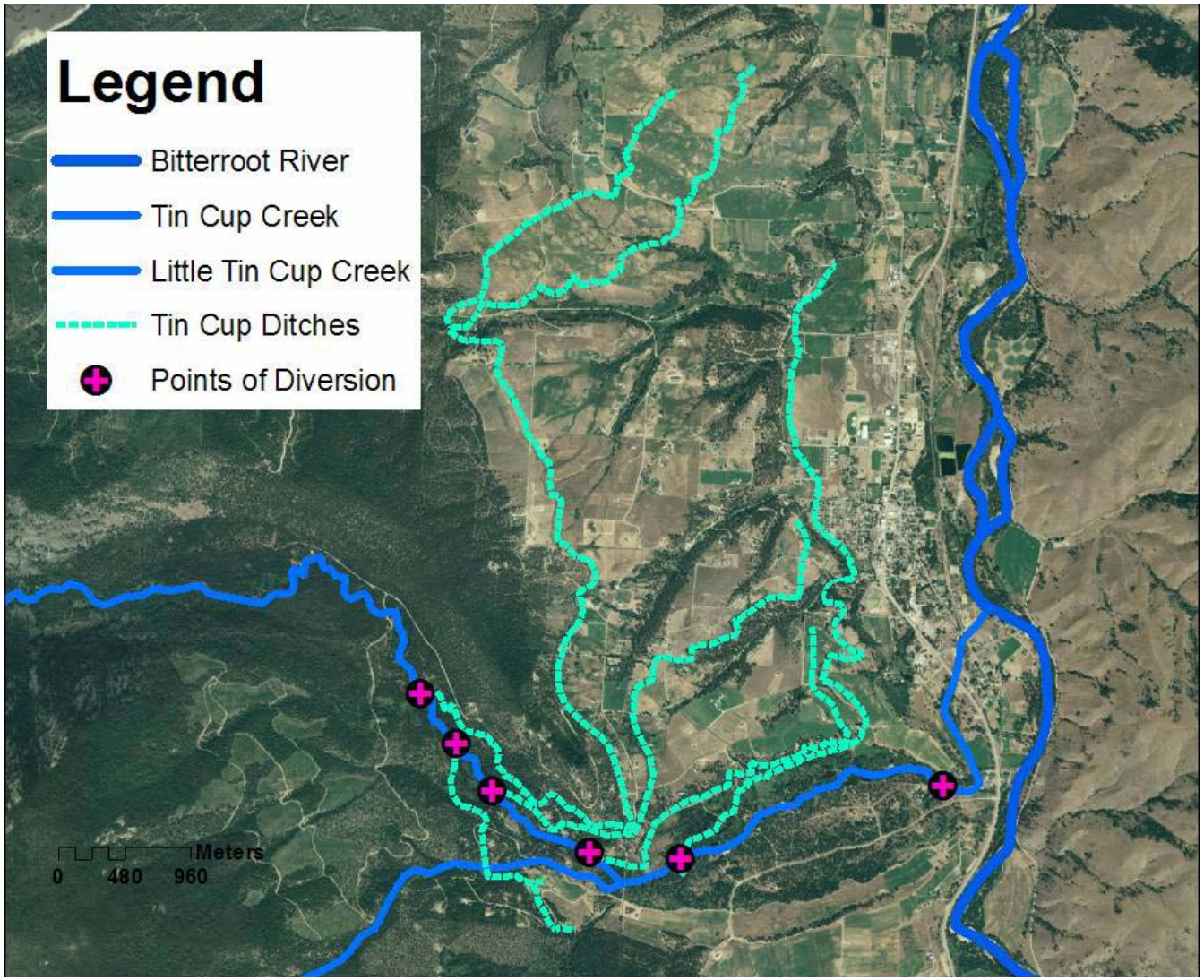

Figure 8. Aerial photograph of the Tin Cup Creek study area, showing the location of Lost Horse Creek, the Bitterroot River, irrigation canals, and points of diversion.

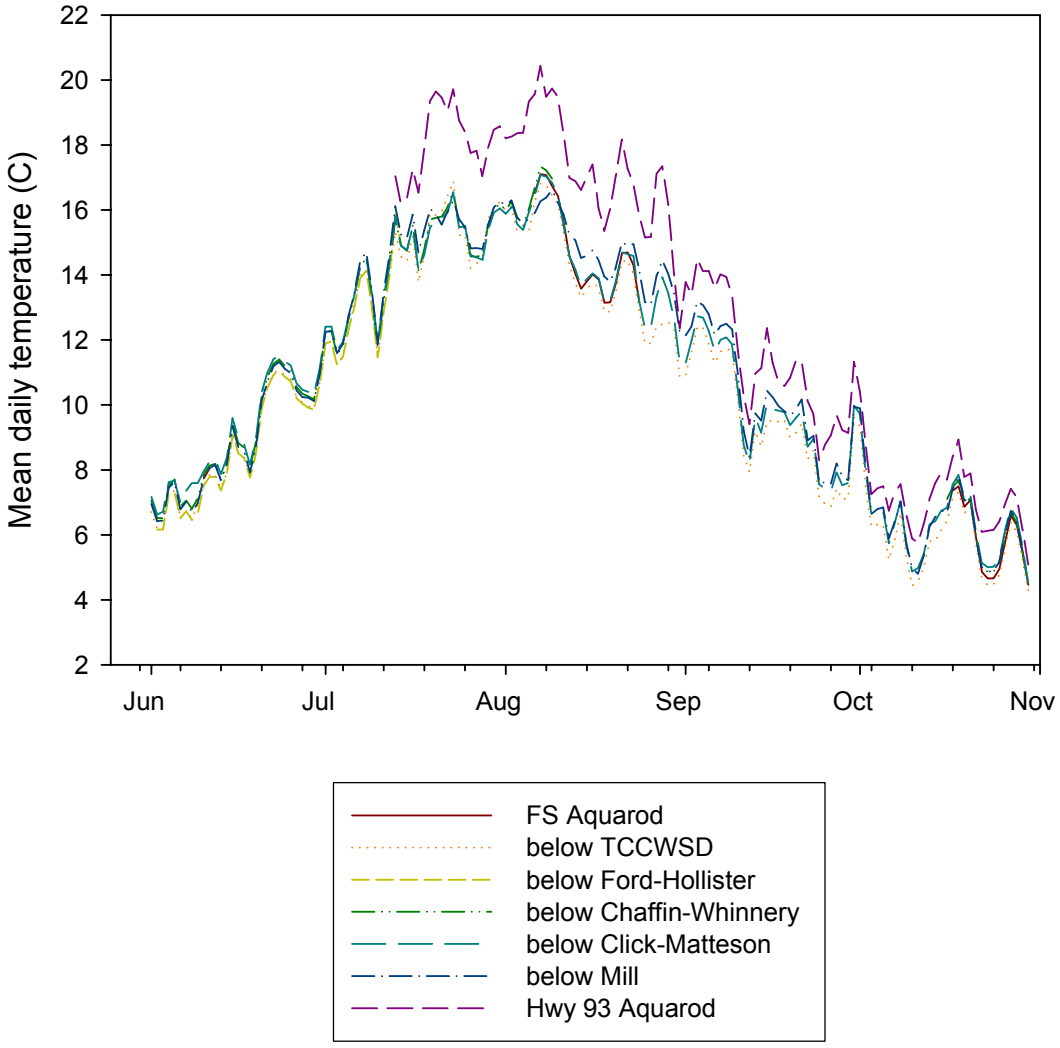

Figure 9. Mean daily water temperatures above and below Tin Cup Creek diversion dams in 2005.

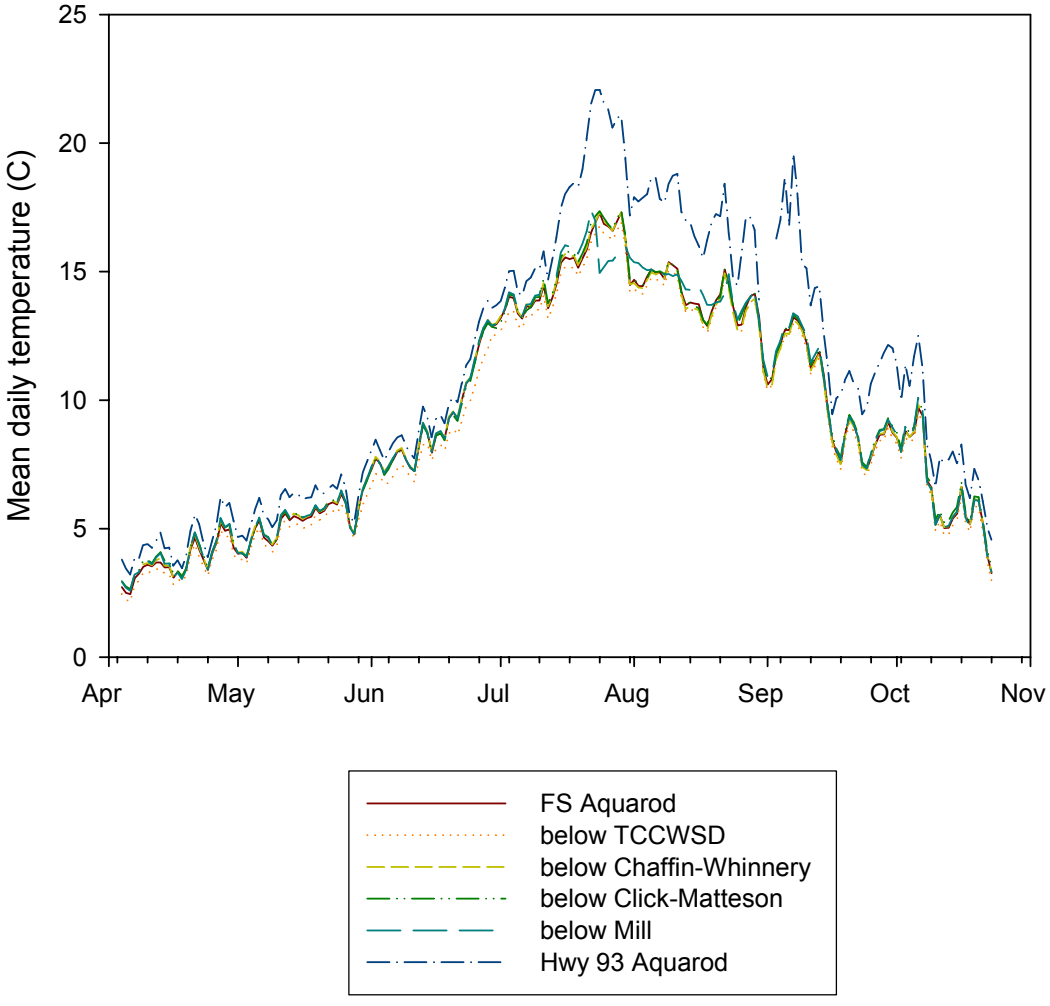

Figure 10. Mean daily water temperatures above and below Tin Cup Creek diversion dams in 2005.

Blodgett Creek is located three drainage systems downstream of Lost Horse Creek. Its headwaters are located on Forest Service land within the boundary of the Selway-Bitterroot Wilderness, about 29 km west of where Blodgett joins the Bitterroot mainstem. It is a third-order stream that enters private land at about 8 km above its confluence with the mainstem of the Bitterroot River. High Lake, located at the headwaters of Blodgett Creek, is a natural lake which has been augmented for storage purposes for irrigation. Blodgett Creek is dewatered by 7 main diversions. These are, in descending order from the uppermost diversion, the Fourth Right Ditch, First Right Ditch, Second Right Ditch, Third Right Ditch, Fifth Right Ditch, Sixth Right Ditch, and Woodside Ditch (Appendix A). Average bankfull widths for these diversions range from 0.77 to 5.39 m. The Woodside Ditch is supplemented by a canal conveying Bitterroot River water across the dammed Blodgett Creek after spring freshets (early to mid July). The Blodgett Creek fish assemblage includes westslope cutthroat trout, bull trout, brook trout, rainbow trout, brown trout, mountain whitefish, longnose dace, and slimy sculpin (Clancy 2005).

METHODS

Entrainment in Canals

I evaluated entrainment in canals by comparing characteristics of entrained fish with those of fish in adjacent stream reaches. I compared abundances and timing of age-0 fish entrained into irrigation canals with age-0 fish moving in a downstream direction. I compared species composition and size of entrained juvenile (> 40 mm total length (TL)) and adult fish with those observed in adjacent stream reaches. Techniques used to quantify entrainment in irrigation canals during the 2005 and 2006 field seasons included stationary trap-netting to assess losses of age-0 fish and snorkeling to assess losses of juvenile and adult fish.

Age-0 Fish

Stationary trap nets fabricated by Research Nets, Inc. (Bothell, Washington), were used to quantify entrainment of small juvenile salmonids (less than 40 mm total length) during the primary emigration period from May to September. These trap nets have a rectangular entrance 61 cm high x 91 cm wide and are 305-cm long (1.6 mm mesh). A PVC collar (11.4 cm diameter) leads to a 61 cm x 61 cm x 61 cm live box (1.6 mm mesh). This configuration has an open area ratio (the ratio of the open area of the net to its mouth area) of 5:1, which creates a filtering efficiency of 95% (Trantor and Smith 1968; Gale 2005). All fish captured were identified to family or species, counted, measured

(mm), and a subset of about 10% weighed (g). Trout less than 40 mm were difficult to identify to species in the field and were identified only to family.

Trap nets were placed in irrigation canals 50 m downstream from headgates, and 50 m downstream from irrigation canal diversion dams in stream locations. Thirteen sites were sampled on Lost Horse Creek, 7 in irrigation canals and 6 in stream locations downstream of dams. Nine or 10 sites were captured with trap netson Tin Cup Creek, 6 in irrigation canals and 3 (in 2005) or 4 (in 2006) in stream locations; the Chaffin-Whinnery Diversion stream site was sampled in 2006 but not in 2005. Stationary trap nets were fished twice a month, from May (in 2006) or June (in 2005) through the end of September in canals, and after spring runoff (usually occurring in early July) through the end of September in stream locations. Trap nets were fished for 48 h, and checked at 24-h intervals.

The ratio of discharge flowing through the opening of the net to overall diversion or creek discharge for each sampling period was used as a proxy for mark-recapture efficiency estimates to calculate total annual entrainment at each site (Table 3) because of the infrequency of obtaining sufficient numbers of age-0 fish (15 or more) for mark-recapture estimates while trap netting in both 2005 and 2006. Seven mark-recapture opportunities using a 1:30,000 Bismarck Brown Y dye solution (Hennessey 1998) occurred in 2006. These were not sufficient to obtain site-specific efficiencies, nor to pool several efficiencies estimates within a certain site. In 2006, for each sampling period, the proportion of discharge

through the opening of the trap net (using a velocity meter) versus the total discharge at that channel cross-section (from weekly discharge readings) was calculated. Discharge ratio appeared to be a reasonable proxy for mark-recapture efficiencies as evidenced by linear regression analysis of discharge ratio on trap net efficiency (r^2=0.74, *P*=0.01, n=7; Figure 11). These discharge ratios were therefore used to estimate trap net efficiencies. The 2006 discharge ratios were applied to 2005 raw trap net results for concurrent trapping periods because discharge ratios were not calculated in 2005. Overall annual entrainment per diversion was calculated by using the expanded raw trap net results and the area-under-the-curve (AUC) method (English et. al 1992). I was unable to calculate 95% CIs for estimates of annual entrainment of age-0 fish from mark-recapture efficiencies because of the paucity of mark-recapture opportunities. A set of 1,000 AUC curves were generated by “bootstrapping”, or randomly selecting expanded raw trap net data from one of the two days in each sampling period for the season. The mean of these randomly generated AUCs was used as the estimate for annual entrainment of age-0 fish, and the standard deviation was used as a measure of variability of this estimate to derive a “bootstrap” confidence interval (Manly 1997).

Table 3. Trap net efficiencies and discharge ratios for trap netting sites on Lost Horse and Tin Cup Creeks.

Trap net site	Date	Number marked	Number recaptured	Trap net efficiency	95% CI	Discharge ratio
Ward	5/12/2006	27	6	22.%	9-42%	13%
Ward	5/24/2006	21	1	5%	0-24%	4%
Ward	6/12/2006	16	12	75%	51-99%	61%
Ward	8/7/2006	19	5	26%	9-51%	9%
Ward	8/23/2006	97	23	24%	15-33%	6%
POD 1	7/10/2006	20	10	50%	26-74%	81%
Ford-Hollister	7/25/2006	21	13	62%	39-85%	64%

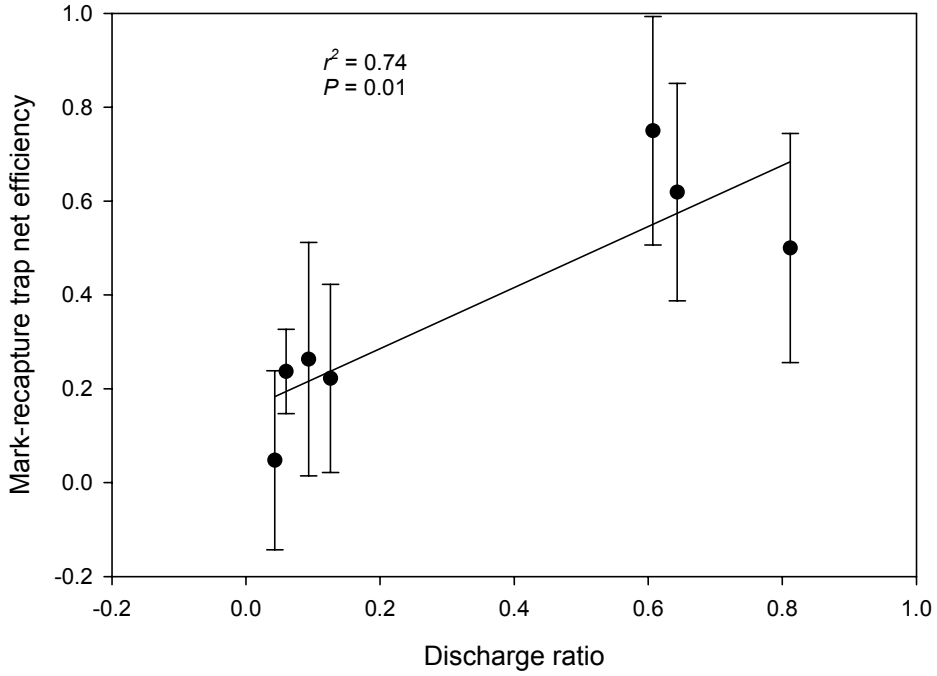

Figure 11. Linear regression of mark-recapture trap net efficiency versus discharge ratios for instances where there were greater than 15 fish marked.

Juvenile and Adult Trout

Large juvenile (> 40 mm TL) and adult abundances were determined by snorkeling periodically throughout the duration of the irrigation season to

estimate annual entrainment. Snorkeling has been used successfully by U.S. Forest Service personnel to count fish in these canals, which are characterized by good water clarity and low conductivity. In low conductivity streams, often characterized by cold and clear water, the effectiveness of electrofishing may be limited (Schill and Griffith 1984; Zubik and Fraley 1988; Kolz 1993). Conductivities were about 15 *µ*s in Lost Horse Creek and between 14 and 17 *µ*s in Tin Cup Creek (Rokosch 2004). Electrofishing in these streams and canals yielded low catches (C. Clancy, personal communication). Underwater observation by snorkeling is unaffected by low conductivity. It is a relatively low-impact technique because fish are minimally disturbed and not handled, which is a useful attribute when studying rare species, protected species, or species of special concern (Thurow 1994) such as bull trout and westslope cutthroat trout in this study. Snorkeling can also be more cost-effective and less time-consuming than electrofishing removal methods (Hankin and Reeves 1988).

Estimates of entrainment in irrigation canals were derived by subsampling canals (Figures 3 and 6). Canal reaches to be subsampled by snorkeling were selected through a stratified-random sampling design stratified by distance from headgate, habitat type, landcover type, and road crossings (Table 4, Figures 4 and 8). Because the lengths of the canals on each stream were variable, numbers of strata among canals were variable, and each stratum was divided into potential 150-m sampling reaches. The stratum of each canal directly behind the headgate was always sampled; its length was about 100 times the channel

width (measured 50 m below the headgate). Two 150-m reaches to be sampled were selected randomly within each subsequent stratum. Because of the absence of fish observed in sampling reaches that were located at relatively far distances (greater than 2.5 km) from points of diversion (Figure 12), some strata were subsequently abandoned in favor of adding reaches to those strata closer to the headgates. This theoretically decreased the variance of abundance estimates within strata closer to headgates by increasing number of samples within a stratum. Strata with consistently few or no fish observed in 2005 were not sampled in 2006 (Appendix A).

Table 4. Number of strata and reaches designated for each irrigation diversion. Number of reaches sampled within each stratum in 2006 are shown in parentheses.

	Stratum					
	1	2	3	4	5	6
Diversion	Number of 150-m reaches per stratum (number sampled in 2006)					
BRID	1 (1)	36 (3)				
Highline	1 (1)	17 (4)	7	9	13 (2)	
Clubhouse	1 (1)	10 (4)	15			
Low	1 (1)	14 (2)				
POD 1	1 (1)	9 (2)				
POD 5	1 (1)	8 (2)	4			
Ward	1 (1)	15 (3)				
TCCWSD	1 (1)	10 (3)	20 (2)	10	14	14
Ford-Hollister	1 (1)	7 (2)	1 (1)			
Chaffin-Whinnery	1 (1)	13 (3)	10			
Click-Matteson	1 (1)	13 (2)				
Mill	1 (1)	11 (3)	16	14 (2)		

Irrigation canal reaches were sampled by snorkeling once a month throughout the irrigation season, from June through October in 2005 and May through September in 2006. Sampling by snorkeling was not conducted in October in 2006 because in October 2005 fish were observed exhibiting

autumnal or winter behavior such as hiding in cover and substrate. Sampling at these times did not allow for valid comparisons between these observations and those of sampling efforts earlier in the irrigation season.

Block nets were set at the upper boundary of reaches to be sampled by snorkeling to control the upstream movement of fish out of the study reach (Peterson et al. 2005). Divers started at the lower boundary of the reach and counted fish as they passed by or were manually guided past the diver. Two divers were used when width, depth, substrate, or visibility necessitated an additional diver. Observed fish were identified to species; lengths were estimated to the following five size classes: 40-70, 70-99, 100-199, 200-299, and greater than 300 mm TL.

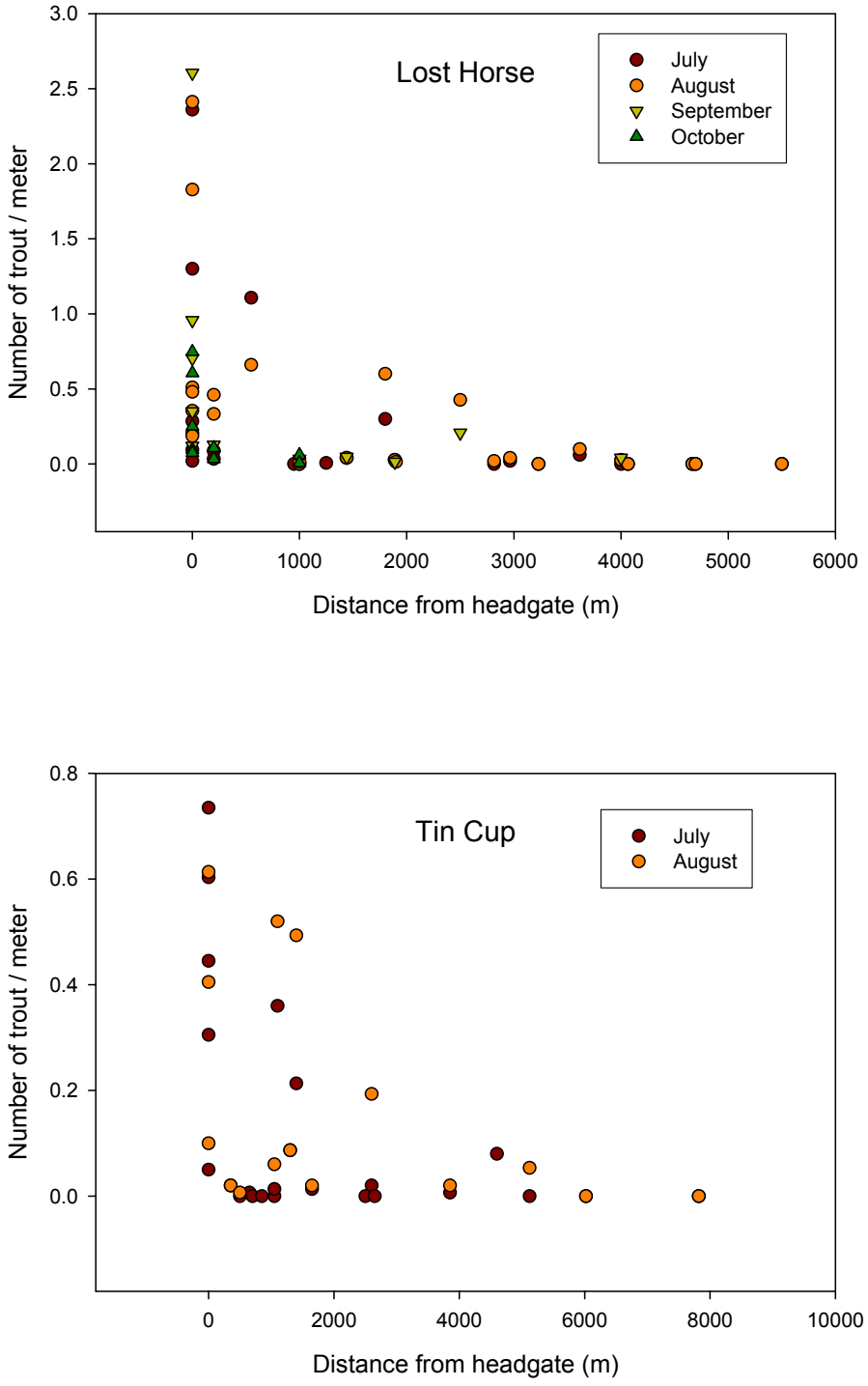

Figure 12. Counts by snorkeling versus distance from headgate for Lost Horse and Tin Cup sites in 2005.

Snorkeling efficiency was calculated by a combination of electrofishing and snorkeling in a subset of snorkeling reaches (n=8 in July 2006) that had 10 or more fish, as determined by sampling in July 2005. Electrofishing with a backpack electrofisher was used to estimate baseline abundances by the Leslie depletion method (Population Estimation by Removal v. 1.1 software, Pisces Conservation Ltd. 1998). Reaches selected for electrofishing were partitioned by block nets at upstream and downstream ends to prevent fish from leaving the reaches. Because conductivity was too low to capture fish effectively, salt blocks were placed in sampling reaches to temporarily raise conductivities for electrofishing. The effectiveness of salt blocks at raising local conductivity levels was evaluated for each pass by measuring conductivities with a conductivity meter (YSI, Inc., Yellow Springs, OH) at several points within the reach. Fish captured by multi-pass removal electrofishing were anesthetized with a solution of tricaine methanesulfonate (MS-222), identified to species, measured (mm), and weighed (g). Fish were also marked by dorsal fin punches or fin clips, allowed to recover in-stream for a minimum of 10 minutes, and released. Snorkeling of the block-netted reaches occurred a minimum of one hour after electrofishing (Table 5). A regression relationship between electrofishing and snorkeling estimates for the efficiency sites concurrently sampled in July 2006 was then constructed (Figure 13). Only data for salmonids greater than 70 mm TL were used in the regression because including fish less than this size added a considerable amount of variability to the relationship.

The regression relationship was used to adjust the mean raw snorkeling counts for detectability, and also to calculate variances for the adjusted means. The Cochran regression estimator formula (Williams et al. 2002) and the Hankin and Reeves (1988) ratio estimator method for subsampling with snorkeling and electrofishing were modified in order to use the eight efficiency trials conducted for the study. To do this, the regression relationship between snorkel counts and electrofishing estimates was assumed to be applicable to all canals in the study area and was assumed to capture the range of snorkeling efficiencies in the study area, which is reasonable considering the high R-squared value of the relationship (0.84). In the formula as given in Williams et al. (2002), I used n = number of sites sampled by snorkeling and electrofishing in the entire study area (i.e., across all diversions); n' = number of sites sampled by snorkeling in the entire study area; N = number of sites total in the entire study area; and $\bar{x}'$-$\bar{x}$ = difference between unadjusted and adjusted snorkel means. The total number of salmonids estimated to be present in each canal by month and associated variance was calculated by expansion of mean snorkel counts and variances within strata and summation across strata. Total canal variance and $t_{0.95,n'-H}$, where H is the number of strata in the entire study area, were used to calculate 95% confidence intervals. Total annual entrainment was defined as the peak monthly within-canal abundance, because monthly estimates generally increased throughout the season and because escapement of entrained fish was assumed to be low.

Table 5. Snorkeling efficiencies for irrigation canals.

Diversion	Reach	Date	# Snorkel	Electrofishing estimate	Efficiency
Brid	S2R2	7/20/2006	22	24.58003	0.90
Clubhouse	S1R1	7/6/2006	20	29.39801	0.68
Highline	S1R1	7/21/2006	10	17.69203	0.31
Low	S1R1	7/6/2006	3	3.499154	0.86
Chaffin-Whinnery	S1R1	7/7/2006	19	33.76513	0.56
Click-Matteson	S1R1	7/13/2006	23	42.32625	0.54
Ford-Hollister	S3R1	7/14/2006	13	15.59127	0.83
Mill	S2R1	7/24/2006	8	7.01542	1.14

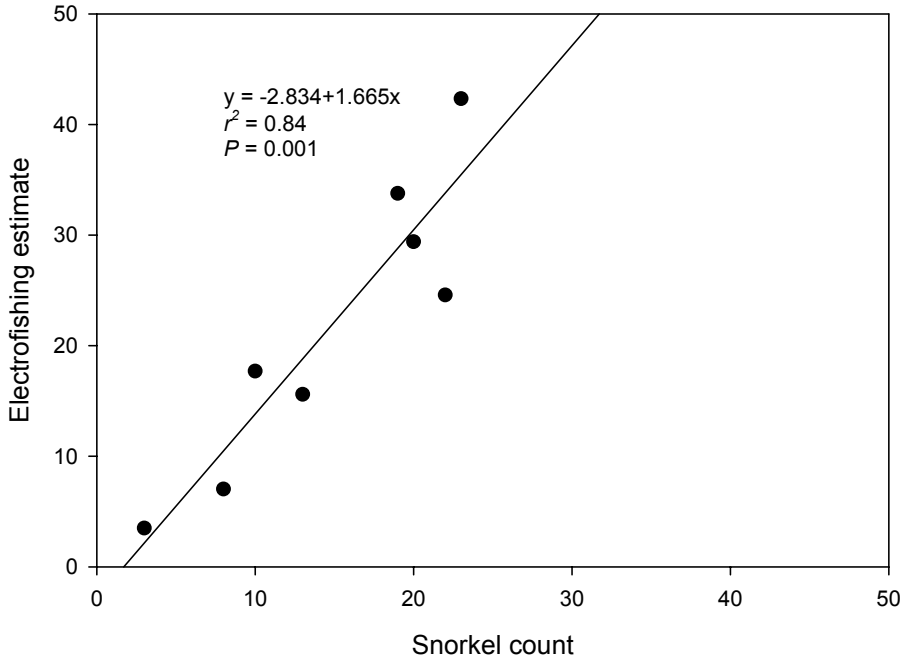

Figure 13. Regression relationship between snorkel counts and electrofishing estimates for the entire study area, July 2006.

Canal Reconnaissance Following Dewatering

Anecdotal evidence suggests that in some cases reconnaissance of canals following dewatering may allow inference of magnitude of entrainment, especially of adults. I explored this possibility as time permitted in autumn 2005 and 2006. Dry or nearly dry canals were either visually reconnoitered for stranded fish carcasses, or remaining isolated pools were single-pass electrofished and captured fish were “rescued” by returning them to the stream. In 2005, fish losses were documented by visual reconnaissance in the POD 1 diversion on Lost Horse Creek and the Chaffin-Whinnery diversion on Tin Cup Creek. Fish “rescues” were performed in the Highline, Clubhouse, Low, and Ward diversions on Lost Horse Creek, and the TCCWSD and Mill diversions on Tin Cup Creek. A combination of both methods was used for the Chaffin-Whinnery diversion on Tin Cup Creek. In 2006, “rescues” were performed in all 12 canals on Lost Horse and Tin Cup Creeks, because I was able to sample them within 1-3 days of end-of-season headgate closures. Electrofishing isolated pools in shut-down canals was a more effective sampling method than visual reconnaissance, because it revealed the presence of trout stranded in isolated, shallow, pools that visually appeared to be fishless. Fish were identified to species if possible, and lengths were estimated to size classes corresponding with snorkeling data.

Stream Population Surveys

Historic fish population data for Lost Horse and Tin Cup creeks is sparse, especially for reaches between the confluence with the Bitterroot River and Forest Service boundary or public land. Snorkel surveys were conducted in stream reaches adjacent (50 m above diversion dams) to ditches in 2006. Species composition and size class of salmonids observed in these stream reaches were compared with values observed in associated diversions.

Physical Characteristics of Canals

Channel Characteristics

Characteristics of diversions and canals that could potentially relate to the magnitude of entrainment were identified in part from a review of the literature and were subsequently measured (Table 6) (Clothier 1953; Spindler 1955; Reiland 1997).

Spatial characteristics such as order of diversions on a stream (e.g., 1 to 7 from an upstream to downstream direction), river kilometers at headgate, and position of diversion with respect to stream (e.g., outside/inside bend, angle in relation to the thalweg of the stream), were investigated. River kilometers were calculated using the measure function in ArcMap (ArcGIS 9, 2005). Angle of the canal in relation to the thalweg of the stream 50 m downstream and upstream was measured using a surveyor's transit; the point at which the canal hypothetically intersected the thalweg was chosen as a reference point for the upstream and downstream measurements (Reiland 1997).

Diversion dam characteristics, including construction materials (boulder, boulder/tarp, or wood), length, height, and width, and status of the diversion as a seasonal fish passage barrier, were documented. A diversion was considered a probable seasonal barrier if it completely blocked the channel, was constructed of impermeable materials, was tall, and had relatively little downstream flow. Our assessments of diversions as barriers concurred with those of Rokosch (2004).

Stream characteristics 50 m upstream and downstream of diversion dams were measured, including gradient, habitat type, substrate, and overhead and instream cover. Gradient was measured using a clinometer and a height reference point. Habitat units were defined as pools, riffles, or runs (Reiland 1997; Arend 1999). Substrate was visually estimated according to the modified Wentworth scale into percent silt, sand, gravel, cobbles, and boulders (McMahon 1996). Overhead cover such as overhanging vegetation, rootwads, overhanging banks, and overhanging rocks, was visually estimated into high, medium, and low categories (Reiland 1997; Stevenson and Mills 1999). Instream cover such as large woody debris, aquatic vegetation, concealing water depths, and boulders was also visually estimated into high, medium, and low categories, and defined as any structure within the bank full width (Reiland 1997; Stevenson and Bain 1999).

If diversions had intake channels at the point of diversion (versus a headgate), total intake length was measured, and all measurements described above were performed. Characteristics of canals were also measured at the

headgate and 50 m beyond, including habitat measurements described above, as well as headgate type, headgate area, headgate velocity, and bankfull width at 50 m. Headgate type was defined as with or without a culvert. Headgate area was calculated by measuring the maximum possible wetted length and widths for conveying water. Velocities in the headgate opening were mapped at a fine scale across the opening (minimum of 10 measurements for each sample), both horizontally and vertically, in a grid pattern, at multiple times throughout the 2006 field season using a Global Water Instrumentation, Inc. (Gold River, California) Flow Probe or a Marsh-McBirney Flo-Mate Velocity Flowmeter (Frederick, Maryland)velocity meter.

HOBO Pendant temperature loggers (Onset Computer Corp., Bourne, Massachussetts) were placed in stream channels to quantify the potential effects of water withdrawals by irrigation canals on stream temperature. Temperature loggers were placed in 9 locations on Lost Horse Creek and 6 locations on Tin Cup Creek, about 50 m below diversion dams of each diversion and at a site above all diversions. Loggers were deployed from May through October, and data was downloaded several times throughout the field season. Temperatures were recorded once an hour for this period, and mean daily temperatures for each site were calculated from these readings (Figures 5, 6, 10, and 11). Degree-days for modeling purposes were defined as mean daily temperature (°C) summed for the period from July 18 to October 1, as per the Montana Fish, Wildlife, and Parks monitoring for this region (Clancy 1993).

Physical characteristics were measured once in fall 2006, except for headgate velocities, which were measured throughout the 2006 field season; temperature, which was measured as described above; and discharge, which was measured as described below.

Discharge. Reliable information about discharge in Lost Horse and Tin Cup Creeks and the diversions on these creeks is rare or non-existent. Although historical flow data taken by the USGS at the National Forest boundary is available for both Lost Horse and Tin Cup Creeks, effects of successive water withdrawals on flow regimes is unknown. Discharge readings from fixed measuring devices already installed in canals (i.e., Parshall flumes or box weirs) were taken once a week in canals, and calibrated with at least three measurements using a velocity meter. The velocity meters were used to measure the average velocity of water at 0.6 depth at regular intervals across the stream or ditch channel, from which discharge was calculated.

Two gauge types were used for discharge measurements in Lost Horse and Tin Cup Creeks. Two Aquarods, continuous-logging staff gauges from Advanced Measurement and Controls, Inc. (Camano Island, Washington), were deployed on each creek. One location was upstream of all diversions, and the other location was close to the confluence with the Bitterroot River. On Lost Horse Creek, one diversion was located downstream of the downstream Aquarod site, whereas on Tin Cup Creek, the Aquarod site was downstream of the most downstream diversion. Aquarods were deployed from June through October in

2005 and from April through October in 2006, and stage height was logged at 30-minute intervals. Aquarod data was calibrated with a rating curve calculated from a minimum of three measurements by a USGS Type AA or Pygmy current meter or a Marsh-McBirney Flo-Mate. In addition, staff gauges were installed in creeks below diversion dams at sites that were not directly adjacent to Aquarod sites, and a rating curve was established for these gauges. Proportion of water diverted was then calculated from these data.

Table 6. Physical characteristics of irrigation canals measured in 2006. Variable description, category, units, and type (continuous or categorical) are displayed.

Variable	Grouping	Units of measurement	Continuous or categorical
Discharge	Discharge	Cubic meters/second	Continuous
Discharge ratio	Discharge	Upstream creek:ditch ratio	Continuous
Degree-days	Temperature	Degrees C summed 7/18-10/1	Continuous
Order	Canal location	Numbered from 1 as upstream-most	Categorical
River kilometers	Canal location	Kilometers	Continuous
Upstream angle	Canal position	Angle with upstream thalweg	Continuous
Downstream angle	Canal position	Angle with downstream thalweg	Continuous
Angle difference	Canal position	Degrees difference	Continuous
Position	Canal position	Outside, inside, or straight	Categorical
Dam as barrier	Dam characteristics	Seasonal, or not a barrier	Categorical
Dam type	Dam characteristics	Boulder, tarp, or wood	Categorical
Dam length	Dam characteristics	Meters	Continuous
Dam height	Dam characteristics	Meters	Continuous

Table 5—continued.

Variable	Grouping	Units of measurement	Continuous or categorical
Dam width	Dam characteristics	Meters	Continuous
Upstream % pool	Stream characteristics	Percentage	Continuous
Upstream dominant habitat	Stream characteristics	Pool, riffle, or run	Categorical
Upstream dominant substrate	Stream characteristics	Wentworth scale	Categorical
Upstream overhead cover	Stream characteristics	Low, moderate, or high	Categorical
Upstream instream cover	Stream characteristics	Low, moderate, or high	Categorical
Upstream gradient	Stream characteristics	Percentage	Continuous
Downstream % pool	Stream characteristics	Percentage	Continuous
Downstream dominant habitat	Stream characteristics	Pool, riffle, or run	Categorical
Downstream dominant substrate	Stream characteristics	Wentworth scale	Categorical
Downstream overhead cover	Stream characteristics	Low, moderate, or high	Categorical
Downstream instream cover	Stream characteristics	Low, moderate, or high	Categorical
Downstream gradient	Stream characteristics	Percentage	Continuous

Table 5—continued.

Variable	Grouping	Units of measurement	Continuous or categorical
Intake channel length	Intake channel	Meters	Continuous
Intake channel present/absence	Intake channel	Present or absent	Categorical
Intake dominant habitat	Intake channel	Pool, riffle, or run	Categorical
Intake % pool	Intake channel	Percentage	Continuous
Intake dominant substrate	Intake channel	Wentworth scale	Categorical
Intake overhead cover	Intake channel	Low, moderate, or high	Categorical
Intake instream cover	Intake channel	Low, moderate, or high	Categorical
Intake gradient	Intake channel	Percentage	Continuous
Length of irrigation season	Canal characteristics	Weeks	Continuous
Ditch headgate area	Canal characteristics	Square meters	Continuous
Ditch bankfull width	Canal characteristics	Meters	Continuous
Ditch headgate type	Canal characteristics	With or without culvert	Categorical

Table 5—continued.

Variable	Grouping	Units of measurement	Continuous or categorical
Ditch dominant habitat	Canal characteristics	Pool, riffle, or run	Categorical
Ditch % pool	Canal characteristics	Percentage	Continuous
Ditch dominant substrate	Canal characteristics	Wentworth scale	Categorical
Ditch overhead cover	Canal characteristics	Low, moderate, or high	Categorical
Ditch instream cover	Canal characteristics	Low, moderate, or high	Categorical
Ditch gradient	Canal characteristics	Percentage	Continuous
Ditch depth	Canal characteristics	Meters	Continuous
Ditch headgate velocity	Canal characteristics	Meters/second	Continuous

Model-Building

I sought to build a model that identified important predictor variables for entrainment of juvenile and adult trout into irrigation canals. Because the sample size of canals was low (n=12), I narrowed down the number of candidate habitat variables in the resultant model to less than twelve, in order to have fewer predictor variables than samples (Burnham and Anderson 2002). I began by taking the 46 physical habitat measurements described above and grouping them into related categories (Table 6). I then put these variables and values into a Spearman-Rank correlation matrix with total entrainment, first stratum entrainment of diversions (i.e., in reaches directly behind the headgate), and age-0 entrainment. First stratum entrainment was included because, ultimately, an application of the model would be to allow managers to identify ditches with high potential for entrainment. With limited time or resources, sampling to ground-truth entrainment rates as predicted by the model might only be possible in select reaches of ditches. Such sampling would be most effective in reaches directly behind the headgate, because first stratum entrainment of ditches was highly correlated with total entrainment (r^2= 0.87, P< 0.001). I chose to build models for all three response variables to determine if different variables were selected for them.

For the purposes of model-building, I used the averages of entrainment, discharge, and temperature data for 2005 and 2006. Habitat variables for modeling were selected at the $P \leq 0.15$ significance level from the correlation

matrix. I chose this high significance level because of the sampling variability inherent in small sample sizes. I further removed variables that were highly correlated with other variables, categorical variables with more than two levels, and variables with many missing values, to make the resultant models more robust. I investigated the resultant variables, including the response variables, for normality using the Shapiro-Wilk test (R v.2.3.1, 2006), and performed transformations to linearize them if necessary. Linearized variables passed tests for normality.

I developed a suite of models using all possible combinations of the remaining variables, for all three response variables, using multiple linear regression in R. Models including pairs of variables that were highly correlated ($r > 0.80$) were not included in comparisons. All remaining models were assumed to be plausible models for the data.

I used the Akaike Information Criterion (AIC) to rank the candidate suite of models. AIC is a simple, objective, and parsimonious means of calculating the goodness of fit of multiple models based on log-likelihood (Burnham and Anderson 2002; Camel 2006). I calculated AIC values in R for each model, and input these values into the AICc formula, which corrects for small sample sizes (Welch and McMahon 2005):

$$AICc = AIC + (2K / (K + 1))/(n - K - 1),$$

where K is the number of model parameters (number of variables + 1 for logistic regression), and n is the number of observations (Welch and McMahon 2005). I

calculated Akaike weights (W_i). which represent the probability that a model is the best among a candidate suite, using the following formula:

$$W_i = \exp(-½ \{AIC_c - \min(AIC_c)\}) / \sum \exp(-½ \{AIC_c - \min(AIC_c)\}).$$

Models were ranked and selected based on the highest values W_i (Welch and McMahon 2005; Camel 2006). I chose to use *AICc* weights calculated from a suite of possible models rather than an automated procedure in a statistical program because of the small sample size of the dataset.

Model Verification

I tested the utility of the model by predicting responses and 95 prediction intervals for the Blodgett Creek dataset. I compared the predicted to observed responses by calculating the Mean Squared Prediction Error (MSPR), and comparing this value to the Mean Squared Error (MSE) from the original model. In addition, I re-estimated the regression coefficients using the Blodgett Creek dataset to see how well they compared to the original model from the Lost Horse and Tin Cup Creek datasets (Kutner et al. 2005).

RESULTS

Entrainment in Canals

Age-0 Fish

An estimated 18,061 age-0 salmonids were entrained in the seven Lost Horse Creek canals in 2005 from June through September (Table 7, Figure 14). An additional 8,972 age-0 salmonids were entrained during this period in 2006. The Ward diversion entrained the most age-0 salmonids in both 2005 and 2006 (14,229 and 7,000); it is the largest, furthest downstream diversion on Lost Horse Creek. Most of the age-0 fish captured in this canal were sampled in June and early July when native westslope cutthroat trout fry were not present. Of the other Lost Horse canals, the BRID diversion in 2005 (1,352) and the Clubhouse diversion in 2006 (870) entrained the most age-0 salmonids.

Fewer fish were captured in Lost Horse Creek than in its diversions. An estimated 6,728 age-0 salmonids in 2005 and 405 age-0 salmonids in 2006 (Table 7) moved directly downstream of diversion dams from mid-July through September. These low numbers, especially at the Clubhouse, Low, POD 1, and POD 5 instream sites, indicate that fairly little downstream migration of age-0 salmonids is occurring during this time period, which may be attributable to entrainment of these fish. More fish were captured in Lost Horse Creek in 2005 than in 2006. This difference was associated with a large number of age-0 salmonids moving below the Ward diversion in 2005 but not in 2006 (5,194 and

0). As in the case of the Ward diversion, most of these fish were sampled in June and early July when westslope cutthroat trout fry were not present.

Table 7. Estimates of annual entrainment and downstream movement of age-0 salmonids on Lost Horse Creek. Bootstrap confidence intervals from AUC simulations are shown in parentheses.

	Year			
Site	2005		2006	
BRID	1,352	(1,238-1,466)	457	(79-835)
LH below BRID	1,387	(1,117-1,657)	199	(56-343)
Highline	108	(17-200)	38	(10-66)
LH below Highline	147	(0-297)	0	
Clubhouse intake	0		182	(140-225)
Clubhouse	1,009	(965-1,054)	870	(679-1,060)
Low	757	(617-896)	46	(18-74)
LH below Low	0		0	
POD 1	116	(42-190)	489	(380-599)
LH between POD 1 & 5	0		0	
POD 5	490	(47-576)	72	(16-128)
Ward	14,229	(8,267-20,191)	7,000	(3,784-10,215)
LH below Ward	5,194	(2,037-8,352)	24	(0-49)
Total in canals	18,061	(11,193-24,573)	8,972	(4,966-12,977)
Total moving downstream	6,728	(3,154-10,306)	405	(196-617)

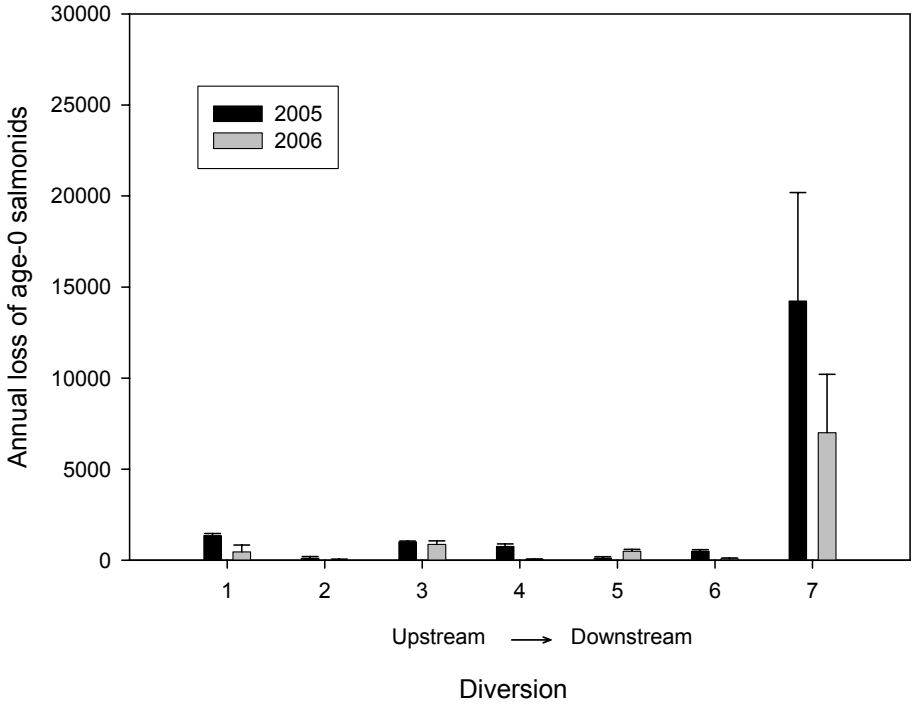

Figure 14. Entrainment of age-0 salmonids on Lost Horse Creek.

Non-salmonid native fish species were also entrained in Lost Horse canals (Table 8). Longnose dace were entrained at all the canals on Lost Horse except the BRID diversion, especially in the Low ditch. Longnose suckers were entrained in the Ward diversion and a few slimy sculpins were entrained in the BRID diversion.

Table 8. Estimates of annual entrainment of non-salmonid fish species (<40 mm TL) captured in stationary trap nets in Lost Horse Creek canals. Bootstrap confidence intervals from AUC simulations are shown in parentheses.

	Species				
Site	*Longnose dace*		*Longnose sucker*		*Slimy sculpin*
	2005	2006	2005	2006	2005
BRID	0	0	0	0	26 (0-53)
Highline	55 (54-56)	155 (72-238)	0	0	0
Clubhouse	10 (0-20)	35 (7-63)	0	0	0
Low	1,401 (1,374-1,428)	5,910 (4,077-7,881)	0	0	0
POD 1	0	172 (53-291)	0	0	0
POD 5	19 (0-38)	16 (4-26)	0	0	0
Ward	0	9,509 (6,688-12,330)	940 (335-1,545)	15,214 (11,698-18,731)	0
Total in canals	1,485 (1,426-1,542)	15, 797 (10,901-20,829)	940 (335-1,545)	15,214 (11,698-18,731)	26 (0-53)

An estimated 2,995 age-0 salmonids were entrained in the five Tin Cup Creek canals from June through September in 2005 (Table 9, Figure 15). In 2006, 2,312 age-0 salmonids were entrained during this time period. The TCCWSD diversion, which is the largest diversion on Tin Cup Creek, entrained the most age-0 salmonids in 2005 (2,004). In 2006, the Ford-Hollister diversion off Little Tin Cup Creek entrained the most age-0 salmonids (1,290), followed by the TCCWSD ditch (724). This diversion has water inputs from both Tin Cup and Little Tin Cup Creeks, and the fish lost to this section of canal could be from either source. In contrast to Lost Horse Creek, the majority of trout fry lost to Tin Cup Creek diversions occurred in the July and August sampling periods when the peak emigration of westslope cutthroat trout fry occurs.

Estimated numbers of age-0 salmonids moving downstream past Tin Cup Creek diversions were 3,529 in 2005 and 1,352 in 2006 (Table 9). Downstream movement on Tin Cup Creek in 2005 and 2006 showed no apparent spatial trend. No native non-salmonid fish (<40 mm TL) were captured in Tin Cup Creek canals or instream nets.

Table 9. Estimates of annual entrainment and downstream movement of age-0 salmonids for Tin Cup Creek canals. Bootstrap confidence intervals from AUC simulations are shown in parentheses.

	Year			
Site	2005		2006	
TCCWSD	2,004	(1,456-2,549)	724	(342-1,107)
TC below TCCWSD	2,633	(2,124-3,142)	281	(154-408)
Ford-Hollister off TC	75	(8-141)	18	(9-27)
Chaffin-Whinnery	143	(18-267)	76	(40-112)
TC below Chaffin-Whinnery	-		954	(728-1,180)
Click-Matteson	403	(312-495)	124	(58-190)
TC below Click-Matteson	780	(383-1,176)	117	(60-174)
Ford-Hollister off Little TC	111	(67-155)	1,290	(473-2,107)
Mill	259	(200-319)	80	(23-137)
TC below Mill	116	(30-202)	0	
Total in canals	2,995	(2,061-3,926)	2,312	(945-3,680)
Total moving downstream	3,529	(2,537-4,520)	1,352	(942-1,762)

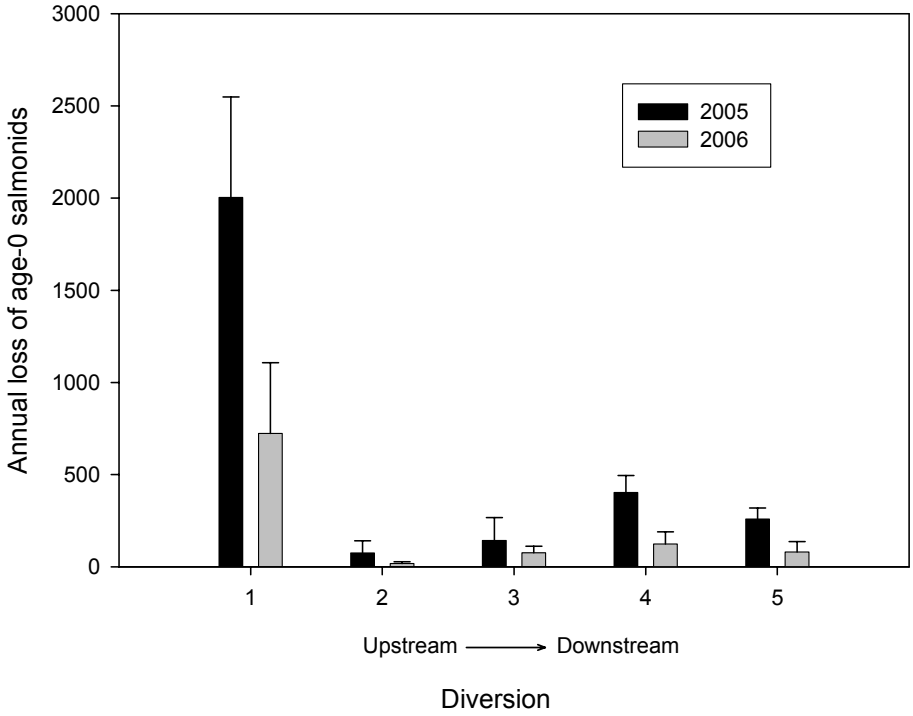

Figure 15. Entrainment of age-0 salmonids on Tin Cup Creek.

Juvenile and Adult Trout.

Estimated entrainment of juvenile and adult salmonids in Lost Horse Creek canals was 7,947 in 2005, and 7,877 in 2006 (Table 10, Figure 16). In both years the Ward (3,166 in 2005 and 2,574 in 2006) and BRID (2,624 in 2005 and 2,866 in 2006) diversions entrained the greatest or second greatest numbers of fish. Overall, entrainment in these two diversions accounted for the majority of the entrainment in Lost Horse Creek canals and was an order of magnitude greater than in the remaining 5 canals (with the exception of the Clubhouse Ditch in 2006, which entrained 1,630 salmonids). The POD 1 and POD 5 diversions entrained the fewest fish. Highest abundances of entrained fish were observed in either August or September in Lost Horse Creek canals except in those that were shut down earlier in the season.

Table 10. Estimates and 95% CIs (shown in parentheses) of juvenile and adult salmonid entrainment on Lost Horse Creek by diversion, month, and year. Highlighted values are annual entrainment estimates for each canal. Double dashes (--) denote sampling periods in which canals had been shut down for the season.

	Year and Month						
	2005			2006			
Diversion	July	August	September	June	July	August	September
BRID	1,391 (712-2,069)	**2,624** (1,764-3,485)	1,219 (725-1,712)	113 (0-437)	2,223 (1,342-3,105)	2,078 (1,302-2,853)	**2,866** (1,774-3,958)
Highline	479 (225-733)	**701** (407-995)	148 (0-311)	1 (0-192)	81 (0-273)	**198** (0-397)	127 (0-321)
Clubhouse	156 (0-327)	**541** (304-777)	385 (237-533)	22 (0-112)	164 (61-267)	806 (544-1,068)	**1,630** (1,131-2,130)
Low	90 (0-221)	**874** (530-1,217)	103**	1 (0-126)	113 (0-244)	329 (167-490)	**385** (206-564)
POD 1	11 (0-93)	**41**	--	10 (0-90)	41 (0-123)	**85** (0-172)	--
POD 5	--	--	--	19 (0-91)	**139** (55-222)	--	--
Ward	3,098 (2,040-4,156)	**3,166** (2,152-4,180)	1,535**	1,015 (667-1,364)	**2,574** (1,796-3,353)	1,961 (1,321-2,601)	1,415 (963-1,866)
Total annual entrainment	**7,947 (5,198-10,695)**			**7,877 (4,962-10,796)**			

*Values without confidence intervals shown from 2005 are given for canals for which only the first stratum was sampled. These values represent a minimum known value of entrained salmonids for the sampling month, but are lower than what would be expected had all strata been sampled.

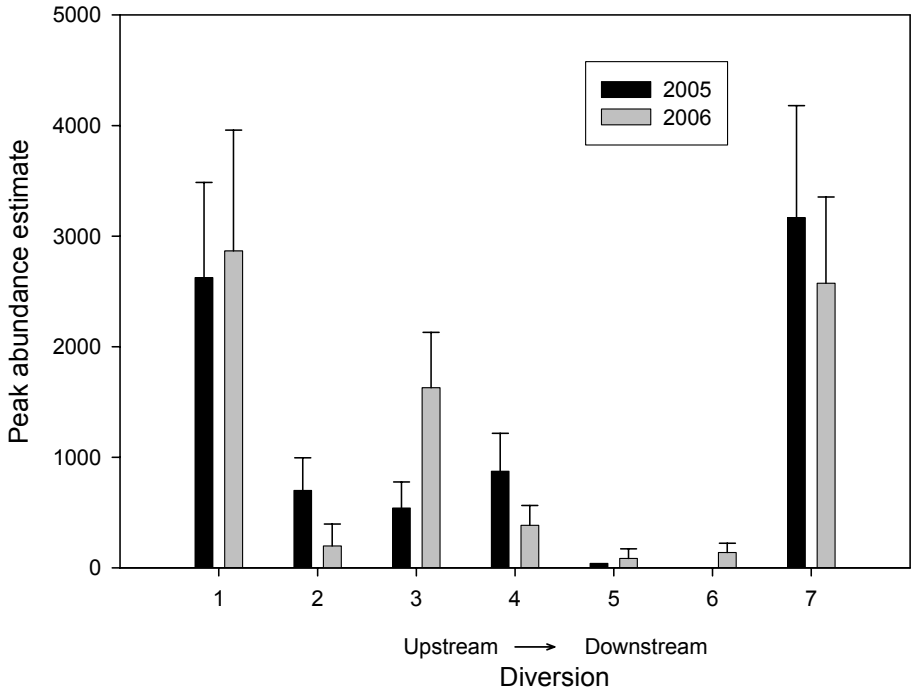

Figure 16. Entrainment of juvenile and adult salmonids on Lost Horse Creek.

Tin Cup Creek canals entrained fewer salmonids than those on Lost Horse Creek (Table 11, Figure 17). In 2005, an estimated 2,554 salmonids were entrained, and 1,691 salmonids were entrained in 2006. In both years, the TCCWSD diversion entrained the most fish (1,889 in 2005 and 1,134 in 2006), with considerably fewer fish entrained in the remaining four canals. The highest numbers of entrained fish were observed in Tin Cup Creek canals in the sampling month directly before the canals were shut down, with the exception of the Mill diversion, where highest abundances occurred in July in both years.

Table 11. Estimates and 95% CIs of juvenile and adult salmonid entrainment on Tin Cup Creek, ditch, month, and year. Highlighted values are annual entrainment estimates for each ditch.

	Year and Month				
	2005		2006		
Diversion	July	August	June	July	August
TCCWSD	955 (565-1,345)	**1,889** (1,300-2,478)	61 (0-261)	507 (272-742)	**1,134** (751-1,516)
Ford-Hollister	49 (0-115)	**69** (2-136)	24 (10-37)	24 (0-88)	**80** (11-148)
Chaffin-Whinnery	**99** (0-224)	--	12 (0-128)	**48** (0-165)	--
Click-Matteson	**217** (66-367)	--	18 (0-134)	47 (0-165)	**150** (19-280)
Mill	**280** (38-522)	97 (0-205)	157 (0-321)	**279** (106-453)	252 (81-423)
Total annual entrainment	**2,554 (1,406-3,727)**		**1,691 (887-2,562)**		

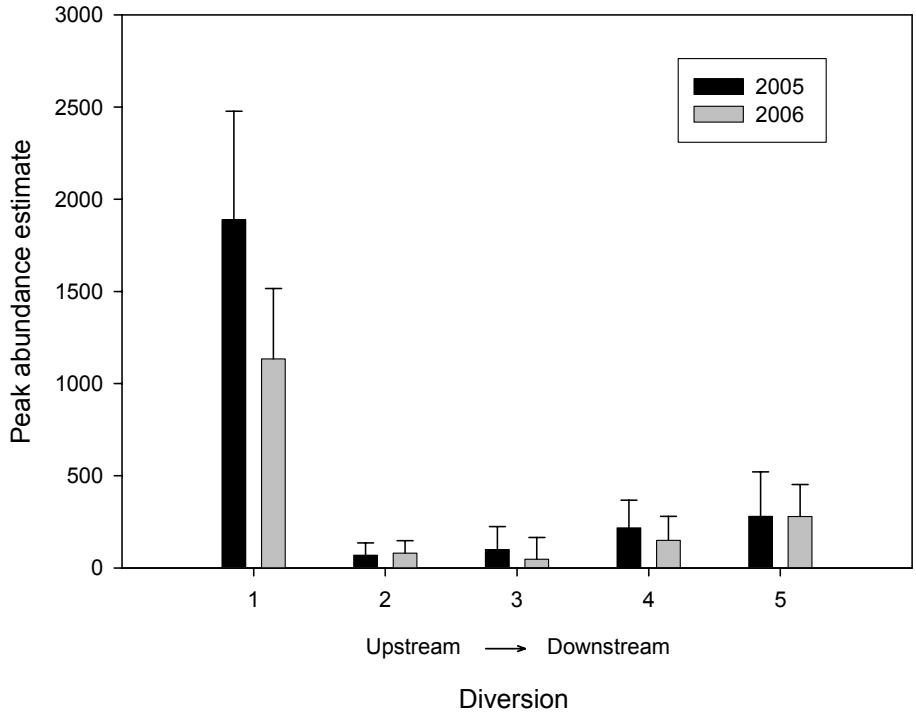

Figure 17. Entrainment of juvenile and adult salmonids on Tin Cup Creek.

Species Composition. Salmonids observed in Lost Horse Creek canals were primarily brook trout (74.2% in 2005, 79.0% in 2006) and native westslope cutthroat trout (20% in 2005, 13.2% in 2006) (Figure 18). The Clubhouse (88.3% in 2005, 82.9% in 2006) and Ward diversions (78.1% in 2005, 84.2% in 2006) were dominated by brook trout, whereas a higher proportion of fish in the BRID, Highline, Low, and POD 1 ditches were westslope cutthroat trout. Bull trout were rare in Lost Horse Creek diversions (0.1% in 2005, 0.04% in 2006).

In contrast, the species composition of salmonids observed in Tin Cup Creek diversions was composed primarily of westslope cutthroat trout (69.5% in 2005 and 61.0% in 2006), followed by brook trout (16.1% in 2005 and 20.1% in 2006) and brown trout (13.4% in 2005 and 13.2% in 2006) (Figure 19). The Mill

Diversion contained a lower proportion of westslope cutthroat trout (51.7% in 2005 and 44.3% in 2006) and higher proportion of brown trout (28.2% in 2005 and 24.7% in 2006) than the remaining ditches on Tin Cup Creek.

Mountain whitefish, longnose dace, longnose suckers, and slimy sculpins were also entrained in Lost Horse and Tin Cup Creek diversions (Table 12). These species were widely distributed throughout Lost Horse Creek diversions, and were less present in Tin Cup Creek diversions.

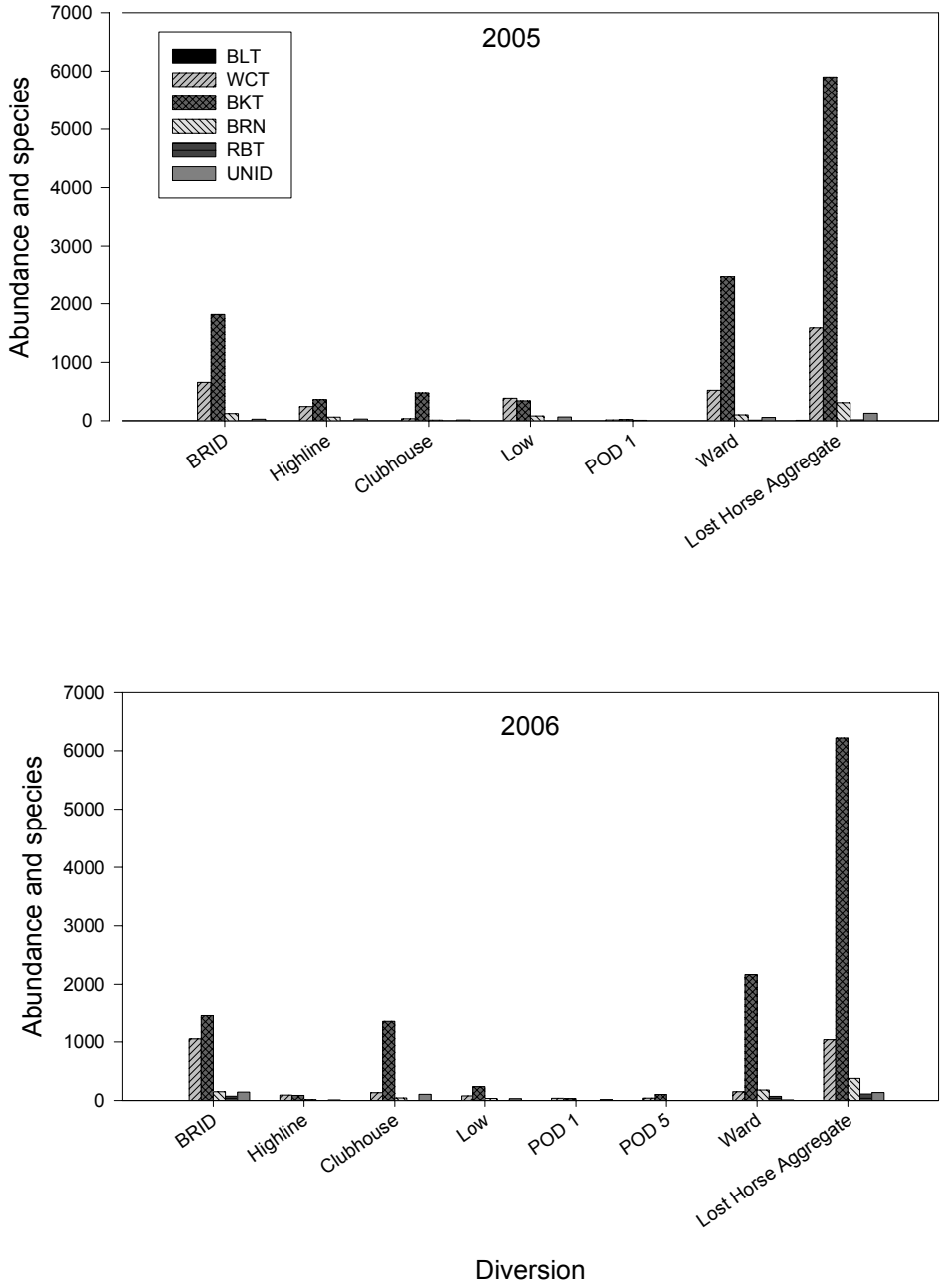

Figure 18. Abundance and species composition of salmonids entrained in 2005 and 2006 in Lost Horse Creek canals. BLT=bull trout, WCT=westslope cutthroat trout, BKT=brook trout, BRN=brown trout, RBT=rainbow trout, UNID=unidentified trout.

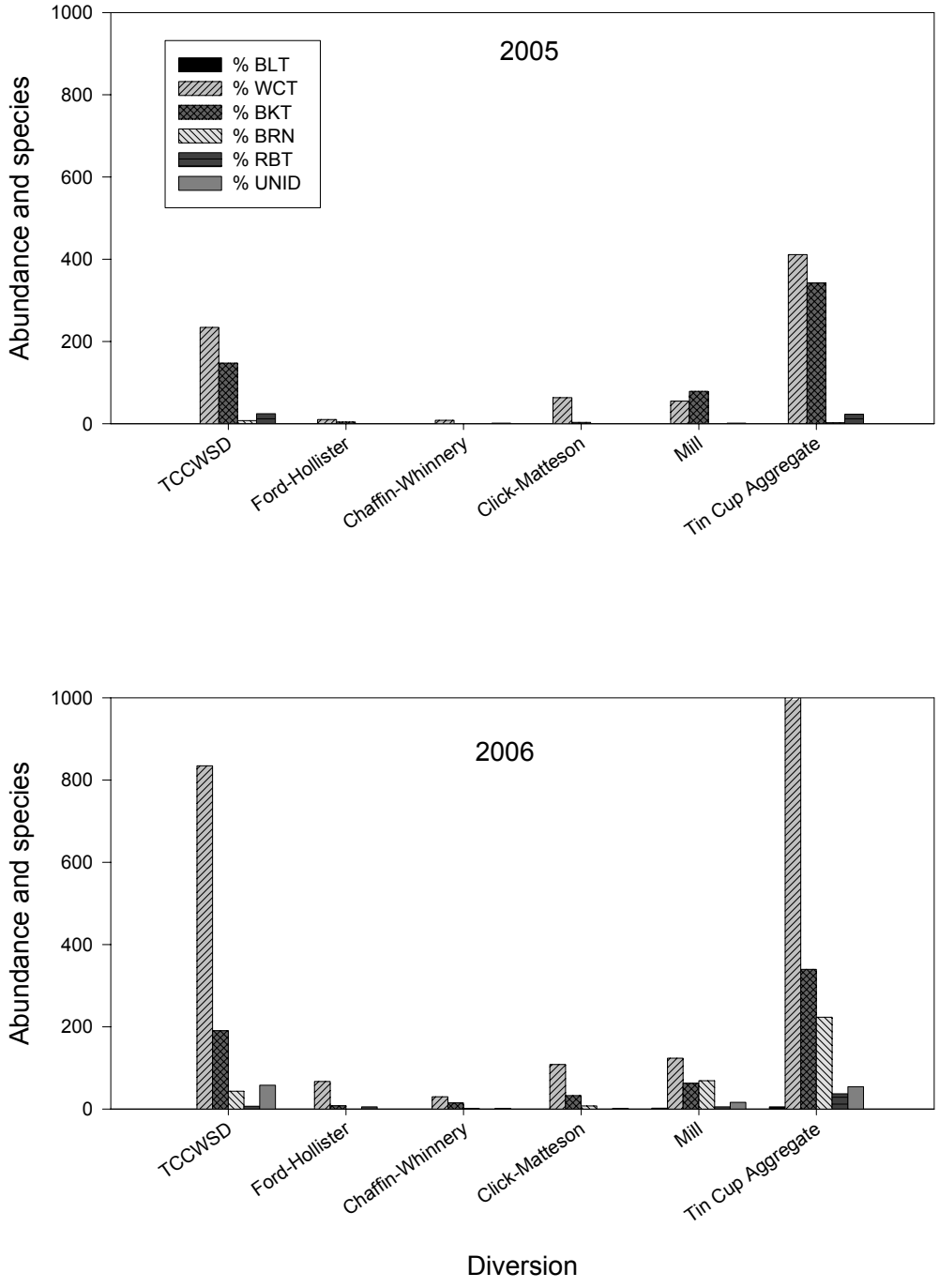

Figure 19. Abundance and species composition of salmonids entrained in 2005 and 2006 in Tin Cup Creek canals.

Table 12. Presence-absence of mountain whitefish, longnose dace, longnose suckers, and slimy sculpins in Lost Horse and Tin Cup Creek canals.

Creek and Ditch	Species							
	Mountain whitefish	*Longnose dace*	*Longnose sucker*	*Slimy sculpin*	*Mountain whitefish*	*Longnose dace*	*Longnose sucker*	*Slimy sculpin*
	2005				**2006**			
Lost Horse								
BRID		X		X		X	X	X
Highline		X		X		X		X
Clubhouse	X	X	X		X	X	X	
Low	X	X	X	X	X	X	X	X
POD 1	X	X	X	X		X		X
POD 5		X				X	X	X
Ward	X	X	X	X	X	X	X	X
Tin Cup								
TCCWSD				X			X	X
Ford-Hollister Off TC								
Chaffin-Whinnery								
Click-Matteson			X					
Mill		X		X				

Size. Entrained salmonids in both Lost Horse and Tin Cup Creeks were small. A high proportion of salmonids observed in Lost Horse Creek canals were less than 100 mm (74.2% in 2005 and 76.8% in 2006); a similarly high proportion of salmonids observed in Tin Cup Creek canals were less than 100 mm (90.5% in 2005 and 75.3% in 2006). Few larger adult salmonids (>200 mm TL) were observed in canals.

Canal Reconnaissance Following Dewatering

Canal reconnaissance and rescues provided evidence, both anecdotal and quantitative, that fish entrained into irrigation canals often remain in the canals at the end of the irrigation season and are ultimately lost to the stream population (Table 13). The majority of trout rescued were less than 100 mm TL. The greatest numbers of trout were rescued from the BRID, Clubhouse, and Ward diversions on Lost Horse Creek. The greatest numbers of trout were rescued from the TCCWSD diversion on Tin Cup Creek. These diversions entrained the highest abundances of trout on their respective streams. The magnitude and spatial pattern of rescued trout was similar to that of entrainment in the first stratum for these diversions.

Table 13. Number of trout detected by canal reconnaissance and fish rescues in 2005 and 2006 in ditches after being shut-down for the season. Peak entrainment observed in the first strata of each diversion in 2006 are also displayed. Reaches sampled visually rather than electrofished are denoted with an asterisk.

	Year		First stratum entrainment
Stream and diversion	2005	2006	2006
Lost Horse			
BRID	--	318	643
Highline	35	30	101
Clubhouse	294	509	305
Low	106	39	87
POD 1	0*	54	39
POD 5	--	26	38
Ward	370	440	949
Tin Cup			
TCCWSD	1263	1093	197
Ford-Hollister	--	80	18
Chaffin-Whinnery	7*	62	45
Click-Matteson	255*	188	121
Mill	17	134	136

Stream Population Surveys

Stream population surveys conducted 50 m above diversion dams on both creeks in August 2006 provided a point of comparison for species composition and size class between canals and adjacent stream reaches (Figures 20 and 21). The Highline, Clubhouse, POD 1, POD 5, and Ward ditches had lower proportions of westslope cutthroat and higher proportions of brook trout than in adjacent stream reaches. The BRID diversion had the opposite pattern. The

ditches on Tin Cup creek had more similar species compositions between ditches and adjacent stream reaches, with the exception of the Mill ditch, which had a higher proportion of brook and brown trout and lower proportion of westslope cutthroat trout than in the adjacent stream reach.

The majority of canals on Lost Horse and Tin Cup Creeks (with the exception of the BRID diversion), entrained a higher proportion of smaller trout (<100 mm TL) than adjacent stream reaches (Figures 22 and 23).

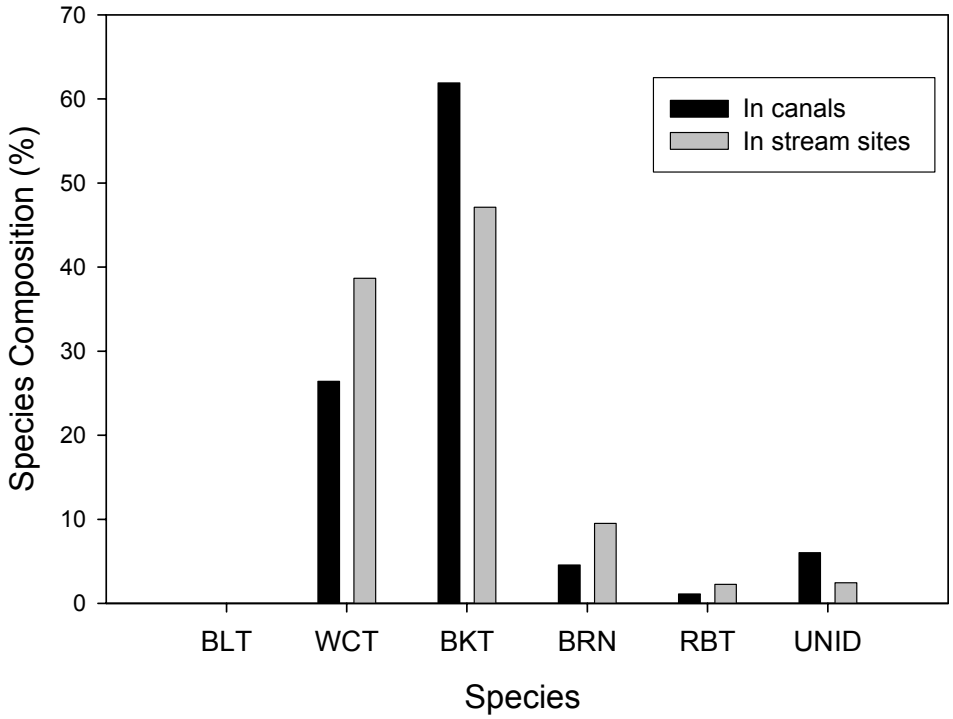

Figure 20. Species composition of salmonids observed in diversions and associated stream reaches 50 m above diversion dams on Lost Horse Creek.

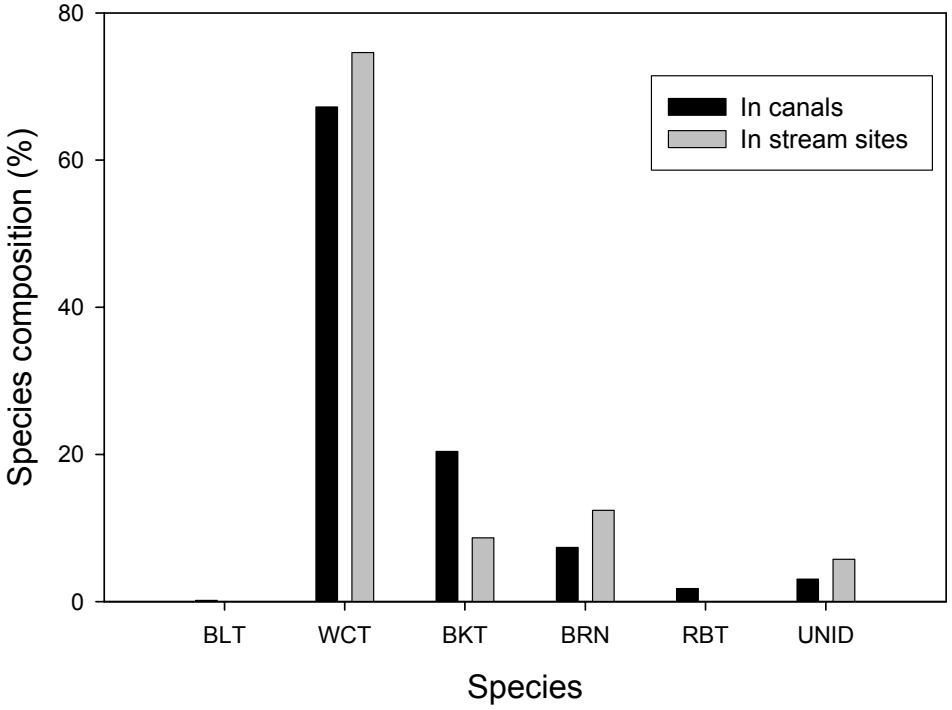

Figure 21. Species composition of salmonids observed in diversions and associated stream reaches 50 m above diversion dams on Tin Cup Creek.

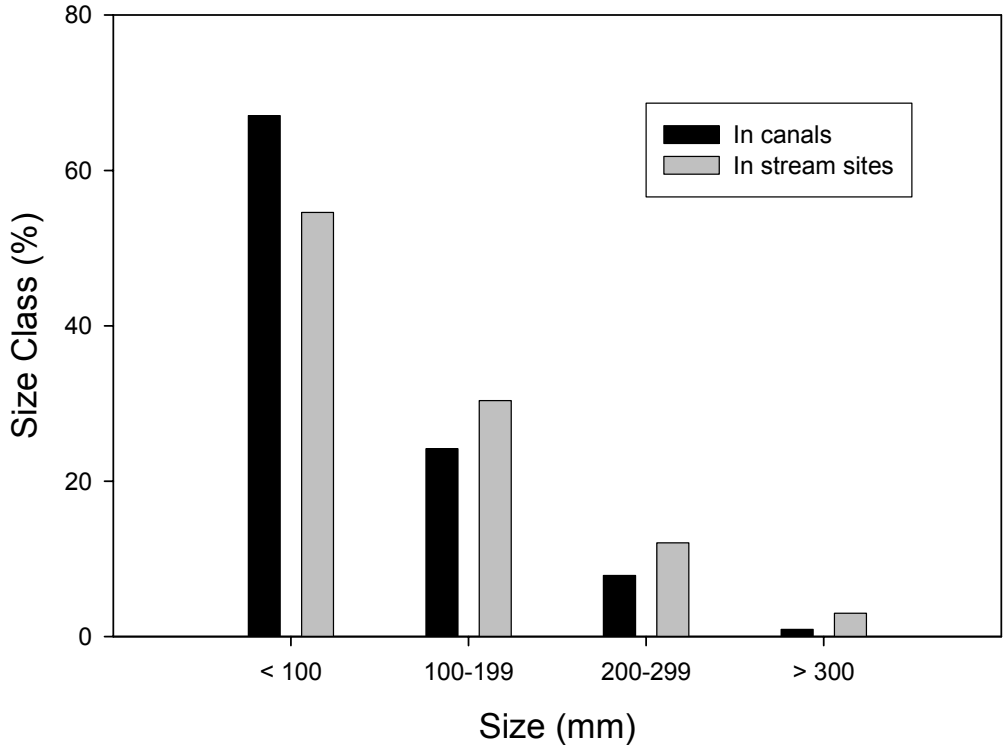

Figure 22. Size class of salmonids observed in diversions and associated stream reaches 50 m above diversion dams on Lost Horse Creek.

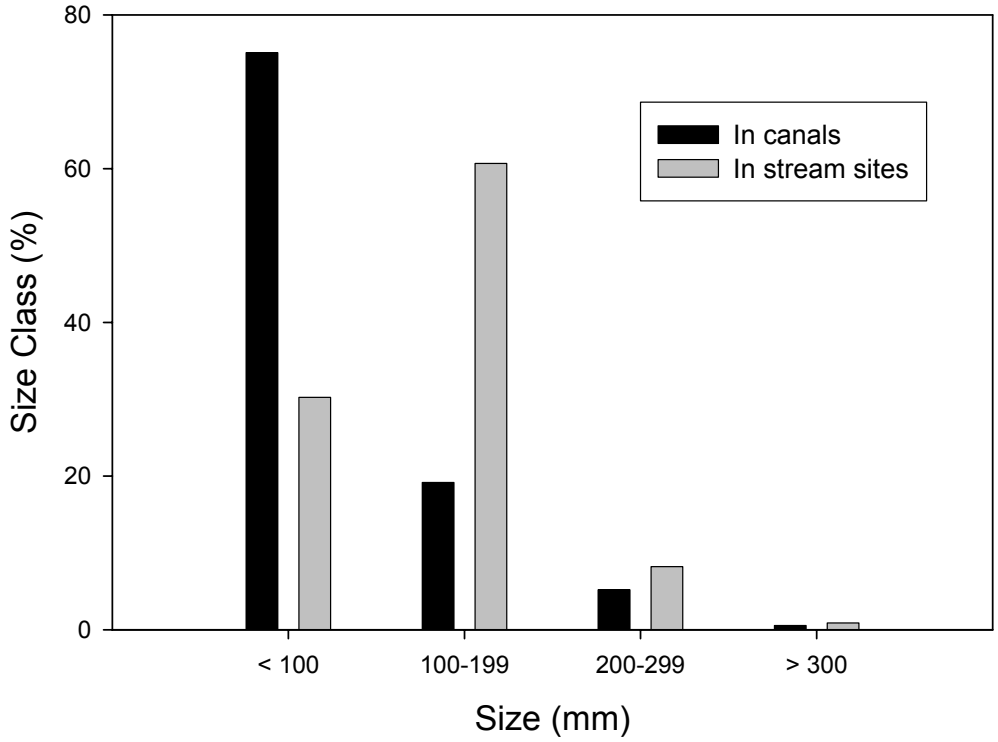

Figure 23. Size class of salmonids observed in diversions and associated stream reaches 50 m above diversion dams on Tin Cup Creek.

Physical Characteristics

Channel Characteristics

Ten physical characteristics of diversions were significantly associated with entrainment of juvenile and adult salmonids and met requirements for initial inclusion into a predictive model (Table 14); seven of these were considered for further inclusion into a predictive model including discharge (averaged weekly from 7/1 – 8/1), discharge ratio, temperature in degree-days, downstream angle to the thalweg, dam height, upstream gradient, and length of irrigation season. Values and associations of all habitat variables with entrainment of juvenile and adult salmonids are displayed in Appendix B. Discharge was highly correlated with both headgate area and bankfull width and was selected as the representative variable for diversion size for modeling purposes. Dam height was highly correlated with dam length and was selected as the representative variable for modeling purposes. Of these seven variables, discharge had the highest r^2 and lowest *P*-values by far with both response variables.

Ten variables were significantly associated with age-0 salmonid entrainment and met requirements for initial inclusion into a predictive model (Table 15); five of these were considered for further inclusion into a predictive model including discharge (averaged weekly from 7/1 – 8/1), discharge ratio, temperature in degree-days, river kilometer, downstream angle to the thalweg, and dam height. Downstream angle was highly correlated with upstream angle and was selected as the representative variable for modeling. Discharge and

dam height were once again selected as representative variables over headgate area, bankfull width, and dam length. Of these 5 variables, discharge had the highest r^2 and lowest *P*-values when regressed against age-0 salmonid entrainment. Upstream angle and length of irrigation season were included into the model of juvenile and adult salmonid entrainment but not included into the model of age-0 salmonid entrainment.

Table 14. Physical habitat variables associated with entrainment of juvenile and adult salmonids. "Total entrainment" refers to the response variable of total estimated entrainment for each ditch, whereas "first strata entrainment" refers to the response variable of estimated entrainment in the first stratum of each ditch (directly behind the headgate), adjusted for size differences among strata. Direction of association (+ or -) is shown in parentheses.

	Total entrainment		First strata entrainment	
Variable	r^2	*P*	r^2	*P*
Discharge (+)	0.87	<0.001	0.67	<0.001
Discharge ratio (+)	0.38	0.032	0.33	0.050
Temperature (+)	0.27	0.086	0.31	0.061
Downstream angle (+)	0.21	0.131	0.23	0.114
Dam length* (+)	0.23	0.133	0.39	0.041
Dam height (+)	0.24	0.130	0.28	0.096
Upstream gradient (-)	0.39	0.017	0.49	0.017
Length of irrigation season (+)	0.30	0.065	0.27	0.086
Ditch headgate area* (+)	0.64	0.002	0.48	0.013
Ditch bankfull width* (+)	0.65	0.002	0.50	0.010

* Dam length, ditch headgate area, and ditch bankfull width were excluded from modeling because they were highly correlated with other selected variables.

Table 15. Physical habitat variables associated with entrainment of age-0 salmonids.

	Age-0 entrainment	
Variable	r^2	*P*
Discharge (+)	0.57	0.004
Discharge ratio (+)	0.38	0.032
Temperature (+)	0.46	0.015
River kilometer (-)	0.35	0.044
Downstream angle (+)	0.46	0.015
Upstream angle* (+)	0.32	0.054
Dam length* (+)	0.42	0.031
Dam height (+)	0.32	0.068
Ditch headgate area* (+)	0.49	0.012
Ditch bankfull width* (+)	0.38	0.034

* Upstream angle, dam length, ditch headgate area, and ditch bankfull width were excluded from modeling because they were highly correlated with other selected variables.

Discharge. The hydrographs of both Lost Horse and Tin Cup Creeks peaked in late May or early June in both years and declined to extremely low discharges by the end of August. The end of August corresponds with the timing of the greatest water withdrawals for irrigation, which leaves these tributaries chronically dewatered,

The average weekly discharge into Lost Horse Creek canals from July 1st to August 1st in 2005 and 2006 was higher than the discharge upstream of all diversions (Table 16). More water can be diverted than exists upstream of all diversions because there are additional inputs of water in the downstream reaches from small springs, tributaries, and a canal conveying water from the Bitterroot River. The disparity between instream discharge and discharge into canals demonstrates the high allotment of water into Lost Horse creek canals in comparison with the discharge in the stream. The average amount of water

diverted into Tin Cup Creek canals for this same time period was less than the amount discharged upstream of all diversions (Table 16).

Table 16. Average discharge and discharge ratio (cms) by diversion, stream, and year, for July 1- August 1.

	2005		2006	
Stream and gauge site	Average	Ratio	Average	Ratio
Lost Horse				
Upstream Aquarod	2.814		2.056	
BRID	1.854	0.615	0.234	0.136
Highline	0.412	0.415	0.449	0.288
Clubhouse	0.144	0.385	0.113	0.179
Low	0.261	0.588	0.203	0.648
POD 1	0.111	0.248	0.087	0.243
POD 5	0.029	0.058	0.044	0.156
Downstream Aquarod	1.489		0.958	
Ward	1.043	0.695	1.484	0.667
Discharge in all Canals	3.854		2.614	
Tin Cup				
Upstream Aquarod	2.179		1.664	
TCCWSD	0.297	0.202	0.480	0.409
Ford-Hollister	0.085	0.130	0.109	0.198
Chaffin-Whinnery	0.083		0.076	0.113
Click-Matteson	0.081	0.112	0.047	0.184
Mill	0.282	0.354	0.321	0.552
Downstream Aquarod	0.790		0.501	
Discharge in all Canals	0.546		0.712	

* The discharge of the Ward diversion is supplemented by Bitterroot River water from mid-July to October. These quantities include this supplemental water.

Model-Building

The seven variables included in model-building for juvenile and adult salmonids were discharge, upstream gradient, discharge ratio, length of irrigation season, degree-days, dam height, and downstream angle. Total entrainment, first strata entrainment, and discharge were log-transformed ($\log_e(x_i)$) to pass the Shapiro-Wilk test for normality. Degree-days were inverse-transformed ($1/x_i$). The best model for both total entrainment and first stratum entrainment were the models containing $\log_e$(discharge) and upstream gradient (Table 17). The first stratum entrainment model was the stronger of the two models containing these two predictor variables.

The five variables included in model-building for age-0 salmonids were discharge, discharge ratio, degree-days, dam height, and downstream angle. Age-0 entrainment and discharge were log-transformed ($\log_e(x_i)$) to pass the Shapiro-Wilk test for normality. Degree-days were inverse-transformed ($1/x_i$). The best model for age-0 entrainment was the model containing discharge ratio (Table 18).

Table 17. Best 10 models for juvenile and adult entrainment selected by AICc weights. a= $\log_e$(discharge), b=upstream gradient, c= discharge ratio, d= length of irrigation season, e= 1/(degree-days), f= dam height, and g= downstream angle.

Model and response	AICc	AICc weight	Equation	MSE	r^2	*P*
Total entrainment						
ab	26.6	0.23	y = 8.192 + 0.830a + 0.566b	0.58	0.85	0.001
a	27.1	0.18	y = 7.379 + 1.031a	0.66	0.79	0.000
ad	28.9	0.08	y = 5.936 + 0.816a + 0.052d	0.64	0.82	0.001
ae	29.0	0.07	y = 11.62 + 0.928a - 4340e	0.64	0.82	0.001
ag	30.1	0.04	y = 8.025 + 1.173a - 0.010g	0.67	0.80	0.002
ac	30.1	0.04	y = 6.726 + 0.868a + 1.221c	0.68	0.80	0.002
af	30.3	0.04	y = 7.810 + 1.0978a - 0.454f	0.68	0.80	0.002
abg	30.3	0.04	y = 8.836 + 0.972a + 0.565b - 0.010g	0.59	0.87	0.002
aef	30.4	0.04	y = 15.64 +1.024a - 7350e – 1.141f	0.59	0.87	0.002
aefg	30.4	0.04	y = 20.01 + 1.322e - 10050e - 1.462f - 0.022g	0.48	0.92	0.002
First stratum entrainment						
ab	20.9	0.32	y = 5.937 + 0.403a + 0.531b	0.44	0.78	0.000
a	22.9	0.12	y = 5.173 + 0.591a	0.54	0.64	0.003
abc	24.5	0.05	y = 6.722 + 0.517a + 0.646b - 1.161c	0.45	0.81	0.007
b	24.6	0.05	y = 5.996 + 0.879b	0.59	0.58	0.007
ad	25.3	0.04	y = 4.176 + 0.443a + 0.036d	0.54	0.68	0.011
ae	25.3	0.04	y = 8.128 + 0.519a - 3023e	0.54	0.68	0.011
abg	25.4	0.03	y = 6.131 + 0.446a + 0.531b - 0.003g	0.47	0.79	0.009
abe	25.6	0.03	y = 5.497 + 0.405a+ 0.556b + 0.448e	0.48	0.79	0.010
abf	25.6	0.03	y = 5.888 + 0.395a + 0.531b + 0.051f	0.48	0.78	0.010
abd	25.6	0.03	y = 5.991 + 0.407a + 0.538b - 0.002d	0.48	0.78	0.010

Table 18. Best 10 models for age-0 selected by AICc weights. a= $\log_e$(discharge), b=discharge ratio, c= 1/(degree-days), d= dam height, and e= downstream angle.

Model and response	AICc	AICc weight	Equation	MSE	r^2	*P*
Age-0 entrainment						
b	40.16	41.50	y = 4.319 + 4.684b	1.26	0.37	0.046
a	40.26	41.60	y = 7.089 + 0.792a	1.27	0.37	0.048
c	41.69	43.03	y = 18.82 – 12800c	1.36	0.28	0.095
e	42.30	43.63	y = 4.480 + 0.032e	1.40	0.24	0.128
ac	40.69	43.69	y = 14.76 + 0.605a – 7844c	1.25	0.45	0.091
ab	41.39	44.39	y = 5.646 + 0.432a + 2.700b	1.25	0.41	0.117
bd	42.08	45.08	y = 4.157 + 4.446b + 0.034d	1.34	0.38	0.151
ae	42.17	45.17	y = 6.633+ 0.691a + 0.007e	1.34	0.37	0.155
ad	42.26	45.26	y = 7.022 + 0.781a +0.070d	1.35	0.37	0.161
d	44.15	45.48	y = 4.845 + 1.382d	1.52	0.10	0.348

Model Verification

I used values for first stratum entrainment of juvenile and adult salmonids, discharge, and upstream gradient obtained by sampling Blodgett Creek diversions in August 2006 to test the applicability of the first stratum entrainment model created from the Lost Horse and Tin Cup Creek datasets. Discharge rates were measured at Blodgett diversions on a single day in August and were likely not comparable to the average discharge values that were input into the Lost Horse-Tin Cup model. I therefore used headgate area as a proxy for average discharge because these variables were highly correlated ($r^2 = 0.79$) (Table 20). The mean-squared predicted error calculated from the Blodgett Creek values (5.406) was different from the mean-squared error of the Lost Horse-Tin Cup model (0.445) indicating a poor statistical fit However, several of the observed values for entrainment fell within the 95% PIs for the response calculated from the Lost Horse-Tin Cup model, and remaining values were close to these prediction intervals. In addition, a multiple linear regression model built from the Blodgett dataset with the response variable as first strata entrainment and the predictor variables as discharge (proxy, see above) and upstream gradient yielded similar model coefficients to those from the Lost Horse-Tin Cup model, a significant *P*-value (0.003), and a high r^2 (0.978). This indicates that although the Lost-Horse-Tin Cup model under-predicted abundances of entrained trout in Blodgett Creek canals, discharge and upstream gradient may nevertheless be important predictors of entrainment into irrigation canals. The Lost Horse-Tin Cup

model was able to correctly identify the Woodside Diversion as the diversion that would entrain the most juvenile and adult salmonids on Blodgett Creek.

The equation for the Blodgett Creek model was:

$$\log_e(\text{first stratum entrainment}) = 7.891 + 0.771*\log_e(\text{discharge}) + 0.360*\text{upstream gradient}.$$

Table 20. Variables and values for Blodgett Creek diversions. Values in parentheses are the 95% PIs for predicted entrainment.

	Variable					
Diversion	First stratum entrainment	Predicted entrainment	Discharge (proxy)	Downstream angle	Dam height	Upstream gradient
Fourth Right	118	11 (1, 133)	0.42	19	--	-6
First Right	99	6 (0, 103)	0.30	7	0.49	-7
Second Right	100	7 (0, 103)	0.29	29	0.59	-6.5
Third Right	149	14 (2, 96)	0.21	47	0.55	-5
Fifth Right	136	41 (13, 133)	0.06	42	0.9	-2
Sixth Right	--	--	0.07	28	0.16	-3.5
Woodside Ditch	1568	175 (54, 561)	1.06	74	1.18	-1.5

DISCUSSION

Entrainment in Canals

Entrainment occurred in all irrigation canals on Lost Horse, Tin Cup, and Blodgett Creeks. All of these canals are currently unscreened. The Ward and BRID diversions on Lost Horse Creek and the TCCWSD diversion on Tin Cup Creek were the primary entrainers of trout on their respective creeks, and may be appropriate candidates for fish screens to reduce these annual losses.

The estimated number of age-0 trout entrained in Lost Horse Creek canals exceeded estimates of downstream migration. In contrast, the estimated number of age-0 trout entrained in Tin Cup Creek canals was less disparate from estimates of downstream migration. This may be attributable to the higher instream flows present in Tin Cup Creek during the height of the irrigation season. These instream flows are made possible by a ~4 cfs water lease for instream flow protection on Tin Cup creek purchased and monitored historically by Montana Fish, Wildlife, and Parks for fisheries protection and currently owned by the Montana Water Trust, a non-profit organization dedicated to purchasing water rights for instream flow protection for the benefit of aquatic resources.

Diversion dams on Tin Cup Creek may be partial or seasonal barriers to movement throughout the irrigation season, but are not as extreme in size as several large diversion dams on Lost Horse Creek. For example, the cobble and boulder diversion dam of the Ward diversion on Lost Horse Creek is rebuilt each

year by construction equipment for the purpose of conveying supplemental water from a canal containing Bitterroot River across the dewatered channel. This completely obstructs connectivity between Lost Horse Creek in its lower reaches and the Bitterroot River. The Ward canal entrained higher numbers of trout fry than the other canals on Lost Horse Creek. The Low diversion, constructed of large boulders and subsequently covered with a large tarp that spans the entire channel, is also a seasonal barrier to fish movement. Instream flow below these diversion dams is virtually non-existent by mid-August, and dead fish were observed in isolated pools below these dams.

The lowermost canals on Big and Blodgett Creeks, two tributaries of the Bitterroot River, entrained large numbers of downstream-drifting age-0 rainbow trout (20% in 1991 and 41% in 1992) (Clancy 1993). The majority of age-0 trout entrainment on Lost Horse Creek also occurred at the lowermost diversion (Ward) in June and early July. Although I was unable to identify trout fry to species, both the timing and location of this entrainment indicate that these trout fry were most likely non-native brook or rainbow trout. The timing and location of peak age-0 trout entrainment on Tin Cup Creek occurred in July and August at the furthest upstream diversion on this stream, indicating that these trout fry were most likely westslope cutthroat trout fry. Gale (2005) observed a similar spatial pattern of entrainment for age-0 westslope cutthroat trout on Skalkaho Creek. The furthest upstream diversion on Skalkaho Creek entrained 71% of downstream drifting trout fry, whereas far less downstream movement or

entrainment of westslope cutthroat trout fry was detected in canals located further downstream.

The spatial pattern of entrainment of larger juvenile and adult trout on Lost Horse creek differed from the spatial pattern of age-0 trout entrainment. The furthest upstream (BRID) and downstream (Ward) canals on Lost Horse Creek entrained a large proportion of juvenile and adult trout. These canals were the two largest canals on this stream with respect to size and discharge. Larger canals in the Big Wood River, Idaho, also entrained more fish than smaller canals (Megargle 1999). Entrainment of juvenile and adult trout occurred at moderate to high levels in several of the other canals on Lost Horse Creek. Canals that entrained relatively few age-0 trout entrained larger juvenile and adult trout at intermediate levels. On Tin Cup Creek, the spatial pattern of entrainment of trout fry and juvenile and adult trout was similar. The furthest upstream canal on Tin Cup Creek (TCCWSD) was the largest in terms of size and discharge, and entrained both the greatest numbers of trout fry and juvenile and adult trout.

The temporal pattern of peak entrainment varied among canals. I chose the peak annual abundance estimate to represent annual entrainment in a given canal despite inconsistencies in the timing of this peak because movement and mortality information for entrained trout at the end of the season was unknown. Abundances of entrained juvenile and adult trout in canals increased from the start of the irrigation season until July or August, after which several different

outcomes existed. The POD 1 and POD 5 diversions on Lost Horse Creek and the TCCWSD, Ford-Hollister, Chaffin-Whinnery, and Click-Matteson diversions on Tin Cup Creek were shut down as instream flows decreased during this time period because other diversions had more senior water rights. Little or no real opportunity for escapement was available to entrained trout in these canals, and these fish were therefore lost to the stream population. Estimated abundances in the other canals followed different temporal trends; some increased while others decreased in September. Diversions that withdrew water in September and later months reduced their withdrawal levels during this period.

The lower numbers of trout observed in certain canals in September could indicate that trout were able to successfully exit the canal and return to the stream via the headgate. Staged drawdowns were effective in West Gallatin River, Montana, canals as a method for stimulating up-canal movement of trout, although headgate velocities could impede these movements (Clothier 1953). Reiland (1997) found a 90% rapid drawdown (while leaving adequate flows for fish movement) to effectively stimulate up-canal trout movement. Harnish (2007) observed that 90% of pit-tagged westslope cutthroat trout remaining in the Highline Diversion on Skalkaho Creek in late September exited the canal through the headgate in response to a staged drawdown. Rapid or staged drawdowns as described in these previous studies were not employed on the canals in my study area, and may have been effective given the spatial distribution of entrained trout (highest abundances in reaches closest to the headgate). Other possible

alternatives for observing fewer trout in the September sampling period were lower detectability caused by lower stream temperatures (Jakober et al. 1998), preferential movement to pools at these lower, often very shallow water levels, and higher susceptibility to predation. I observed a large pod of over 200 adult trout in a deep, pool-like section about 1 km downstream from the headgate? in the BRID diversion (adjacent to one of my sampling reaches) in autumn 2006 after water withdrawals had decreased in this diversion. This demonstrated an example of preferential movement by entrained trout into pools within a canal. High headgate velocities in September and end-of-season fish rescues of trout in the first stratum behind the headgate supported the assumption that there was not necessarily a large number of entrained juvenile and adult trout exiting canals at end of the irrigation season.

The majority of fish entrained in canals on Lost Horse and Tin Cup Creeks were juvenile trout (< 100 mm TL), which is consistent previous studies. Canals in the Blackfoot and Big Wood rivers, Idaho, entrained juvenile fish at higher rates than adult fish and at levels that could potentially affect recruitment (Thurow 1980, 1981, and 1988). Similarly, the Carseland Bow River Headworks Canal in Alberta, Canada, entrained fish less than 150 mm at higher rates than larger fish (Post et al. 2006). All canals except the BRID diversion in this study contained a greater proportion of juvenile trout than adjacent stream reaches.

The species composition of entrained trout on Lost Horse Creek was dominated by non-native brook trout whereas entrainment on Tin Cup Creek was

dominated by native westslope cutthroat trout. This difference may be in part related to the higher temperatures associated with Lost Horse Creek diversions, as well as the greater degree of habitat fragmentation and degradation in the lower stream reaches of Lost Horse Creek. Competition between age-0 brook trout and cutthroat trout may be an important mechanism for the displacement of native cutthroat trout populations (Shepard et al. 2003; Peterson et al. 2004). In addition, brook trout may have a competitive advantage over cutthroat trout in disturbed habitats because of their higher tolerance for warmer temperatures and higher sediment levels (DeStaso and Rahel 1994; Shepard 2004). Habitat degradation and loss can make habitat unsuitable for westslope cutthroat trout, regardless of the effect of non-native species. Westslope cutthroat trout are found in colder water and have lower thermal tolerances than many other salmonid species (Feldmuth and Eriksen 1978; McIntyre and Rieman 1995; Bear et al. 2007) implying a greater sensitivity to increases in water temperature.

Bull trout have lower thermal tolerances than non-native trout (Selong et al. 2001), and are particularly sensitive to the effects of habitat degradation, fragmentation, and sedimentation (Fraley and Shepard 1989). Small remnant populations of bull trout exist in Lost Horse and Tin Cup creeks upstream of where diversions are present, above river km 16.4 on Lost Horse Creek and 11.6 on Tin Cup Creek (Clancy 2005). These are most likely small populations of fluvial, resident bull trout. I observed a total of 8 bull trout in Lost Horse Creek canals and 1 in Tin Cup Creek canals in 2005 and 2006. Sampling by snorkeling

during the day may have contributed in part to the low numbers of bull trout detected in these canals because bull trout detectability is higher at night than during the day (Thurow et al. 2005). However, I observed a spawning pair of bull trout greater than 300 mm TL in the Ward diversion in autumn 2006, which provided evidence that the fluvial-adfluvial form of this species, although greatly reduced in this system, may still be present. The other 6 bull trout observed in canals were also possibly fluvial-adfluvial, because resident bull trout are absent in the stream reaches where diversions exist.

I did not assess downstream movement of larger juvenile and adult trout in this study. Without this information, I cannot quantify the impact of entrainment on potential migrating westslope cutthroat and bull trout. Selection against the fluvial-adfluvial life form has occurred in the Bitterroot River drainage since the onset of irrigation practices. Although documentation of remnant migratory populations exists (Javorsky 2002) through radiotelemetry of fluvial adult westslope cutthroat trout and my own limited observations of bull trout, factors such as habitat fragmentation and barriers to fish movement continue to select against migratory trout in these and other tributary systems (Nelson 1999; Schrank and Rahel 2004; Colyer at al. 2005).

Resident trout undertake diel and seasonal movements (Hilderbrand and Kershner 2000). Schrank and Rahel (2006) found that smaller Bonneville cutthroat trout *Oncorhynchus clarkia utah* (<150 mm TL) were more mobile than larger trout during the summer. The high numbers of juvenile trout observed in

irrigation canals could have been the result of juvenile resident trout moving into canals from nearby stream reaches.

Historical population data for Lost Horse and Tin Cup creeks is too sparse to allow for an assessment of the proportion of stream populations that was entrained. A population estimate for Tin Cup Creek obtained in 1992 by electrofishing at river km 10.6 estimated 178 westslope cutthroat trout (> 125 mm TL), 267 brook trout (> 100 mm TL), and 13 brown trout (> 125 mm TL) per kilometer. Extrapolation of these values to the entire length of Tin Cup Creek and subsequent comparison to my entrainment estimates suggests that about 2 to 3% of all trout species and 3 to 5% of westslope cutthroat trout may be entrained. The percentage of the juvenile trout lost to irrigation diversions is unknown.

Physical Characteristics

Associations of physical characteristics of diversions and entrainment of juvenile and adult salmonids were biologically reasonable. Diversions with high discharges and high proportional discharges are more likely to entrain trout because they divert more water. Diversions that irrigate for longer periods of time have more opportunity to entrain fish. High dams are more likely to be passage barriers, thereby encouraging movement into canals. Low upstream gradient may be adjacent to stream reaches that are slower in velocity and more habitable to juvenile trout, which make up the majority of entrained fish. The importance of temperature and downstream angle may have been overly influenced by the particulars of this dataset; canals on Lost Horse Creek which had high

abundances of entrained fish had higher water temperatures than canals on Tin Cup Creek, and the larger diversions had headgates that were positioned perpendicular to diversion dams.

Variability existed in rates of entrainment of trout and nongame fish among canals on the West Gallatin River, with entrainment rates not necessarily correlated with size of diversion or volume of discharge (Clothier 1953). Losses of legal-sized game fish (greater than 175 mm TL) were highest in canals with intake channels located on outer bends, and with higher volumes of flow, but these relationships were not statistically significant (Spindler 1955). The canal with the greatest loss of fish was one into which nearly the entire discharge of the river was diverted. In my study, high discharge and high discharge ratio were also associated with high levels of entrainment.

Trout abundances in West Gallatin River canals were associated with headgate area, amount of cover at headgate, river habitat at point of diversion, and intake channel length (Reiland 1997). The resulting predictive model, which contained headgate area, intake angle in relation to the thalweg of the river, and intake length as predictor variables, had low predictive power, considerably over-estimating the number of trout entrained in canals. My predictive model underestimated the number of juvenile and adult trout entrained in canals in Blodgett Creek.

The best model describing juvenile and adult salmonid entrainment at Lost Horse and Tin Cup creeks included discharge and upstream gradient. Lower-

ranked models also provided reasonable fits to the dataset. Although the model underestimated entrainment in Blodgett Creek, it was successful in identifying the Woodside Diversion as the largest entrainer of trout on this creek. In addition, three of six observed responses fell within the 95% prediction intervals calculated from the Lost Horse-Tin Cup model, despite inadequacies in this validation dataset. The Blodgett model was created from a small dataset (n= 6 diversions), and the range of values for upstream gradients was much wider for this creek than for Lost Horse and Tin Cup Creeks, since many diversions were located in higher-gradient stream reaches. Also, the use of a single snorkel sample in a single year subjected the response variable, entrainment, to the vagaries of sampling variability. The use of headgate area as a proxy for average discharge in the absence of real data likely introduced more sampling error into the predictions of entrainment abundances. Nevertheless, a model built from the Blodgett Creek dataset including discharge and upstream gradient was statistically significant with a high r^2 value. This suggests that these associations may be applicable to other creeks in the study area and beyond, and may help identify diversions that are most likely to entrain trout at levels that would warrant screening.

Management Implications

The BRID and Ward diversions on Lost Horse Creek and the TCCWSD diversion on Tin Cup Creek are responsible for the majority of entrainment occurring on these streams and should be considered for potential screening

projects. In addition, diversions throughout the study area with high discharges and low upstream gradients may entrain fish and high levels and may benefit from the installation of fish screens to reduce these losses.

The BRID and Highline diversions on Lost Horse Creek and the TCCWSD, Mill, and Click-Matteson diversions on Tin Cup Creek were sampled by Rokosch (2004). He recommended the potential screening of the BRID diversion and modification of its diversion dam as well as further investigation of the Highline and other diversions on Lost Horse Creek for the development of a fish screening/passage plan. My results corroborate his recommendation for potential screening of the BRID diversion. I also recommend screening of the Ward diversion and installation of a siphon to convey Bitterroot River water into this diversion to preclude the need for a large diversion dam at this site. However, screening may not be feasible on Lost Horse creek until issues such as instream flow protection and habitat loss and degradation have been addressed.

Rokosch (2004) also recommended screening the TCCWSD diversion, potentially screening the Mill diversion, modifying the Mill diversion dam to improve passage, and further investigation of the other diversions on Tin Cup Creek. My results support his recommendation to screen the TCCWSD diversion, and to modify diversion dams on this stream for improved fish passage. Tin Cup diversions entrained a similar amount of larger juvenile and adult native westslope cutthroat trout as Lost Horse diversions despite having lower total annual entrainment. Tin Cup Creek also had a higher number of downstream

migrating age-0 trout. This creek maintains connectivity with the Bitterroot River throughout the year because of its instream water lease for fisheries. With respect to a “mouth to headwaters” passage plan, this stream may be a more feasible candidate for a comprehensive screening and passage plan and may provide more benefit to remnant migratory native trout populations in the Bitterroot River drainage than Lost Horse Creek.

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APPENDICES

APPENDIX A

SITES SAMPLED

Table A.1. Sites sampled by snorkeling, electrofishing, and reconnaissance in 2005 on Lost Horse and Tin Cup Creeks. HUC 17010205, Bitterroot, Montana.

Stream	Diversion	Site	Latitude*	Longitude*
Lost Horse	BRID	Stratum 1 Reach 1	46.100511	114.259406
		Stratum 2 Reach 15	46.100625	114.233361
		Stratum 2 Reach 25	46.103500	114.217000
		Stratum 2 Reach 35	46.091894	114.215994
	Highline	Stratum 1 Reach 1	46.103578	114.236283
		Stratum 2 Reach 8	46.114939	114.235219
		Stratum 2 Reach 12	46.117864	114.228981
		Stratum 3 Reach 1	46.120425	114.221203
		Stratum 3 Reach 2	46.121186	114.219969
		Stratum 4 Reach 6	46.133242	114.209642
		Stratum 4 Reach 8	46.134956	114.208719
		Stratum 5 Reach 1	46.124758	114.212689
		Stratum 5 Reach 4	46.123589	114.205408
	Clubhouse	Stratum 1 Reach 1	46.118286	114.217461
		Stratum 2 Reach 1	46.118075	114.215667
		Stratum 2 Reach 7	46.119719	114.208219
		Stratum 3 Reach 1	46.122989	114.203922
		Stratum 3 Reach 10	46.122508	114.185828
	Low	Stratum 1 Reach 1	46.117356	114.206853
		Stratum 2 Reach 1	46.118056	114.204931
		Stratum 2 Reach 7	46.121389	114.194553
	POD 1	Stratum 1 Reach 1	46.115083	114.205697
		Stratum 2 Reach 6	46.110786	114.199311
		Stratum 2 Reach 9	46.108094	114.201197
	POD 5	Stratum 1 Reach 1	46.115578	114.203006
		Stratum 2 Reach 2	46.114944	114.199944
	Ward	Stratum 1 Reach 1	46.114603	114.173933
		Stratum 2 Reach 2	46.118822	114.175322
		Stratum 2 Reach 9	46.124381	114.178672
Tin Cup	TCCWSD	Stratum 1 Reach 1	46.009097	114.221228
		Stratum 2 Reach 7	46.001681	114.208783
		Stratum 2 Reach 9	46.000872	114.205369
		Stratum 3 Reach 5	46.006578	114.205386
		Stratum 3 Reach 14	46.014492	114.207092
		Stratum 4 Reach 2	46.024083	114.210447
		Stratum 4 Reach 8	46.031600	114.217169
		Stratum 5 Reach 9	46.041778	114.208697

Table A.1—continued

Stream	Diversion	Site	Latitude*	Longitude*
		Stratum 5 Reach 13	46.042922	114.205247
		Stratum 6 Reach 10	46.038611	114.201461
		Stratum 6 Reach 12	46.040083	114.199200
	Ford-Hollister	Stratum 1 Reach 1	46.005325	114.216944
		Stratum 2 Reach 2	46.002133	114.217144
		Stratum 2 Reach 3	46.001286	114.215775
		Stratum 3 Reach 1	45.997575	114.213614
	Chaffin-Whinnery	Stratum 1 Reach 1	46.002578	114.213364
		Stratum 2 Reach 1	46.000028	114.202706
		Stratum 2 Reach 2	46.000164	114.200603
		Stratum 3 Reach 7	46.011206	114.199167
		Stratum 3 Reach 11	46.017611	114.185864
	Click-Matteson	Stratum 1 Reach 1	45.998553	114.203875
		Stratum 2 Reach 3	46.000197	114.198694
		Stratum 2 Reach 4	46.001183	114.197825
	Mill	Stratum 1 Reach 1	45.998689	114.196108
		Stratum 2 Reach 5	46.004153	114.189347
		Stratum 2 Reach 9	46.006011	114.183572
		Stratum 3 Reach 6	46.012014	114.183133
		Stratum 3 Reach 7	46.012364	114.181592
		Stratum 4 Reach 3	46.019106	114.181694
		Stratum 4 Reach 9	46.025686	114.186969

*Approximate coordinates from ArcMap.

Table A.2. Sites sampled by snorkeling, electrofishing, and reconnaissance in 2006 on Lost Horse, Tin Cup, and Blodgett Creeks. HUC 17010205, Bitterroot, Montana.

Stream	Diversion	Site	Latitude	Longitude
Lost Horse	BRID	Stratum 1 Reach 1	46.06025	114.15543
		Stratum 2 Reach 1	46.05874	114.15118
		Stratum 2 Reach 2	46.05891	114.14288
		Stratum 2 Reach 3	46.06095	114.13571
	Highline	Stratum 1 Reach 1	46.06259	114.14119
		Stratum 2 Reach 1	46.06540	114.14145
		Stratum 2 Reach 2	46.06896	114.14081
		Stratum 2 Reach 3	46.07065	114.13795
		Stratum 2 Reach 4	46.07092	114.13265
		Stratum 5 Reach 1	46.07450	114.12708
		Stratum 5 Reach 2	46.07379	114.12406
	Clubhouse	Stratum 1 Reach 1	46.07069	114.18107
		Stratum 2 Reach 1	46.07084	114.12962
		Stratum 2 Reach 2	46.07096	114.12490
		Stratum 2 Reach 3	46.07178	114.12524
		Stratum 2 Reach 4	46.07318	114.12361
	Low	Stratum 1 Reach 1	46.07062	114.12365
		Stratum 2 Reach 1	46.07092	114.12239
		Stratum 2 Reach 2	46.07284	114.11770
	POD 1	Stratum 1 Reach 1	46.06912	114.12479
		Stratum 2 Reach 1	46.06663	114.11875
		Stratum 2 Reach 2	46.06462	114.12003
	POD 5	Stratum 1 Reach 1	46.06951	114.12139
		Stratum 2 Reach 1	46.06880	114.12068
		Stratum 2 Reach 2	46.06866	114.11938
	Ward	Stratum 1 Reach 1	46.06886	114.10448
		Stratum 2 Reach 1	46.07142	114.10563
		Stratum 2 Reach 2	46.07283	114.10667
		Stratum 2 Reach 3	46.07834	114.10564
Tin Cup	TCCWSD	Stratum 1 Reach 1	46.00545	114.13244
		Stratum 2 Reach 1	46.00361	114.12894
		Stratum 2 Reach 2	46.00189	114.12717
		Stratum 2 Reach 3	46.00093	114.12607
		Stratum 3 Reach 1	46.00353	114.12235
		Stratum 3 Reach 2	46.00925	114.12424

Table A.2.—continued

Stream	Diversion	Site	Latitude	Longitude
	Ford-Hollister	Stratum 1 Reach 1	46.00497	114.13180
		Stratum 2 Reach 1	46.00359	114.13157
		Stratum 2 Reach 2	46.00346	114.13140
		Stratum 3 Reach 1	45.59828	114.12794
	Chaffin-Whinnery	Stratum 1 Reach 1	46.00262	114.12883
		Stratum 2 Reach 1	46.00014	114.12334
		Stratum 2 Reach 2	46.00022	114.12104
		Stratum 2 Reach 3	46.00068	114.12018
	Click-Matteson	Stratum 1 Reach 1	45.59931	114.12249
		Stratum 2 Reach 1	46.00107	114.11818
		Stratum 2 Reach 2	46.00153	114.11715
	Mill	Stratum 1 Reach 1	45.59912	114.11784
		Stratum 2 Reach 1	46.00001	114.11648
		Stratum 2 Reach 2	46.00258	114.11346
		Stratum 2 Reach 3	46.00324	114.11107
		Stratum 4 Reach 1	46.01159	114.10953
		Stratum 4 Reach 2	46.01525	114.11269
Blodgett	4th Right	Headgate Reach	46.16128	114.13563
	1st Right	Headgate Reach	46.26926	114.22679
	2nd Right	Headgate Reach	46.16368	114.13321
	3rd Right	Headgate Reach	46.16588	114.13025
	5th Right	Headgate Reach	46.16686	114.12671
	6th Right	Headgate Reach	46.16999	114.11740
	Woodside	Headgate Reach	46.17372	114.09728

APPENDIX B

PHYSICAL CHARACTERISTICS OF DIVERSIONS

Table B. Physical Characteristics of Lost Horse and Tin Cup Creek diversions and associated regression statistics (r^2 and *P*). "NA" refers to not applicable.

	Variable					
Diversion	Entrainment total	Entrainment first strata	Discharge (cms)	Discharge ratio	Degree-days	Order
BRID	2745	241	1.044	0.376	964	1
Highline	450	76	0.4305	0.352	1016	2
Clubhouse	1086	229	0.1285	0.282	997	3
Low	630	65	0.232	0.618	1091	4
POD 1	63	39	0.099	0.246	982	5
POD 5	139	38	0.0365	0.107	982	6
Ward	2870	356	1.2635	0.681	1127	7
TCCWSD	512	74	0.3885	0.306	928	1
Ford-Hollister	75	18	0.097	0.164	928	2
Chaffin-Whinnery	74	34	0.080	0.113	945	3
Click-Matteson	184	91	0.064	0.148	952	4
Mill	280	68	0.3015	0.453	963	5
total entrain- r^2		0.87	0.87	0.38	0.27	0.71
total entrain- *P*		0.00	0.00	0.03	0.09	0.22
first strata entrain- r^2			0.67	0.33	0.31	0.71
first strata entrain- *P*			0.00	0.05	0.06	0.22

Table B—continued.

Diversion	Variable					
	River kilometers (km)	Downstream angle (°C)	Upstream angle (°C)	Angle difference	Position	Dam as barrier
BRID	8.3	34	145	181	straight	no
Highline	6.3	44	158	158	outside	no
Clubhouse	4.4	30	185	145	outside	no
Low	3.2	48	152	160	outside	seasonal
POD 1	3.2	26	166	168	straight	no
POD 5	2.9	8	177	176	straight	no
Ward	0.4	91	102	167	straight	seasonal
TCCWSD	6.4	47	132	181	straight	seasonal
Ford-Hollister	5.7	38	123	199	inside	seasonal
Chaffin-Whinnery	5.5	33	196	131	outside	no
Click-Matteson	4.6	27	185	148	outside	no
Mill	3.8	76	125	159	straight	seasonal
total entrain- r^2	0.00	0.21	0.21	0.02	0.14	0.01
total entrain- *P*	0.86	0.13	0.14	0.62	0.51	0.76
first strata entrain- r^2	0.05	0.23	0.12	0.00	0.11	0.00
first strata entrain- *P*	0.48	0.11	0.27	0.90	0.60	0.89

Table B—continued.

Diversion	Variable					
	Dam type	Dam length (m)	Dam height (m)	Dam width (m)	Upstream % pool	Upstream dominant habitat
BRID	boulder	21.70	0.76	7.50	100	pool
Highline	boulder	14.60	1.22	3.34	0	riffle
Clubhouse	boulder	NA	NA	NA	10	riffle
Low	tarp	15.40	0.68	1.08	40	riffle
POD 1	tarp	29.00	0.96	4.29	40	pool
POD 5	boulder	19.00	0.37	1.40	50	riffle
Ward	boulder	35.40	1.33	3.36	20	riffle
TCCWSD	wood	12.30	0.47	0.03	40	riffle
Ford-Hollister	tarp	14.50	0.57	0.60	50	pool
Chaffin-Whinnery	boulder	17.80	0.82	4.34	40	riffle
Click-Matteson	boulder	28.00	0.44	1.30	30	riffle
Mill	wood	12.40	0.27	0.04	40	riffle
total entrain- r^2	0.16	0.23	0.24	0.32	0.07	0.01
total entrain- *P*	0.46	0.13	0.13	0.07	0.41	0.71
first strata entrain- r^2	0.24	0.39	0.28	0.21	0.00	0.00
first strata entrain- *P*	0.29	0.04	0.10	0.16	0.94	0.84

Table B—continued.

Diversion	Variable					
	Upstream dominant substrate	Upstream overhead cover	Upstream instream cover	Upstream gradient (%)	Downstream % pool	Downstream dominant habitat
BRID	cobble	low	low	-1	0	riffle
Highline	boulder	low	low	-2	0	riffle
Clubhouse	boulder	low	moderate	NA	0	run
Low	cobble	low	low	-1.5	0	riffle
POD 1	cobble	low	low	-2	60	pool
POD 5	cobble	low	moderate	-2	0	riffle
Ward	cobble	low	low	-1	0	run
TCCWSD	cobble	moderate	moderate	-3	0	riffle
Ford-Hollister	cobble	moderate	high	-3	0	riffle
Chaffin-Whinnery	cobble	low	moderate	-3	40	riffle
Click-Matteson	cobble	moderate	moderate	-2	0	riffle
Mill	cobble	low	moderate	-1.5	0	riffle
total entrain- r^2	0.00	0.09	0.28	0.49	0.10	0.34
total entrain- *P*	0.99	0.34	0.23	0.02	0.32	0.15
first strata entrain- r^2	0.03	0.08	0.17	0.49	0.10	0.66
first strata entrain- *P*	0.57	0.37	0.42	0.02	0.31	0.01

Table B—continued.

Diversion	Variable					
	Downstream dominant substrate	Downstream overhead cover	Downstream instream cover	Downstream gradient (%)	Intake channel length (m)	Intake channel presence/ absence
BRID	boulder	low	moderate	-3	0	absent
Highline	cobble	low	low	-2.5	61	present
Clubhouse	cobble	low	moderate	NA	541	present
Low	cobble	low	moderate	-2	10	present
POD 1	cobble	low	low	-2	0	absent
POD 5	cobble	low	moderate	-3	103	present
Ward	cobble	low	low	-1.5	15	present
TCCWSD	cobble	moderate	moderate	-3	0	absent
Ford-Hollister	cobble	moderate	moderate	-3	0	absent
Chaffin-Whinnery	cobble	moderate	moderate	-5	48	present
Click-Matteson	cobble	low	moderate	-2	0	absent
Mill	cobble	low	moderate	-2.5	0	absent
total entrain- r^2	0.39	0.11	0.05	0.09	0.00	0.01
total entrain- *P*	0.03	0.30	0.49	0.38	0.87	0.71
first strata entrain- r^2	0.15	0.15	0.07	0.16	0.09	0.05
first strata entrain- *P*	0.21	0.21	0.41	0.23	0.34	0.49

Table B—continued.

Diversion	Variable					
	Intake % pool	Intake dominant habitat	Intake dominant substrate	Intake overhead cover	Intake instream cover	Intake gradient (%)
BRID	NA	NA	NA	NA	NA	NA
Highline	23	riffle	cobble	low	moderate	-2
Clubhouse	0	riffle	sand	moderate	moderate	NA
Low	0	run	sand	low	low	NA
POD 1	NA	NA	NA	NA	NA	NA
POD 5	0	riffle	cobble	moderate	low	-1
Ward	50	run	sand	low	low	NA
TCCWSD	NA	NA	NA	NA	NA	NA
Ford-Hollister	NA	NA	NA	NA	NA	NA
Chaffin-Whinnery	0	run	pebble	high	high	-2
Click-Matteson	NA	NA	NA	NA	NA	NA
Mill	NA	NA	NA	NA	NA	NA
total entrain- r^2	0.69	0.11	0.48	0.25	0.18	0.12
total entrain- *P*	0.04	0.52	0.38	0.65	0.74	0.77
first strata entrain- r^2	0.53	0.02	0.49	0.15	0.14	0.18
first strata entrain- *P*	0.10	0.77	0.36	0.78	0.80	0.72

Table B—continued.

Diversion	Variable					
	Length of season (days)	Ditch headgate area (m^2)	Ditch headgate type	Ditch bankfull width (m)	Ditch % pool	Ditch dominant habitat
BRID	28	2.72	without	5.3	0	riffle
Highline	28	0.53	with	2.3	10	run
Clubhouse	24	0.3	with	1.8	20	riffle
Low	25	0.34	with	1.5	0	riffle
POD 1	19	0.3	with	1.8	10	riffle
POD 5	21	0.14	without	1.3	10	riffle
Ward	26	3.25	without	5.2	0	riffle
TCCWSD	23	1.33	with	4.4	0	riffle
Ford-Hollister	7	1.23	with	1.4	10	riffle
Chaffin-Whinnery	14	0.97	without	1.9	20	riffle
Click-Matteson	15	0.85	without	2.6	0	riffle
Mill	26	1.64	with	2.8	10	riffle
total entrain- r^2	0.30	0.64	0.15	0.65	0.18	0.01
total entrain- *P*	0.07	0.00	0.21	0.00	0.17	0.76
first strata entrain- r^2	0.27	0.48	0.12	0.50	0.07	0.41
first strata entrain- *P*	0.09	0.01	0.27	0.01	0.41	0.75

Table B—continued.

Diversion	Variable					
	Ditch dominant substrate	Ditch overhead cover	Ditch instream cover	Ditch gradient (%)	Ditch depth (m)	Ditch headgate velocity (m/s)
BRID	cobble	low	low	-1	0.27	1.93
Highline	gravel	moderate	low	-1	0.51	1.00
Clubhouse	gravel	moderate	moderate	-2	0.29	0.64
Low	cobble	low	low	-2	0.15	0.97
POD 1	gravel	low	moderate	-1	0.08	0.69
POD 5	gravel	moderate	low	-2	0.07	0.64
Ward	cobble	low	low	-2	0.45	0.53
TCCWSD	gravel	low	low	-2	0.22	0.34
Ford-Hollister	boulder	moderate	moderate	-4	0.24	1.49
Chaffin-Whinnery	gravel	moderate	low	-1	NA	0.29
Click-Matteson	cobble	moderate	moderate	-1.5	0.12	0.56
Mill	cobble	low	low	-1.5	0.16	0.74
total entrain- r^2	0.27	0.20	0.09	0.02	0.28	0.13
total entrain- *P*	0.24	0.15	0.34	0.70	0.09	0.25
first strata entrain- r^2	0.23	0.09	0.01	0.01	0.32	0.01
first strata entrain- *P*	0.31	0.35	0.72	0.75	0.07	0.71