Water Leases and Yellowstone Cutthroat Trout Fry Outmigration from Four Tributaries of the Upper Yellowstone River

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Table of Contents

List of Tables

List of Figures

List of Figures (continued)

Figure		Page

1.0 Summary of Findings and Conclusions

Garcia and Associates (GANDA) contracted with Montana Fish, Wildlife and Parks (FWP) to conduct biological monitoring related to Yellowstone cutthroat trout fry outmigrations from four tributaries of the Yellowstone River in Park County, Montana. Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) fry outmigration has been monitored on Mill, Cedar, and Mol Heron creeks since 1996 to evaluate the effect of existing water leases on fry recruitment to the Yellowstone River, Montana. Yearly variations in water availability and demand have affected how well the leases have functioned to protect developing and outmigrating fry. Both 1996 and 1997 were record spring runoff years, resulting in plentiful water supplies and little contention over in-stream flows. However, the summer of 1998 was warmer and drier than the two previous summers, inducing periods of low flows in both Mill and Cedar creeks, and a total dewatering of Mill Creek in mid-September. Climatic data suggests that July, 1999 was much drier than average for all four project streams, but that higher than average precipitation in August increased available water for streamflow.

GANDA examined how the existing water leases influenced in-stream flows and Yellowstone cutthroat trout fry outmigration from Mill, Cedar, Mol Heron and Big creeks from July 23 to September 22, 1999. Water levels were well above the minimum amount leased in Big and Mol Heron creeks throughout the summer, but declined below lease levels in Mill and Cedar creeks for at least 24 hours in each creek in early August. Mill and Cedar creeks fluctuated at or just above their respective lease levels from mid-August through mid-September. Total numbers of Yellowstone cutthroat trout fry captured were up from surveys conducted in 1998 in Cedar and Mol Heron creeks, but had declined significantly in Mill Creek. A total of 3,429 Yellowstone cutthroat trout fry were trapped in Big Creek during this first year of trapping. Mill Creek experienced an 84% decrease in the number of fry trapped compared to 1998, and a 99.5% decrease compared to 1997. As compared to 1998 counts, the number of fry trapped increased 332% in Mol Heron Creek and 386% in Cedar Creek. However, numbers of fry trapped in Cedar Creek in 1999 were 44% lower than the count in 1997. Although flows have generally met water lease requirements in Mill Creek each year monitored since 1996, Yellowstone cutthroat trout recruitment has been dramatically reduced during the past two years when flows hovered near minimal lease levels. The adequacy of the Mill Creek lease should be reevaluated, and if possible, additional flows should be secured to better protect incubating and outmigrating Yellowstone cutthroat trout fry.

2.0 Introduction

Water leases between FWP and participating Yellowstone River tributary water right holders were in effect in 1999 on Mill, Big, Mol Heron, and Cedar creeks (Table 1). Although Big Creek was on the original list of identified streams for the pilot leasing program initiated by House Bill 707 in 1989, this was the first year that Big Creek has had a water lease in effect. Yellowstone cutthroat trout fry outmigration has been measured for the past three years on Mill, Cedar, and Mol Heron creeks as part of a water leasing effectiveness study completed in 1998 (Hennessey 1998, Roulson 1998). Byorth (1990) monitored Yellowstone cutthroat trout spawning in Big Creek in 1988 and 1989, but little monitoring of the fishery has taken place since. The four water leases involved in this project were established to provide in-stream flows for Yellowstone cutthroat trout reproduction and to generally benefit the Yellowstone River fishery (Spence 1995). This project sought to examine how well the leases functioned in 1999, and to evaluate the effects of potentially lower flows during critical developmental periods on Yellowstone cutthroat trout fry recruitment. The specific objectives of this project were:

1. Monitor fry outmigration from Mill, Big, Cedar and Mol Heron creeks, and compare results from Mill, Cedar, and Mol Heron to those from the previous three years.

2. Monitor streamflows during the project and notify FWP if flows drop below water lease levels.

3. Measure streamflow at staff gauges on Mill and Cedar creeks and verify measurements against existing United States Geological Survey (USGS) rating curves.

4. Collect enough flow measurement data to construct a rating curve for the existing gauge on Mol Heron Creek.

5. Monitor temperatures in all four tributaries using remote thermographs.

6. Assist in the timing for the Mill Creek flushing flow and monitoring fry outmigration to assess its effectiveness.

Table 1. Summary of water lease information for the four Yellowstone water leasing project streams (Spence 1995, EQC 1998, Nelson 1999).

Location	Lessor	Priority of right	Flow leased	Period of use	Date originated
Mill Creek[a]	Mill Creek Water & Sewer District	95 rights with various priorities	up to 41.4 cfs	48- 60 hours in August	August 1992
	individual	1880 and 1903	6.13 cfs	May 1 to October 4	October 1992
	individual	1891	2.64 cfs	May 1 to October 19	August 1995
Big Creek	3 individuals	1883	11-26 cfs[a]	May 1 to November 1	April 1999
Cedar Creek	USFS	1890,1893, 1898, 1904, and 1972	6.4-9.6 cfs[a]	May 1 to October 15	December 1993
Mol Heron Creek	Private organization	1880	5 cfs	May 1 to October 15	May 1998[c]

[a] Actual flows leased may differ from the quantity protected at a downstream measuring device. The Mill Creek lease protects up to 4.4 cfs as measured at the East River Road staff gauge. The Big Creek lease protects 11 cfs as measured at the gauge above Highway 89. The Cedar Creek lease protects a minimum of 1.3 cfs as measured at the staff gauge below the Highway 89 culvert.

[c] An initial verbal agreement was reached 1996, but the water lease was not finalized until 1998.

3.0 Project Area

GANDA conducted this project in Park County, Montana on four tributaries of the upper Yellowstone River (Figure 1). Cedar and Mol Heron creeks are considered high quality spawning areas for Yellowstone cutthroat trout as defined by Clancy (1988). Lower Mill Creek and Big Creek were excluded from this distinction because of decades of dewatering during critical times in the Yellowstone cutthroat trout reproductive cycle. A detailed description of Mill, Cedar, and Mol Heron creeks, along with results from electrophoretic testing of fry from 1996 and 1997, is included in the project completed by Hennessey (1998).

Mill Creek, also located near Emigrant, is the largest tributary of the Yellowstone River in Park County (Figure 1). Mill Creek is a fourth order stream based on the occurrence of perennial streams on USGS 1:24,000 scale topographic maps with an approximate length of 21 miles (34 km), and a mean annual discharge of 160 cfs (4.5 m^3/s); (Parrett 1985). Much of the upper reaches of Mill Creek is within the Gallatin National Forest, and its headwaters are all within the Absaroka Beartooth Wilderness. The Mill Creek Water and Sewer District aqueduct, downstream of the National Forest Boundary, is the largest single diversion on the creek and serves over 95 water right holders. There are many additional irrigation diversions in the lower 10 miles (6.2 km) of Mill Creek. A water commissioner is appointed each year to administrate water rights and flow controls on Mill Creek, including the water leases (EQC 1998). Although the total amount of water involved in the two water leases that are in effect from May to October is 8.77 cfs (0.25 m^3/s), the lease is protected as a flow of 4.4 cfs (0.12 m^3/s) measured at the East River Road Bridge (Table 2); (FWP 1999). The difference in flow is due to water lost to natural seepage into the streambed between the upper headgate where the flow is controlled and the East River Road bridge, where the flow is measured (Nelson 1980).

Big Creek flows out of the Gallatin Mountains from the west, and joins the Yellowstone River approximately 6 miles (9.7 km) south of the town of Emigrant (Figure 1). Big Creek is a second order stream based on the occurrence of perennial streams on USGS 1:24,000 scale topographic maps with an approximate length of 18 miles (29 km). There are several major diversions within the lower 6 miles (9.7 km) of Big Creek after it leaves National Forest land. Historically, Big Creek has supported significant Yellowstone cutthroat trout spawning runs, and it has been on the state list of designated water lease project streams since March, 1990 (EQC 1998).

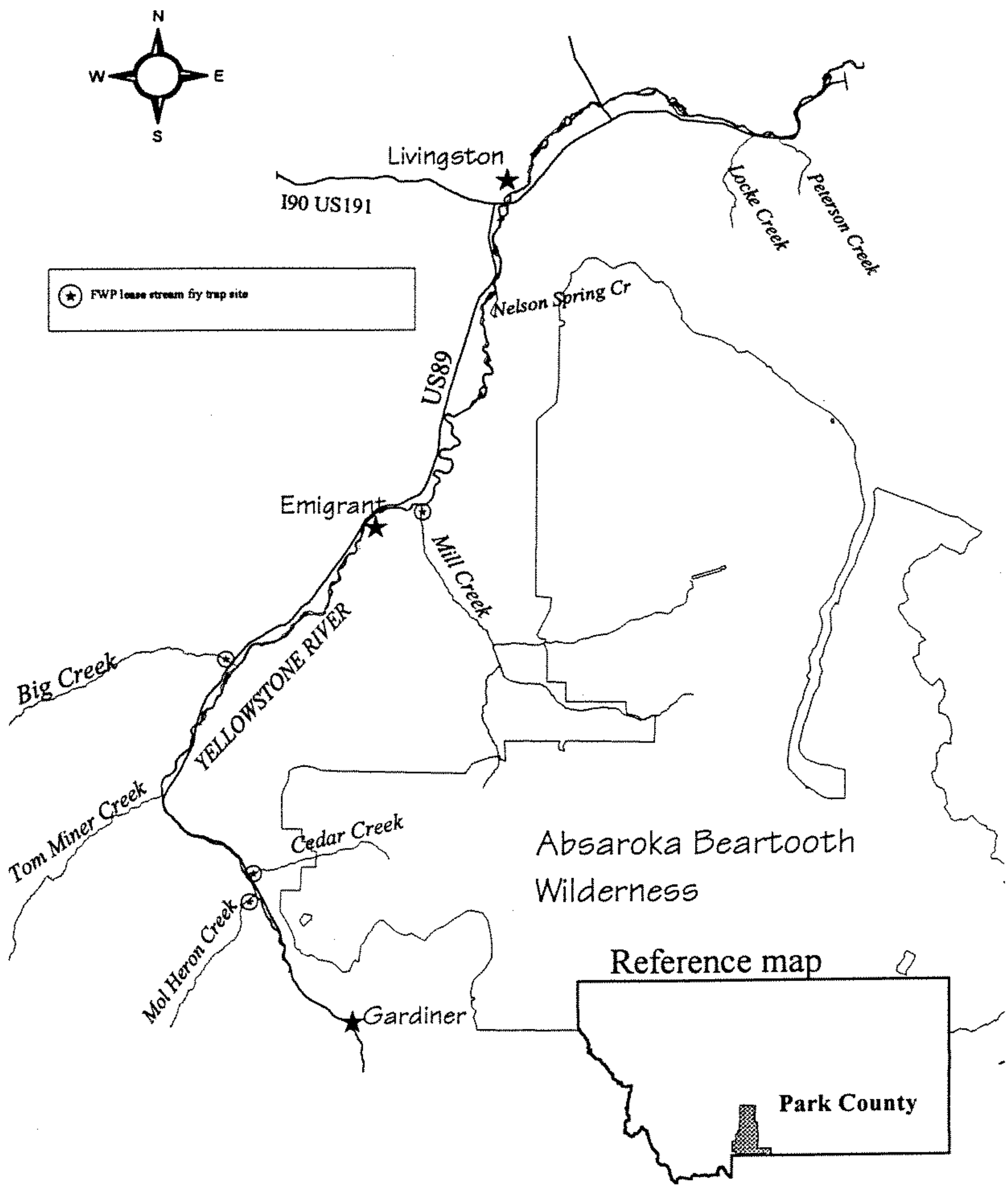

Figure 1. Map of the project area showing the four FWP leasing streams, associated trap sites and additional high quality spawning tributaries as defined by Clancy (1988).

Cedar Creek, near Corwin Springs, is a smaller tributary of the Yellowstone with most of its length under U.S. Forest Service jurisdiction and within the Absaroka Beartooth Wilderness (Figure 1). Cedar Creek is a fourth order stream based on the occurrence of perennial streams on USGS 1:24,000 scale topographic maps with an approximate length of 7.5 miles (12 km), and a mean annual discharge of 9.1 cfs (0.26 m^3/s); (Parrett 1985). There are several irrigation diversions within the lower 0.4 miles (0.7 km) of Cedar Creek where it flows through privately held lands. A downstream water lessor assists in the administration of the Cedar Creek water lease.

Mol Heron Creek flows out of the Gallatin Range and enters the Yellowstone River near the town of Corwin Springs. Mol Heron Creek is a fifth order stream based on the occurrence of perennial streams on USGS 1:24,000 scale topographic maps with an approximate length of 11 miles (18 km), and a mean annual discharge of 25.4 cfs (0.69 m^3/s); (Parrett 1985). There are two irrigation diversions within 0.6 miles (1 km) of the mouth of Mol Heron Creek, and both are controlled by the lessor.

4.0 Methods

4.1 Stream Discharge and Temperature

Discharge was monitored daily in each project stream. Staff gauge readings were recorded and converted to discharge using USGS rating curves for Mill, Big, and Cedar creeks. Bi-weekly measurements were used to construct a discharge rating curve for Mol Heron Creek. The USGS gauge on Big Creek was installed on July 28, and no discharge measurements were collected before this date. The Mill Creek gauge was lowered on its mountings on August 26 to accommodate changes in the channel, and to allow lower flows to be measured more accurately. A new rating curve was constructed by USGS and used to convert the Mill Creek gauge readings after its relocation. Mean, minimum, and maximum seasonal (July to September) discharges were estimated for 1999, and compared to the previous two years for Mill, Cedar, and Mol Heron creeks. Onset Optic StowAway® thermographs were installed at each staff gauge location on June 6, 1999 and programmed to record at 30 minute intervals. Thermographs measured temperatures ranging from -40 °F to 167 °F (-40° C to 75° C) with an accuracy of +/- 0.36 °F (+/- 0.2 ° C) and +/- 0.33 minutes/day.

4.2 Spawning Activity

Spawning was monitored by walking sections of each creek once a week, beginning in late June, until fish were observed actively moving into each creek. After staging or spawning fish were observed, daily monitoring was continued for up to 1 week. At each monitoring visit the number of fish observed, their approximate location, whether they were actively spawning, and time and weather information was recorded. Each monitoring visit lasted a minimum of 30 minutes, and observers walked upstream counting fish as they went. As this was a qualitative survey, only a 52 to 110 yard (50 to 100 meter) subsection of each creek was walked at any given visit. Mill and Big creeks were the sites farthest downstream, and they were monitored first and used to gauge approximate spawning times for other project streams.

4.3 Yellowstone Cutthroat Trout Fry Recruitment

4.3.1 Trapping Protocol

Fry recruitment, defined as the number of fry outmigrating from a tributary and entering the mainstem of the Yellowstone River, was estimated by setting fry traps within each project stream, in the first suitable trap site upstream of the creek mouth. Yellowstone cutthroat trout fry begin downstream outmigration after emergence from the gravel, and most move into the mainstem within a few days (Thurow, Corsi, and Moore 1988). The number of fry trapped was used as an index of total fry recruitment (Byorth 1990; Shepard 1992, Hennessey 1998).

A consistent pattern in Yellowstone cutthroat trout fry outmigration from Locke, Mill, Cedar, and Mol Heron creeks was documented in 1996 and 1997, and confirmed by work on the same tributaries in 1998 (Hennessey 1998, Roulson 1998). A sampling protocol was developed based on the number of fry caught in each tributary as the outmigration period progressed, with the goal of concentrating sampling effort during the days when fry outmigration peaks (Hennessey 1998).

FWP decided to use Hennessey's (1998) protocol during the 1999 surveys to monitor Yellowstone cutthroat trout fry numbers. This protocol allows a reduction in the overall field effort without compromising the accuracy of the index of total fry outmigration (Hennessey 1998, Roulson 1998).

Hennessey's (1998) protocol was used on Mill, Cedar, and Mol Heron creeks. The protocol prescribes trapping each creek 2 days, then skipping 2 days until fry are caught. Once fry are caught a 3-day running mean is calculated, but the trapping pattern is maintained. When trap catch exceeds 1.5 times the 3-day running mean or is greater than 50 fry, sampling increases to every day for the next 10 days. If trap catch on the 11th sampling day is greater than 0.25 times the previous 3-day running mean, then sampling continues for the next 5 days and then stops for the season. If trap catch does not meet this criteria, trapping stops with the 11th day. Hennessey's protocol was shown to sample 83-98% of the total outmigration, as measured by trap catch, on Mill, Cedar, and Mol Heron creeks from 1996-1998 (Hennessey 1998, Roulson 1998). Big Creek was sampled every day after fry were first caught to ensure a complete record of fry outmigration since this was the first year that monitoring had occurred on Big Creek in 10 years.

Traps were placed on each project stream approximately 25 to 30 days after spawning activity was observed (Benson 1960). In Mill Creek, where no spawning was observed, temperature and historical fry trapping data were used to estimate the spawning date (Shepard 1992, Hennessey 1998, Roulson 1998). Beginning on July 23, 1999, fry traps were set overnight for two nights, then pulled for two nights, until protocol criteria for increasing sampling was met. Thereafter, traps were set and checked daily for the prescribed number of days. An effort was made to check traps early in the morning to minimize fry stress (Hennessey 1998). Number and species of fry caught, individual total lengths of a random subsample of 10 fry, water temperatures, and staff gauge readings were recorded.

4.3.2 Trapping Equipment and Locations

Fry outmigration was estimated using fry traps with openings 2.3 ft by 1.5 ft (80 cm by 47 cm), framed with 1/4 in (5 mm) diameter metal rods (McMullin and Graham 1981). A 4.5 ft (1.4 m), 1/16 in (1.6 mm) mesh, net was sewn around the frame. The tapered net ended in a 4 in (10 cm) threaded PVC and metal collar connected to the tail of the trap by screwing into a matching PVC pipe. The tails were approximately 3 ft (1 m) in length, made of the same netting as the trap, and had a drawstring closure (Hennessey 1998).

Traps were placed by pounding a 3 ft (1m) length of rebar into the streambed on either side of the trap mouth. The frame rested against the rebar and was secured with wire. Current flowing through the trap kept it open and straight. The bottom of the trap frame was covered with rocks to prevent fry from swimming under the trap. Captured fry were retained in the tail of the trap where the PVC collar presented a velocity barrier to escapement.

Traps were placed near the first suitable pool upstream from the mouth, so that the tails sat in the deepest portion of the pool just below a riffle. Care was taken not to place the trap over an active redd. Whenever possible, traps were placed in the same location as in previous surveys to maintain comparable trap efficiencies (Hennessey 1998, Roulson 1998).

The main channel of Mill Creek was blocked by a rock berm constructed by a landowner in 1998, and all of the flow was diverted to the North channel. A pool at the end of a low velocity run section in the newly widened North channel of Mill Creek was chosen as the 1998 trap site, and was used again in 1999. During lower flow periods in July of 1999, a second trap was set on the opposite side of the North channel in an attempt to catch a larger percentage of fry. The two traps used in Mill Creek spanned a total of approximately 20% of the channel width.

The trap in Big Creek was placed on the inside of a bend, on the south side, approximately 220 yards (200 m) upstream from the mouth of the creek. Due to higher than anticipated flows and an increase in fry mortality, the trap was moved to the opposite side of the creek after 8 days. The Big Creek trap sampled approximately 30% of the channel width.

The single trap in Cedar Creek was placed in the same location as the past three years, and sampled approximately 50% of the width. In Mol Heron Creek, a single trap was placed in the thalweg near the left bank in approximately the same site as 1999. The thalweg site was chosen to increase trap efficiency, and a plywood box was constructed around the trap tail to reduce stream velocity and stress on the fry. The Mol Heron trap sampled approximately 25% of the creek width.

4.4 Mill Creek Flushing Flow

An annual 48 hour flushing flow is included in the Mill Creek lease, and is intended to help move recently emerged fry out to the Yellowstone River before flows drop to critically low levels during late summer irrigation. The 1999 flushing flow occurred from August 27 to 29. Ideally, the flushing flow should coincide with expected end of peak fry emergence based on outmigration patterns in other project area streams. During the flushing flow, all diversions on Mill Creek were closed in accordance with the lease.

The success of the 1999 flushing flow was evaluated with two traps at the previously described Mill Creek trap site. The staff gauge was read and the traps were checked at 4 hour intervals for the first 12 hours, and every 24 hours throughout the remainder of the flush. Catch records before and after the flush were used to evaluate its timing and effectiveness.

4.5 Climatic Data

Climate data from the two weather stations in the upper Yellowstone River region, Livingston 12S, and Gardiner, were obtained for 1999 and compared to the average readings over the life of the climate stations. The Gardiner station has been gathering data since 1948, while the Livingston 12S station has continuous records dating back 17 years for temperatures and 48 years for precipitation (WRCC 1999). Data examined included average maximum and minimum daily temperature, monthly precipitation, and annual precipitation. At the time of this report the data for 1999 was not complete. Therefore, only trends from January to August were examined for Livingston 12S station, and from January to November for the Gardiner station (WRCC 1999).

5.0 Results

5.1 Stream Discharge and Temperature

5.1.1 Discharge

Below to average snowpack in the Mill Creek basin, and moderate spring temperatures tempered flows in Mill Creek in July, with the 1999 peak on July 23 at 57 cfs (1.61 m^3/s) falling far short of

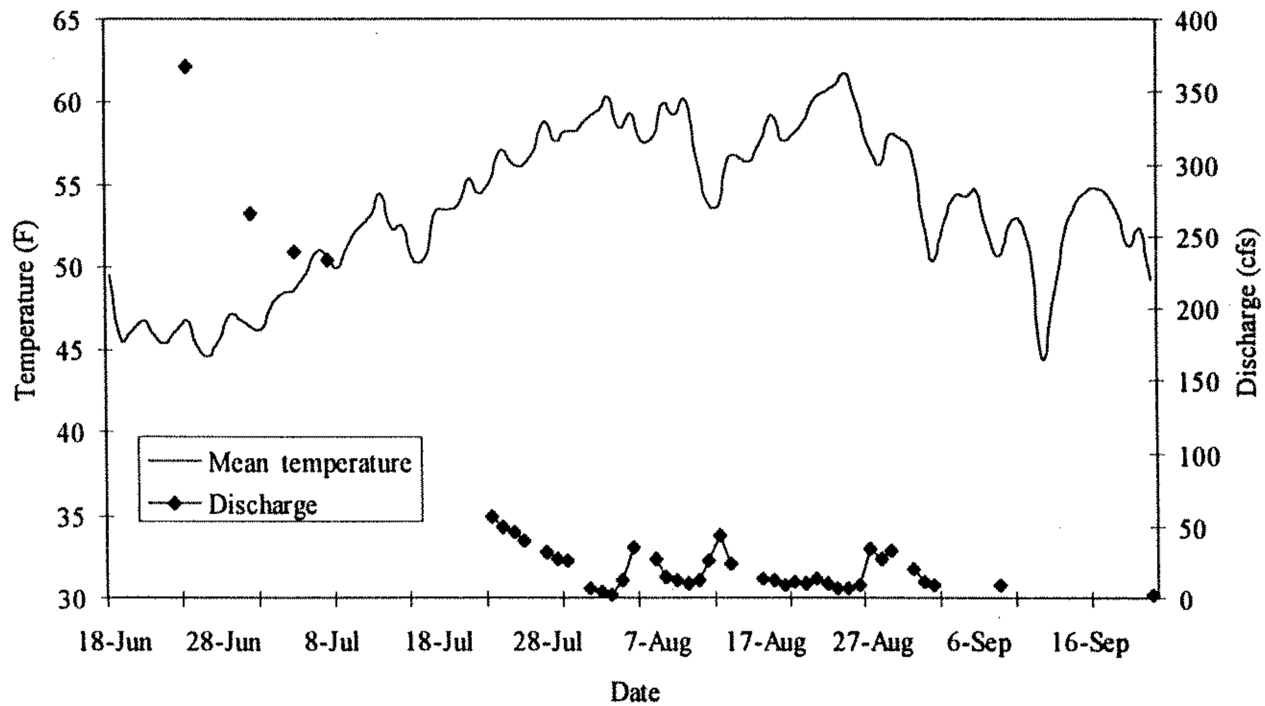

Figure 2. Daily discharge readings and mean daily temperature for Mill Creek, Montana from June to September 1999.

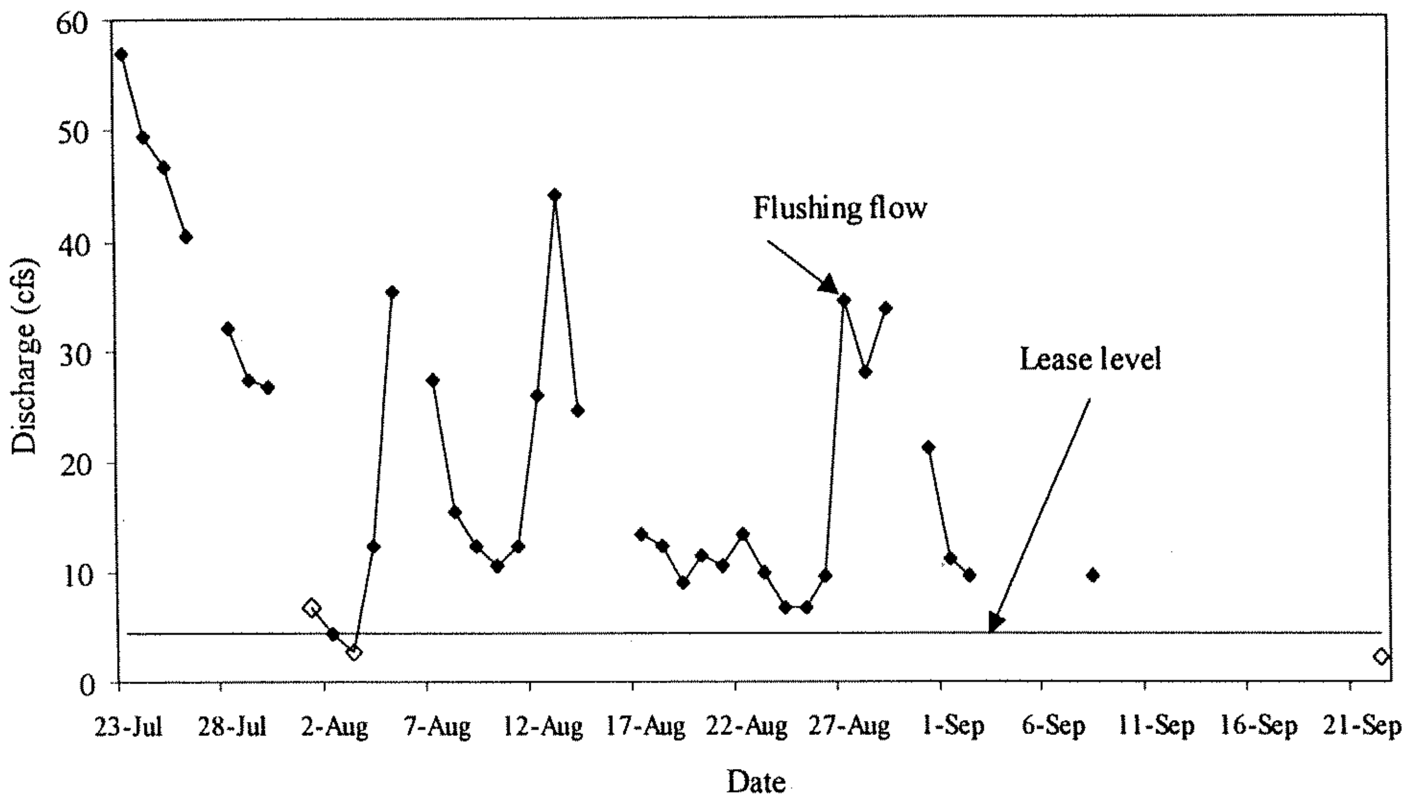

Figure 3. Comparison of daily flows on Mill Creek during the 1999 Yellowstone cutthroat trout fry trapping season with the water lease level (4.4 cfs). Open squares indicate dates when the water lease enforcement contact was notified to improve flows. The peak of the flushing flow is also indicated.

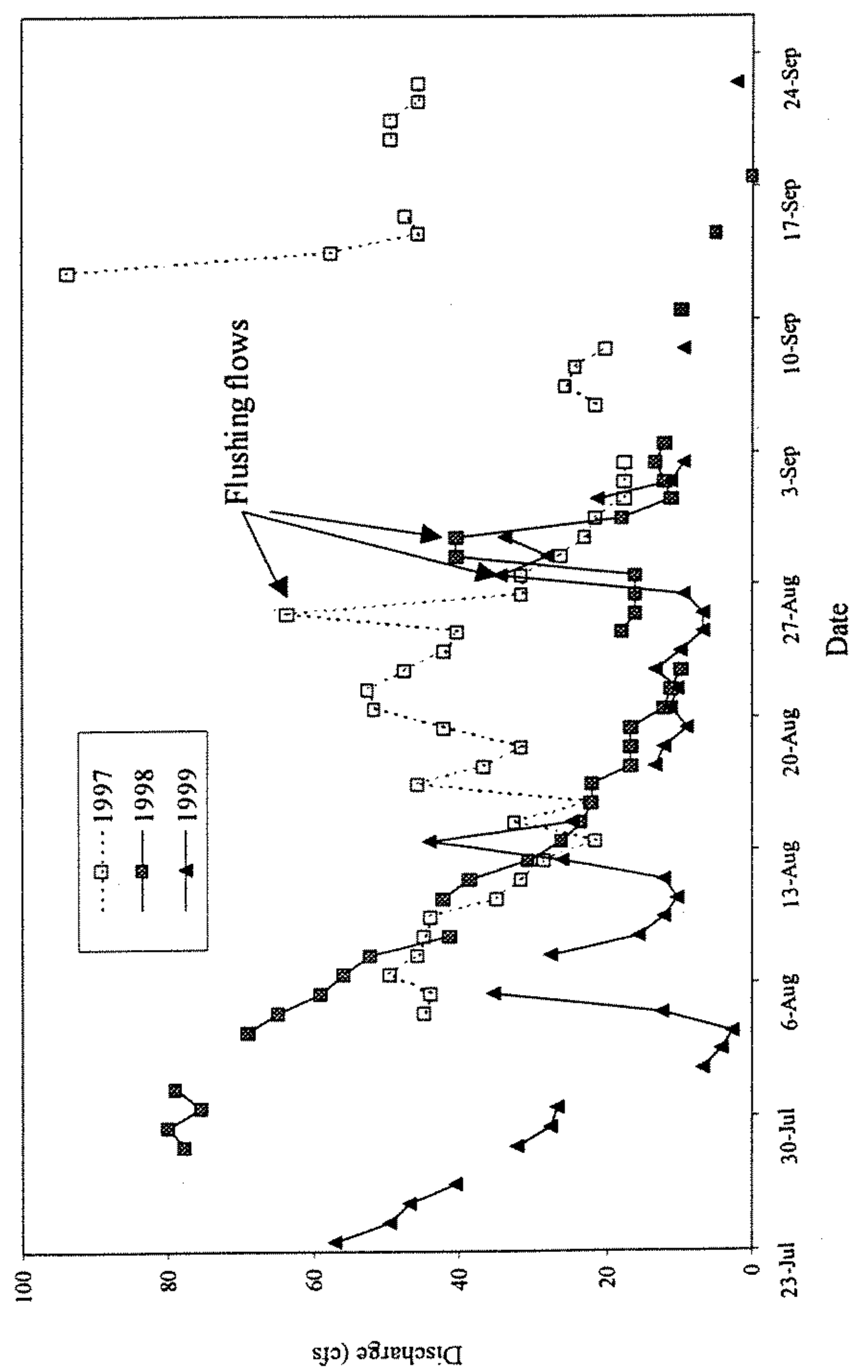

Figure 4. Comparison of daily discharge readings for Mill Creek, Montana from July to August, 1997 to 1999.

the 79 cfs (2.2 m^3/s) peak flow seen in 1998; (Figure 2,Table 2). Flows declined rapidly from this seasonal peak, falling to below the lease quantification level of 4.4 cfs (0.12 m^3/s) by August 3 (Figure 3). Such low flows dewatered much of the main channel width far earlier than the two previous summers (Figure 4). The water lease enforcement contact was notified as soon as flow shortages were recorded and he made adjustments to flows to increase the downstream water supply. However, the first time that the water lease enforcement contact was notified and changed the headgate settings, a water right holder reset the headgate within 12 hours, requiring the water lease enforcement contact to lock the headgate in place.

Flows on Mill Creek increased sporadically after heavy rains on August 5 and 13, but returned to lower levels within a day of each storm event (Figures 2 and 3). Discharge during comparable dates in 1997 and 1998 ranged from 2.75 cfs to 56.95 cfs (0.08 m^3/s to 1.61 m^3/s); (Table 2). Although discharge remained fairly high for 2-3 days after the flushing flow in 1999, it had returned to pre-flush levels by September 3, and dropped well below lease level by September 22, the last day that flows were measured (Figures 2 and 3).

Flows on Big Creek remained well above lease level throughout the entire summer (Figure 5). Early season flows are not available because the staff gauge was not installed until July 29, but between July 29 and Sept 22, total discharge measured was never less than 4 cfs (0.11 m^3/s) above the lease level minimum of 11 cfs (0.31 m^3/s). Based on Byorth's (1990) work, it is unlikely that any redds were dewatered during the 1999 season under these flow conditions.

Flows on Cedar Creek dropped below the lease quantification level of 1.33 cfs (0.03 m^3/s) at least three times between August 9 and 16, and were less than half the lease level on August 16 (Figure 6). No redds were marked in 1999, but based on previous years' data, substantial dewatering of redds can be assumed (Byorth 1990, Hennessey 1998). After August 24, discharge remained stable and slightly above 1999 lease levels (Figure 7). The downstream water lessor was contacted four times during the trapping season to manipulate flows and he took it upon himself to check the staff gauge frequently as part of enforcing the lease. However, it is apparent from Figures 7 and 8 that flows were still lower than in previous years. In 1999, flows during August and September ranged from 0.6 cfs (0.02 m^3/s) to 2.3 cfs (0.06 m^3/s), compared with the 1998 range of 0.4 cfs (0.01 m^3/s) to 2.9 cfs (0.08 m^3/s); (Figure 8,Table 2).

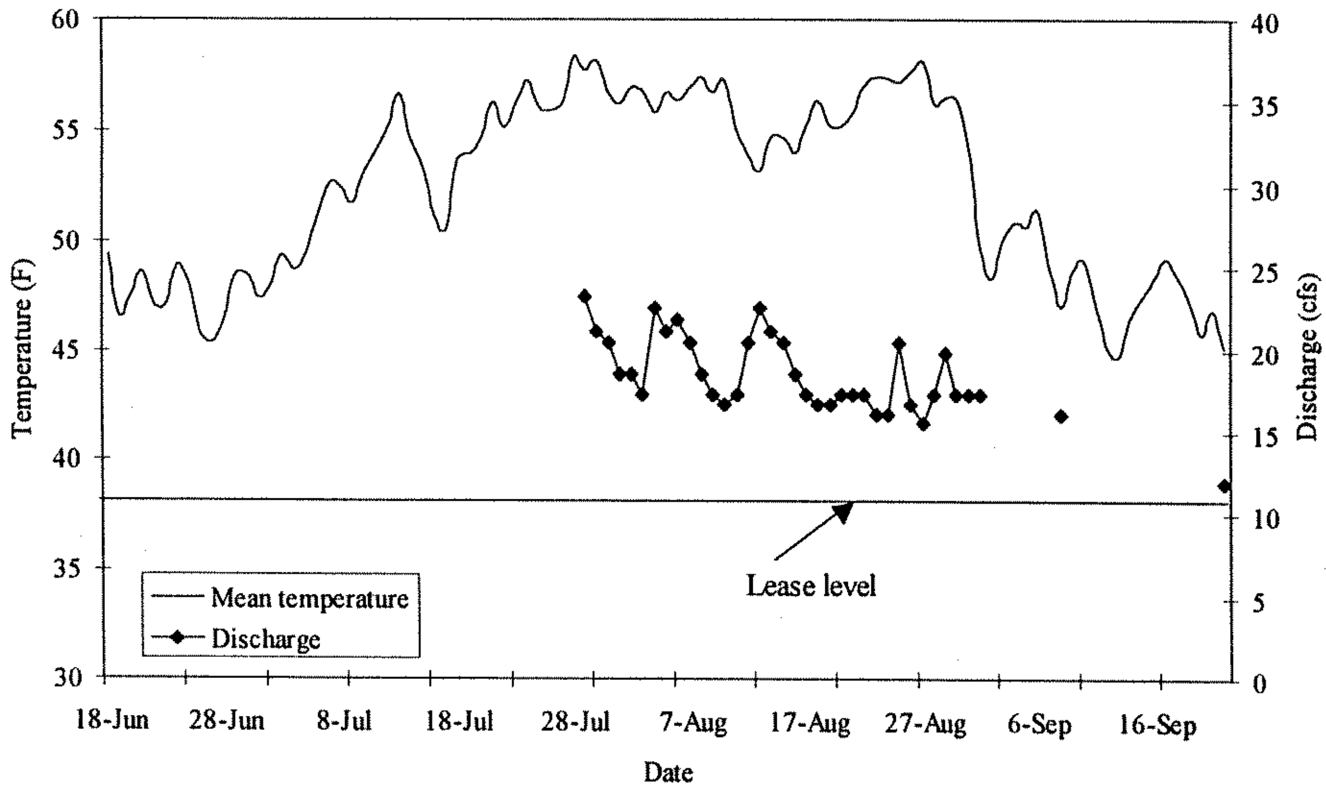

Figure 5. Daily discharge readings and mean daily temperature for Big Creek, Montana from July to September 1999.

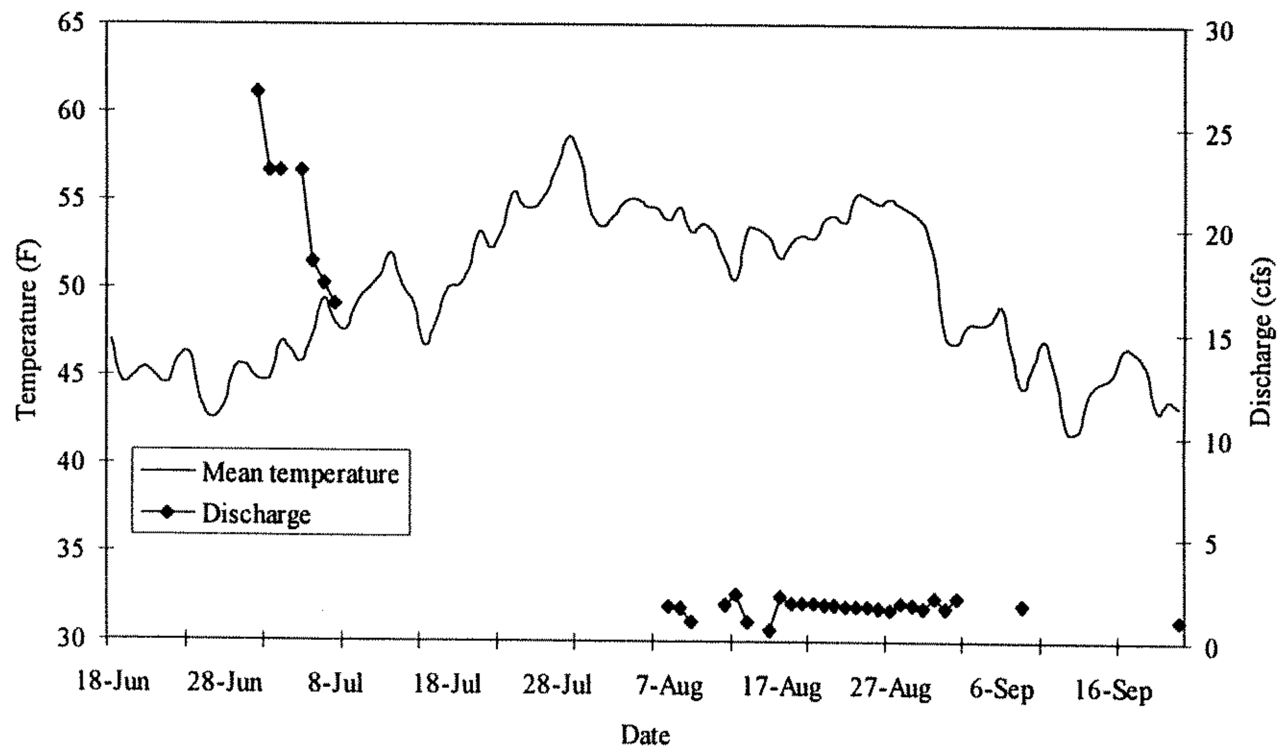

Figure 6. Daily discharge readings and mean daily temperature for Cedar Creek, Montana from June to September 1999.

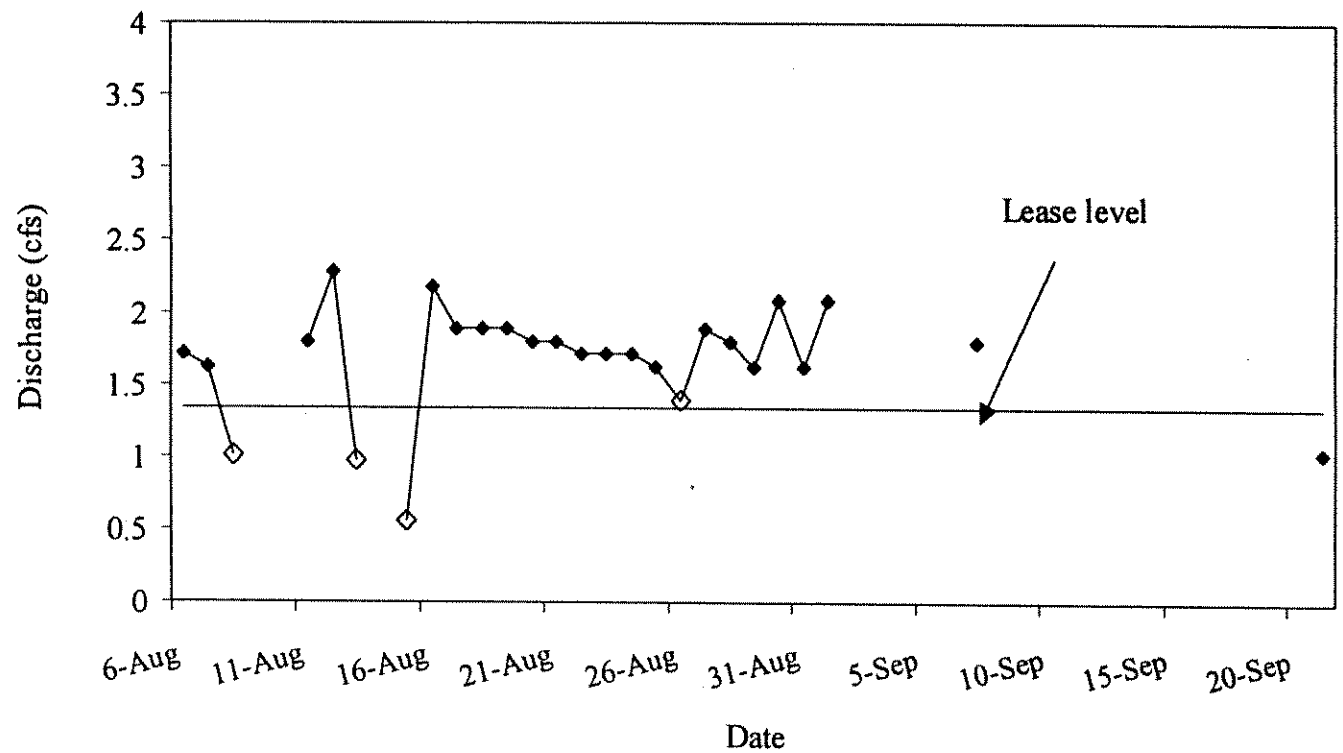

Figure 7. Comparison of daily flows on Cedar Creek during the 1999 Yellowstone cutthroat trout fry trapping season with the water lease level (1.33 cfs). Open squares indicate dates when the water lease enforcement contact was notified to improve flows.

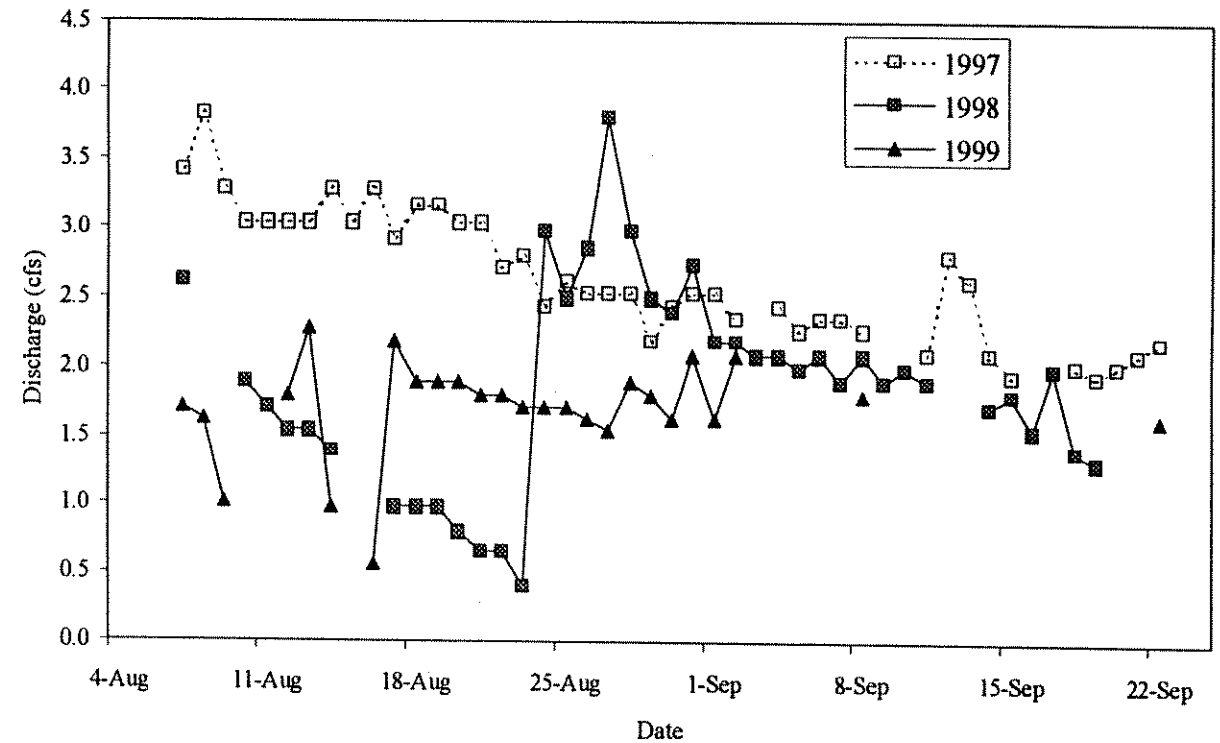

Figure 8. Comparison of daily discharge readings for Cedar Creek, Montana from July to August, 1997 to 1999.

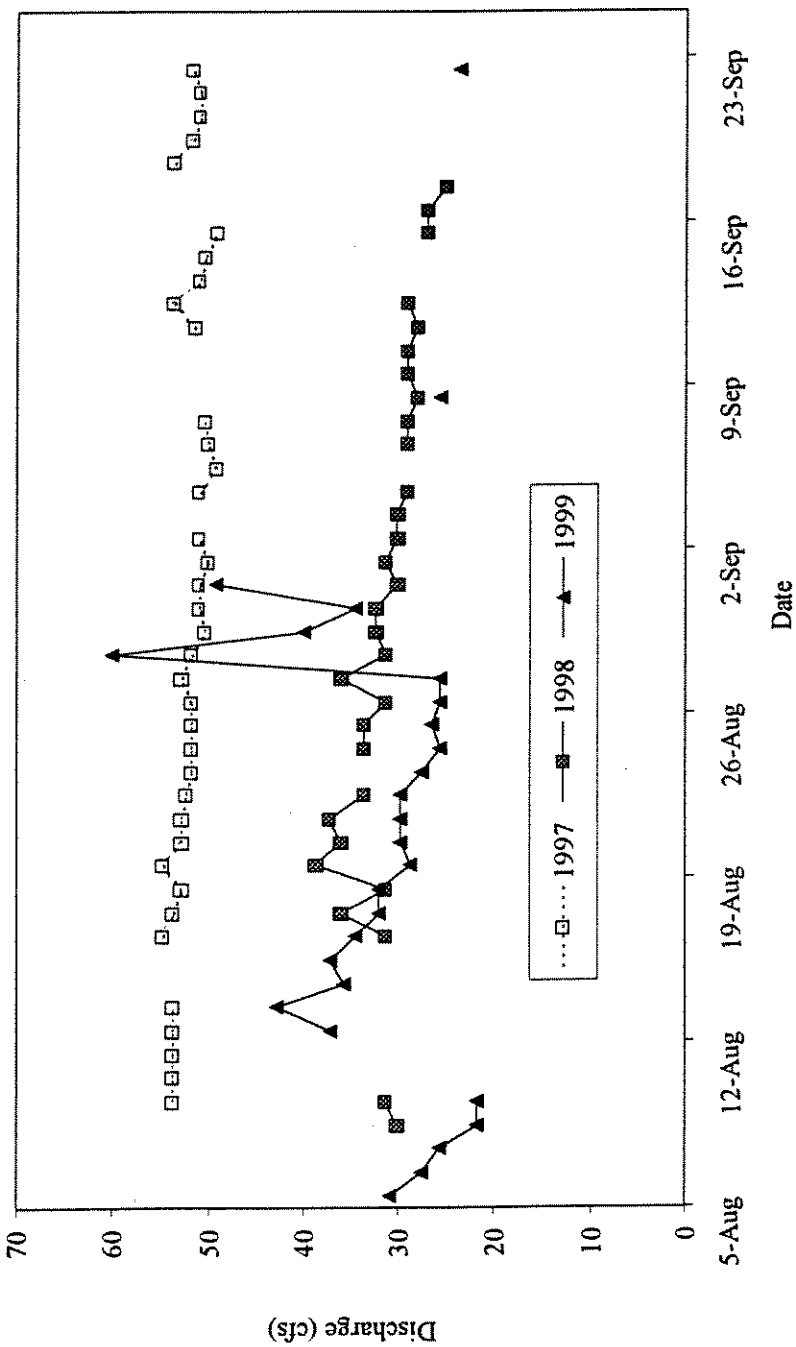

Figure 9. Comparison of daily discharge readings for Mol Heron Creek, Montana from August to September, 1997 to 1999.

The pattern of discharge in Mol Heron Creek in 1999 was less consistent than in 1998 or 1997, but mean stream discharge and the general range of flows was very close to that seen in 1998 (Figure 9,Table 2). Discharge varied from 21.9 cfs (0.62 m^3/s) to 60.1 cfs (1.70 m^3/s) in 1999, and 25 cfs (0.71 m^3/s) to 39 cfs (1.10 m^3/s) in 1998 (Table 2). Flows declined early in August, but increased rainfall later in the month augmented flows and one storm event caused a late season peak on August 28 (Figure 10).

Table 2. Summary of discharge readings for the four Yellowstone water leasing project streams from July to September 1997, 1998, and 1999. These statistics do not include flow measurements gathered during spawning surveys. For pre-trapping season flows, please see Figures 2, 6, and 10.

Project stream	Year	Seasonal mean cfs	Seasonal mean m^3/s	Maximum cfs	Maximum m^3/s	Date	Minimum cfs	Minimum m^3/s	Date
Big	**1999**	**18.7**	**0.53**	**23.3**	**0.66**	**July 29[a]**	**15.6**	**0.44**	**August 27**
Mill	1997	38.5	1.09	95.3	2.70	September 12	17.7	0.50	August 31
	1998	27.9	0.79	78.7	2.23	July 31	0	0	September 17 & 18
	1999	**21.64**	**0.61**	**56.95**	**1.61**	**July 23**	**2.75**	**0.08**	**August 3**
Cedar	1997	2.6	0.075	3.8	0.108	August 8	15.6	0.06	September 15
	1998	1.9	0.053	2.8	0.08	August 24	0.4	0.01	August 23
	1999	**1.7**	**0.05**	**2.29**	**0.06**	**August 13**	**0.6**	**0.02**	**August 16**
Mol Heron	1997	52.0	1.474	54.7	1.55	August 16 &19	49.2	1.39	September 15
	1998	31.3	0.886	38.7	1.096	August 19	25.2	0.71	September 17
	1999	**32.3**	**0.92**	**60.1**	**1.70**	**August 28**	**21.9**	**0.62**	**August 8**

[a] July 29, 1999 was the day that the staff gauge was installed on Big Creek.

** no estimate

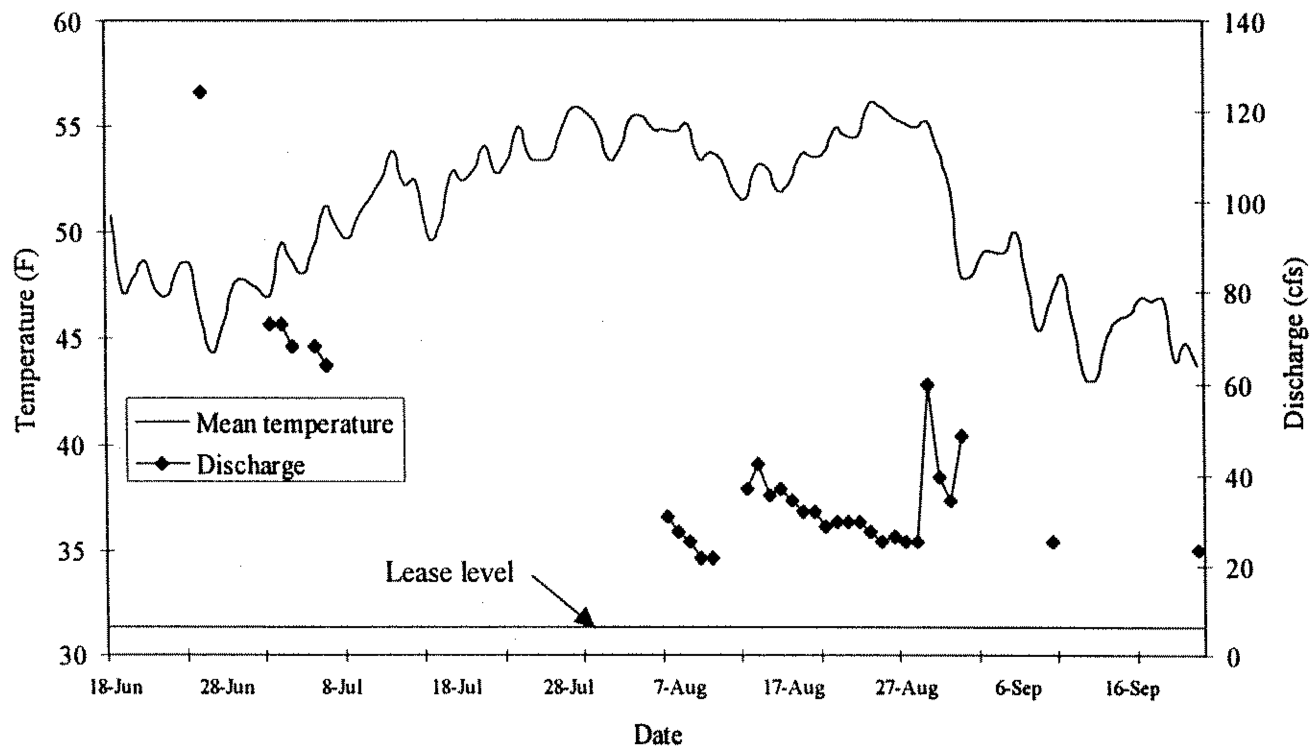

Figure 10. Daily discharge readings and mean daily temperature for Mol Heron Creek, Montana from June to September 1999.

5.1.2 Temperature

Mean daily water temperatures in all creeks climbed as flows declined and air temperatures warmed in late June to early July. All creeks showed a sharp decline in mean daily water temperature on or around August 30, 1999 when daytime temperatures began to decline (NOAA 1999, Figures 2, 4,5, and 10). Despite low flows in early and late August, mean daily temperatures in Mill Creek remained below 60°F (16 °C) throughout the season (Figure 2). The average daily water temperature in Mill Creek fluctuated 12.6°F (6.7° C) in 1999 compared to 12.9°F (6.9°C) in 1998 (Roulson 1998).

Mean daily water temperatures in Big Creek varied little throughout the field season and never exceeded 59 °F (15 °C); (Figure 5). Daily water temperature fluctuation averaged 8.8°F (4.9 ° C) in 1999.

Mean daily water temperatures in Cedar Creek were more variable in 1999 than in previous years, and exceeded 57°F (14 °C) briefly in late July (Figure 6). Daily water temperature fluctuation averaged 7.7°F (4.3 ° C) in 1999, compared to 6.7°F (3.7 ° C) in 1998 (Roulson 1998).

Mean daily water temperatures in Mol Heron Creek remained below 57 °F (14 °C) in 1999. (Figure 10). Daily water temperature fluctuation averaged 10.3°F (5.7 °C).

5.2 Spawning Activity

GANDA monitored Mill Creek four times from June 25 to July 5, 1999, but flows were too high and turbulent for locating spawning fish. Mean discharge during spawning surveys on Mill Creek was 291 cfs (8.24 m^3/s). Big Creek was monitored daily from June 25 to July 3, 1999 with a total of 57 fish observed and 23 actively spawning. Mean water temperature during spawning observations on Big Creek was 50.5 °F (10.3 °C). Mean discharge was not estimated because the stream gauge was not installed on Big Creek until July 29. Spawning activity was concentrated near the Highway 89 bridge, and no spawners were observed above the Bar X diversion. The distribution of spawners is consistent with what Byorth (1990) reported in 1988 and 1989, and the timing of spawning coincides with his 1988 surveys.

Cedar Creek was monitored on June 25, and on a daily basis from July 1 to 8, 1999. No fish were observed on June 25, and a total of 47 fish were observed during the July surveys with 14 actively spawning. Mean water temperature during spawning observations on Cedar Creek was 50.2°F (10.1 °C), and mean discharge was 28.8 cfs (0.82 m^3/s). Field crews observed actively spawning fish above and below the Highway 89 culverts, but the majority of fish were observed below the culvert. The culverts have degraded significantly as the stream has downcut its channel over the past 3 years, and the installed fish ladder is only marginally functional; however, it appears that some fish are still able to negotiate it and spawn successfully. No spawners were observed at the upper gauge sites near the OTO Ranch or above the main ditch upstream of the Highway 89 culverts.

Mol Heron Creek was monitored on June 25, and then daily from July 1 to 6, 1999. No fish were observed on June 25, and a total of 41 fish were observed during the July surveys with 16 actively spawning. Mean water temperature during spawning observations on Mol Heron Creek was 52.5°F (11.4 °C), and mean discharge was 78.0 cfs (2.21 m^3/s).

5.3 Yellowstone Cutthroat Trout Fry Recruitment

More fry were trapped per day of trapping in Cedar and Mol Heron creeks in 1999 than in 1998 (Table 3). Outmigration patterns in 1999 were consistent with those seen in 1997 in all but Mill Creek. Big Creek displayed a modified, bell-shaped curve outmigration pattern similar to that seen in the other project streams (Byorth 1990, Hennessey 1998, Roulson 1998). Information on trapping results from 1996 to 1999 is summarized in Table 3. Incidental trapping mortalities were low in Big and Mill creeks, but there was an increase in mortalities in Cedar and Mol Heron creeks.

Table 3.

Summary of fry trapping results from July to September 1996-1999, for the four Yellowstone water leasing project streams.

Project Stream	Year	Total fry caught	Total days trapped	CPUE[a] (fry/day trapped)	Total days fry caught	Incidental mortalities	% mortality
Mill Creek	1996	59	26	26	19	66	9.9
	1997	2,316	46	50	36	109	4.7
	1998	752	36	21	20	7	0.9
	1999	**125**	**28**	**5**	**11**	**7**	**5.9**
Big Creek	**1999**	**3,429**	**35**	**98**	**28**	**87**	**2.6**
Cedar Creek	1996	13,251	24	552	20	74	0.5
	1997	25,781	41	629	35	89	0.3
	1998	3,791	38	100	27	49	1.3
	1999	**14,658**	**23**	**637**	**20**	**1,413**	**10.7**
Mol Heron Creek	1996	1,865	10	187	10	200	23.1
	1997	1,128	35	32	29	87	7.7
	1998	1,251	31	40	20	3	0.2
	1999	**4,159**	**25**	**166**	**22**	**778**	**26**

[a] Catch per unit effort

5.3.1 Mill Creek

Total fry trap catch in 1999 was less than 17% of the total number captured in Mill Creek in 1998. Catch per unit of effort (CPUE) averaged 5 fry per day in 1999, compared to 21 fry per day in 1998 (Figure 11). Peak outmigration occurred in mid-August, approximately 3 days later than in 1998. Fry outmigration was first detected on August 18, and peaked on the following day, August 19, with 74 fry captured. Outmigration in 1999 was much shorter than in 1997 or 1998, with the majority of fry being trapped over 3 days in 1999, compared to 11 days in 1998, and 29 days in 1997. August 29 was the last successful trapping day in 1999 (Figure 11). A total of 125 fry were caught over 28 trapping days (Table 3). Incidental mortality due to trapping increased from 0.9% in 1998 to 5.9% in 1999, although the number of mortalities was the same in both years (Table 3).

5.3.2 Big Creek

As this was the first year of monitoring on Big Creek in over 10 years, there is no current data with which to compare the trap catch. Fry were first captured in Big Creek on July 30, at a mean water temperature of 58.1°F (14.5 °C), and trap catch peaked on August 15 with 368 fry. CPUE averaged 98 fry per day. August 29 was the last successful trapping day, and the majority of fry were trapped over the 10 days from August 10 to 19 (Figure 12). A total of 3,429 fry were trapped in Big Creek in 1999 (Table 3). Incidental mortality was 2.6% with most (86%) mortalities occurring early in the trapping season before the trap was moved to its final location on August 5. Incidental mortalities were collected, frozen, and provided to Joel Tohtz, the FWP fisheries biologist in Livingston, for genetic analysis.

5.3.3 Cedar Creek

Total fry captured in Cedar Creek in 1999 was almost four times that captured in 1998; however, the 1999 trap catch was still only slightly more than half of that captured in 1997 (Table 3). CPUE was 637 fry per day in 1999, and 100 fry per day in 1998. The first fry was captured five calendar days later than in 1998, but the 1999 trap catch peak was within 2 days of the 1998 peak, and occurred on the same day as the 1997 peak (Figure 13); (Byorth 1990, Hennessey 1998, Roulson 1998). In 1999, fry outmigration was first detected on August 12, at a mean water temperature

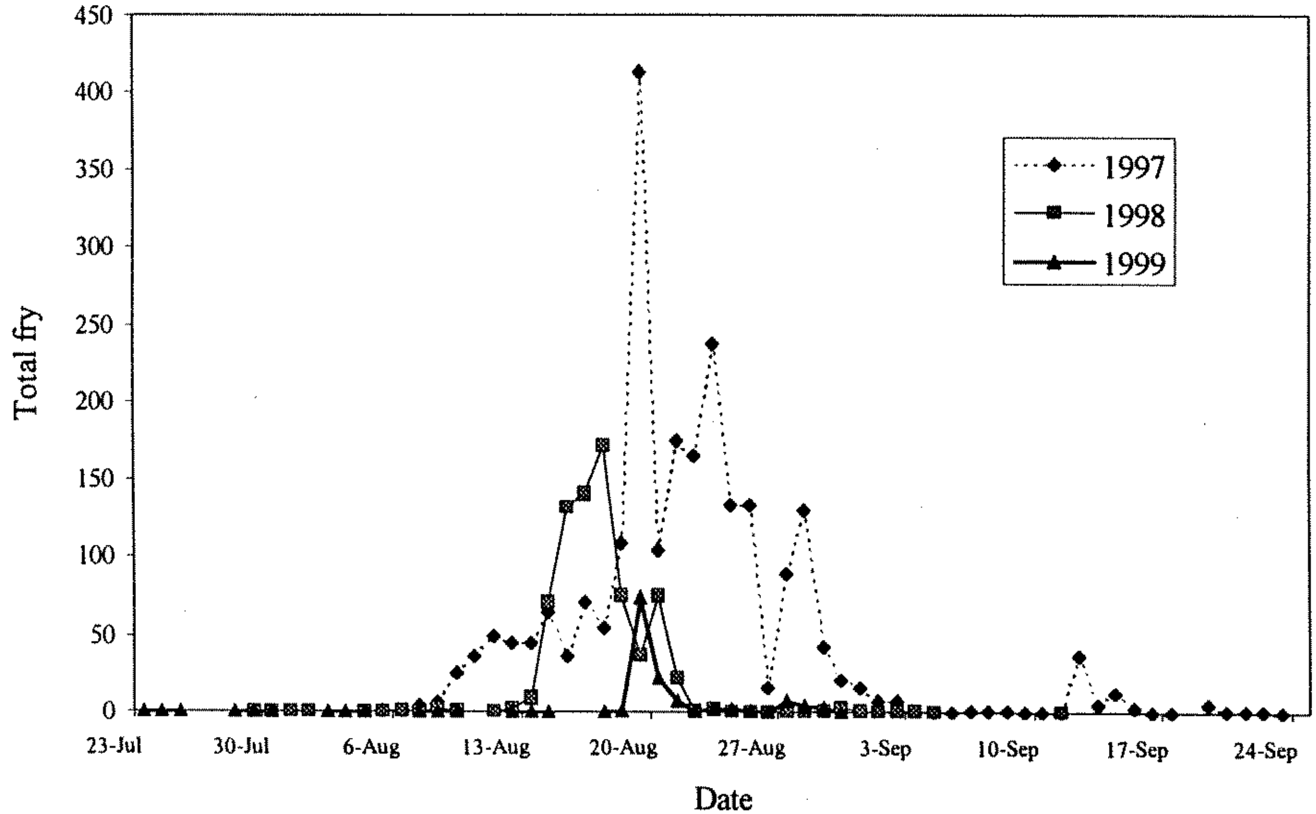

Figure 11. Comparison of the total fry captured each day in Mill Creek, Montana from July to September, 1997 to 1999.

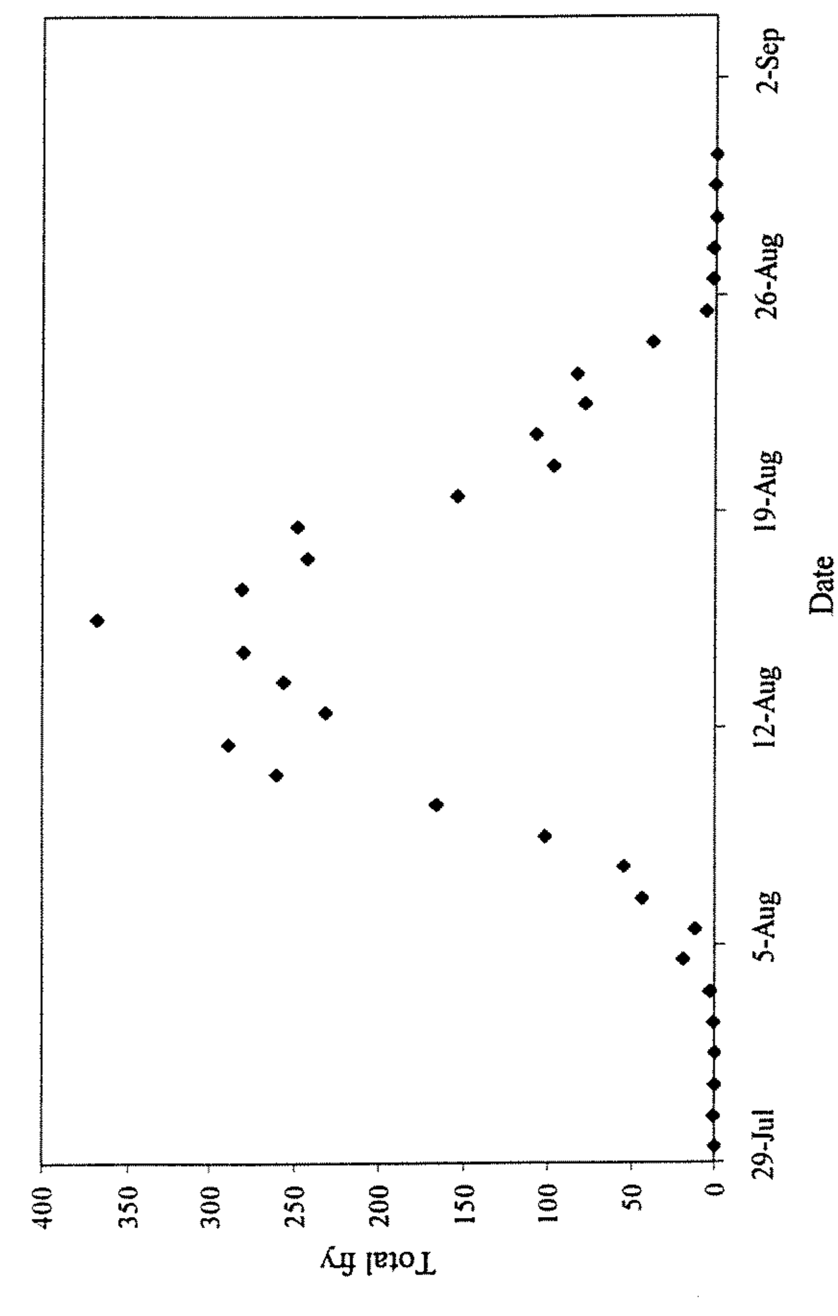

Figure 12. Total fry captured each day in Big Creek, Montana from July to September, 1999.

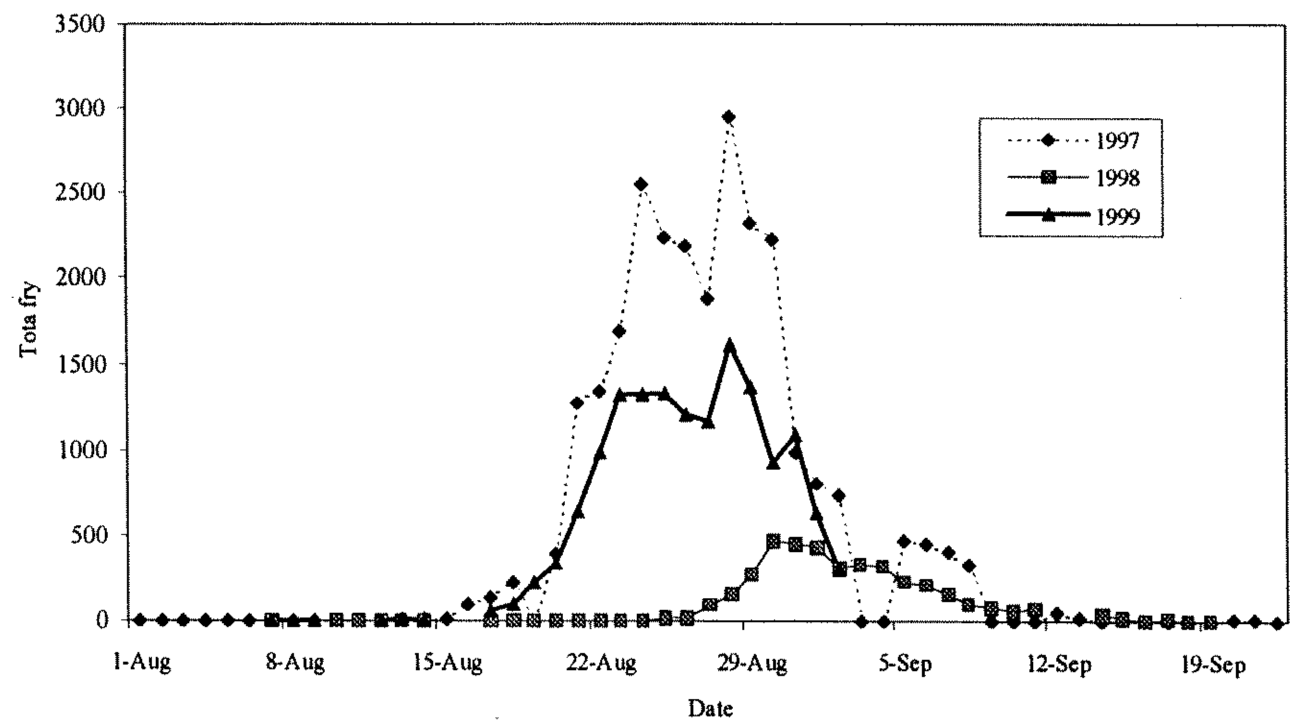

Figure 13. Comparison of the total fry captured each day in Cedar Creek, Montana from August to September, 1997 to 1999.

of 51.4°F (10.8 °C). Outmigration peaked on August 28 with 1,615 fry captured, and trapping was suspended on September 2 when trap catch dropped to 296 fry (Figure 13). A total of 14,658 fry were caught over 23 trapping occasions (Table 3). Incidental mortality increased from 1.3% in 1997 to 10.6% in 1998. Three trapping days accounted for 69% of all mortalities, but there was no apparent common factor involved in these three occasions. There appeared to be little pattern to mortalities, nor did the days when mortalities peaked in Cedar Creek correspond to high mortality days in other creeks. Despite the employment of previously effective tactics to reduce incidental mortalities in Cedar Creek, GANDA was unable to deduce the cause of mortalities.

5.3.4 Mol Heron Creek

Substantially more fry were captured in Mol Heron Creek in 1999 than in 1998 or 1997 (Table 3). CPUE was higher in 1999 at 166 fry per day compared to 40 fry per day in 1998 (Table 3). In 1999, fry outmigration was first detected on August 7, at a mean water temperature of 54.7 °F (12.6 °C). Outmigration increased gradually over the next 5 days, climbed dramatically and peaked on August 23 with 429 fry captured, and then dropped just as rapidly with trap catches declining to 101 fry by August 31, the last trapping day (Figure 14). A total of 4,159 fry were caught over 25 trapping occasions (Table 3). Despite efforts to reduce velocities near the trap tail, large amounts of debris from rainstorms throughout August and high flows late in the season increased incidental mortalities from 0.2% in 1998 to 26.2% in 1999. Although this increase is extreme, 70% of all mortalities were concentrated on three days when the levels of fine debris from storm runoff were highest in the trap, suggesting that the mortalities were due to suffocation rather than stress from too high of a velocity because of trap placement.

5.3.5 Fry Length and Residence Time

Mean fry length and the range of lengths remained much more consistent in 1999 than in past studies. Newly emerged fry , defined as measuring less than 1 inch (25 mm) in total length (TL) were captured during the last weeks of trapping in each creek, and increases in fry length were much less linear than in past years (Kelly 1993, Hennessey 1998, Roulson 1998). Mill Creek was the only site to show a regular increase in fry length over time (Figures 15 and 16). Mean fry length remained below 1.04 in (26 mm) in all but Mill Creek, and very few individual fry longer than 1.2 in (30 mm) were captured from any of the project streams (Figures 15 and 16).

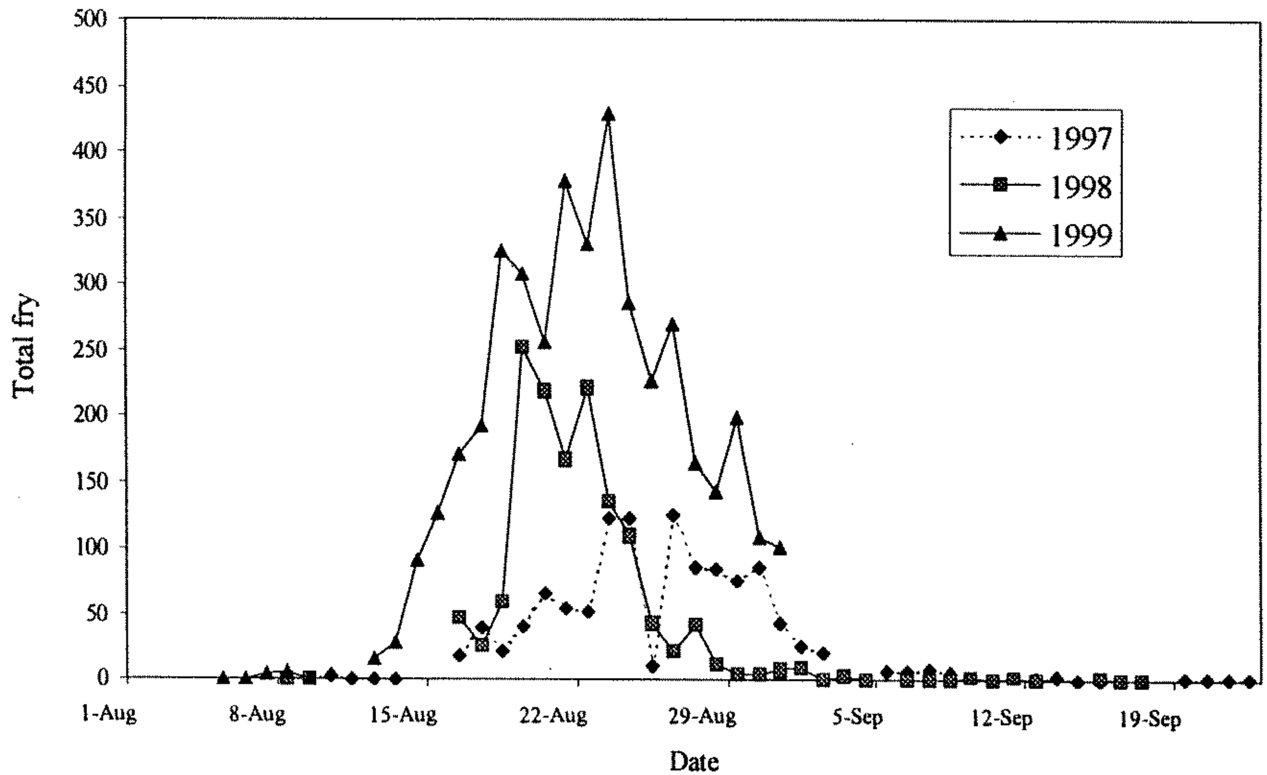

Figure 14. Comparison of the total fry captured each day in Mol Heron Creek, Montana from August to September, 1997 to 1999.

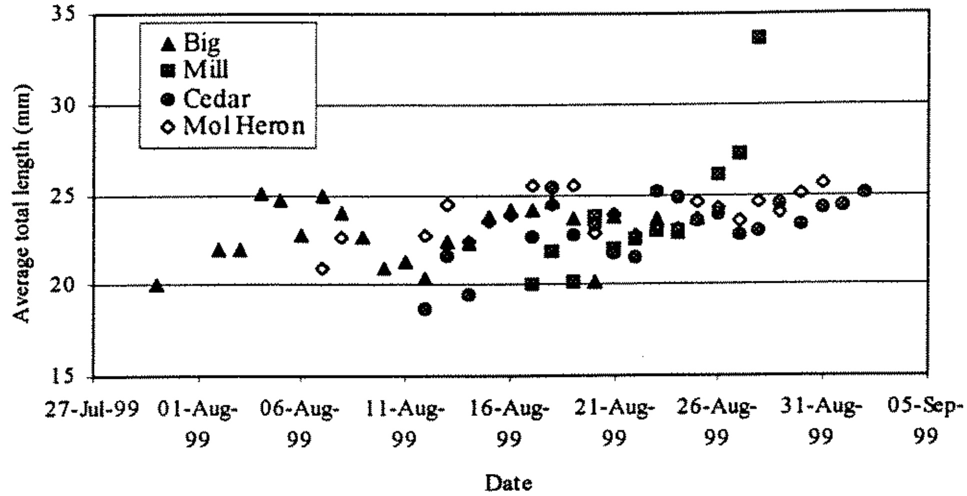

Figure 15. Average total length of a random subsample of Yellowstone cutthroat trout fry by date collected for the four project streams in Montana, 1999.

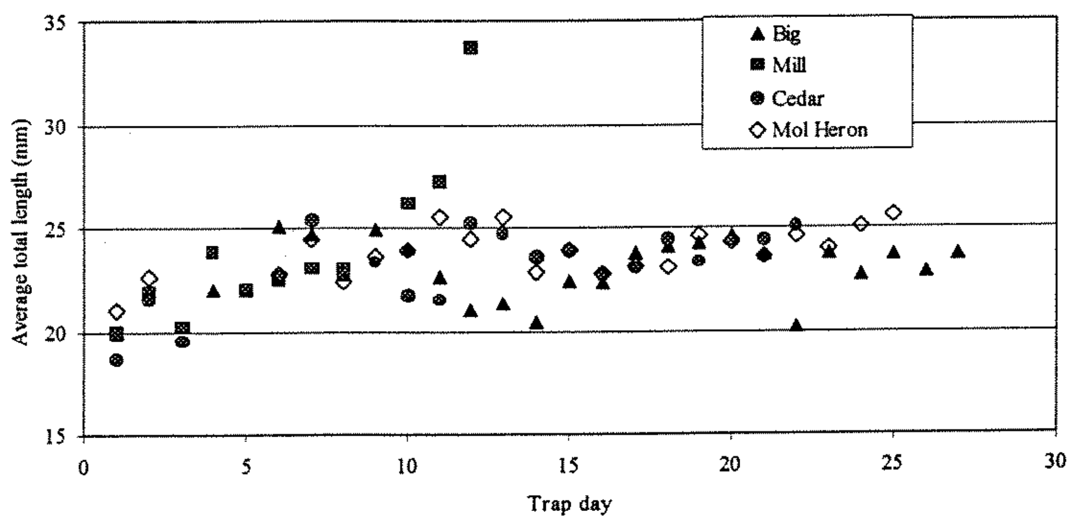

Figure 16. Average total length of a random subsample of Yellowstone cutthroat trout fry by day of sampling period for the four project streams in Montana, 1999.

5.3.6 Mill Creek Flushing Flow

As called for in the lease, all irrigation diversions on Mill Creek were closed at approximately 0500 hours on August 27 and reopened by 0700 hours on August 29, 1998. Discharge at the East River Road bridge increased from 9.6 cfs (0.27 m^3/s) to 34.5 cfs (0.97 m^3/s) by 1100 hours on August 27 (Figure 3). This year's flush level was significantly below the 41 cfs listed in the lease agreement, and much lower than the flushing flows in previous years as well (Table 3, Figure 4). Discharge remained well above pre-flush levels until September 2 when flows returned to 9.6 cfs (0.27 m^3/s). A total of 14 fry were trapped throughout the 1999 flushing flow, accounting for 11% of this year's total trap catch. Only 6 fry were captured during the 5 days before the flush, and no more fry were trapped after August 29 (Figure 11).

5.4 Climatic Data

Trends in average maximum daily temperatures were consistent between the Livingston 12S and Gardiner climatic data stations. Average maximum daily temperatures in 1999 were slightly above average from January to March, and slightly lower than average from April to June. From June until September 1999, average daily maximum temperatures followed the historic pattern very closely at Gardiner. However, July 1999 temperatures were slightly elevated for the Livingston 12S station. Data from the Livingston 12S station for September to November were not available at the time of this report (Figures 17 and 18).

Precipitation varied considerably from the historic pattern at Gardiner with January, May, and August receiving from 1.4 to 4 times the average, and March, July, and September receiving only 20 to 30 percent of the average (Figure 18). Despite the month-to-month variation, total precipitation accumulated at Gardiner by September 1999 was within 1 standard deviation of the mean (WRCC 1999). Precipitation at the Livingston 12S station followed the historic pattern from January to March of 1999, then dropped below normal for the next two months, and was extremely low in July (Figure 17,WRCC 1999). At the end of July, annual precipitation accumulation was only 78% of normal for Livingston 12S (WRCC 1999). However, much higher

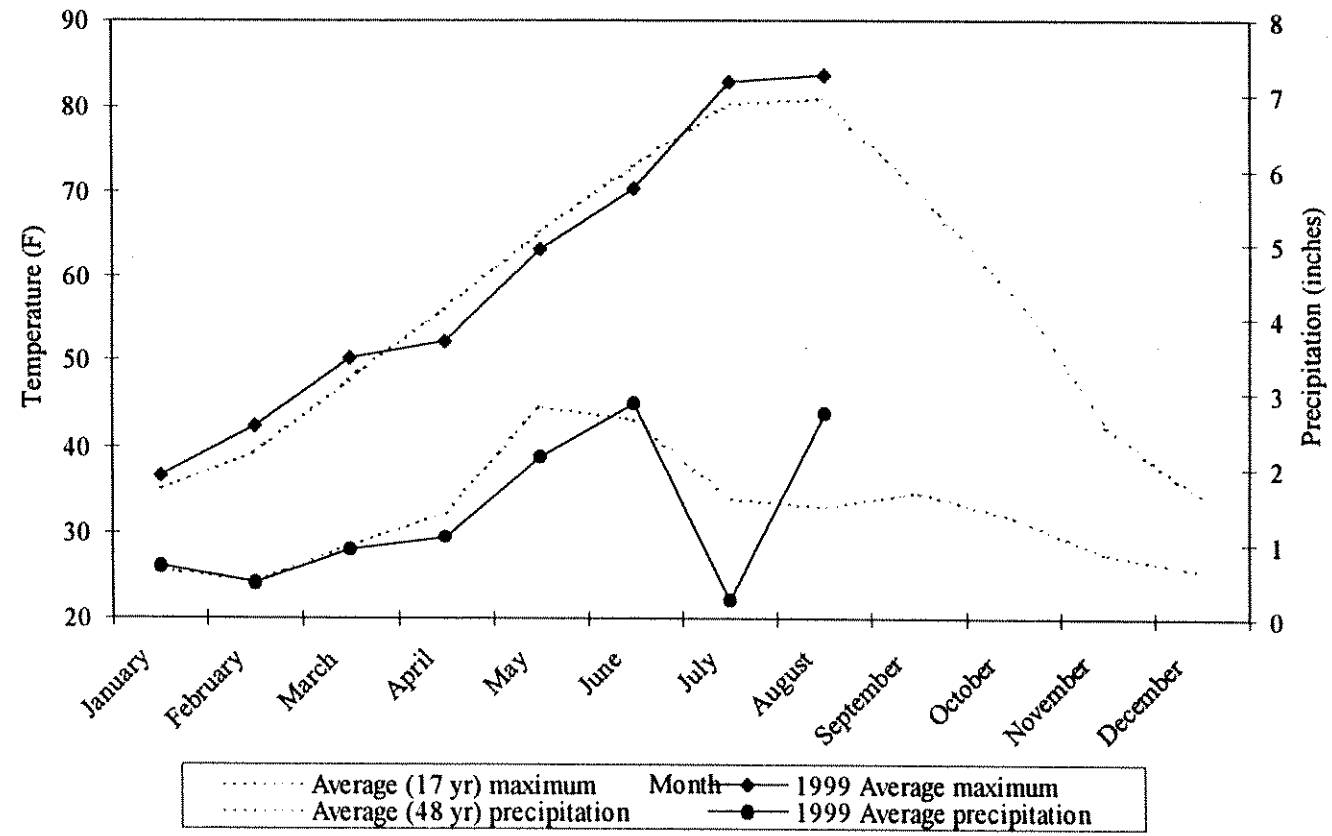

Figure 17. Comparison of the average daily maximum temperature (17 years of record) and monthly precipitation (48 years of record) for the Livingston 12S climate station with the data collected through August, 1999 (WRCC 1999).

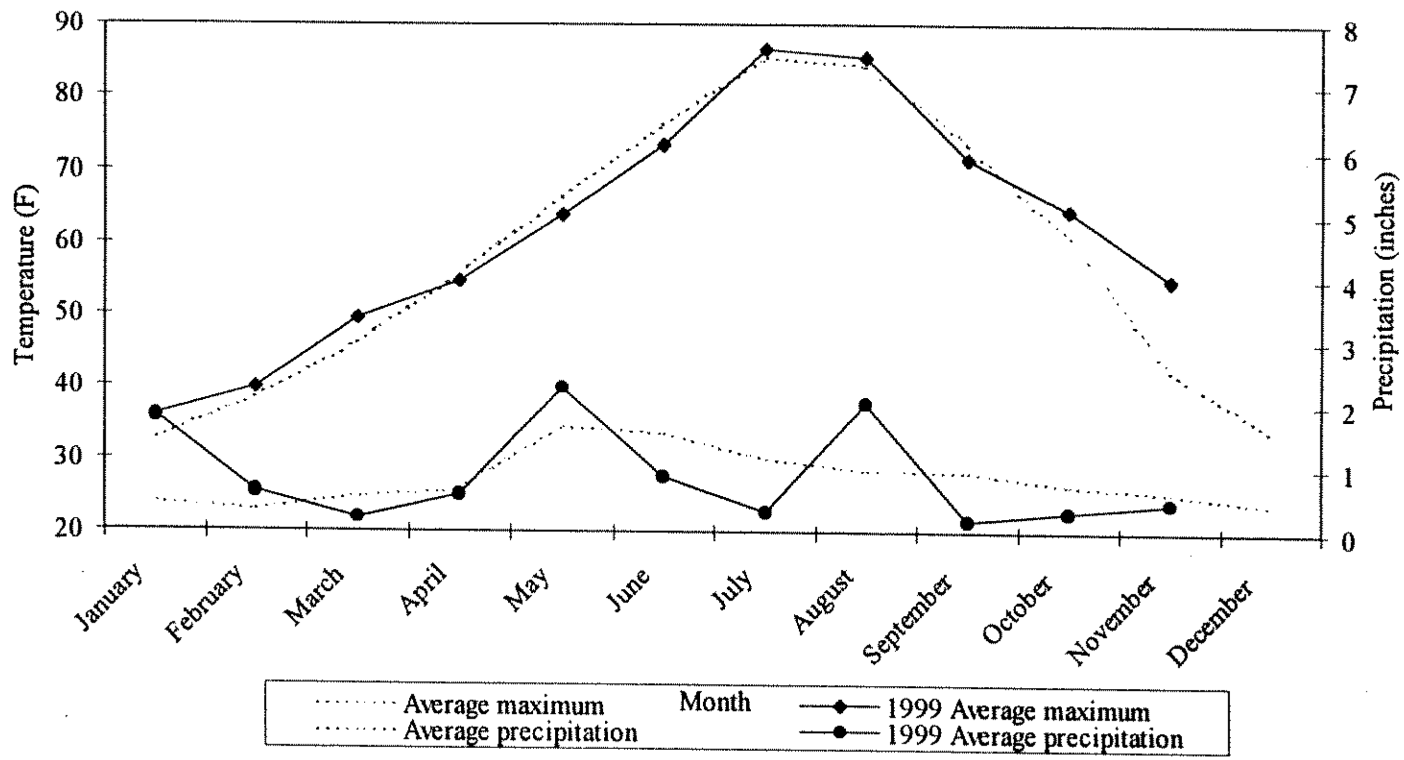

Figure 18. Comparison of the average daily maximum temperature and monthly precipitation for the 44 years of record for the Gardiner climate station with the data collected through November, 1999 (WRCC 1999).

than average precipitation in August brought annual precipitation up to 92% of normal at the Livingston 12S station (Figure 17, WRCC 1999).

6.0 Discussion of Findings

Lower than average local snow pack and lack of rain in July when irrigation demands began to increase, primed conditions for a water shortage in FWP leasing streams during late July and early August. Park County snowpack averaged 30% of normal at the Gardiner station, and 66% at the Livingston 12S weather station in 1999 (WRCC 1999). Irrigation withdrawals from Mill and Cedar creeks affected flows near their respective mouths earlier and kept flows low throughout the summer despite higher than average precipitation in August in both watersheds (Figures 2 and 6). Big and Mol Heron creeks, although subject to similar climatic conditions did not have extensive irrigation demands in 1999, and their water levels remained well above lease level throughout the summer (Figures 5 and 10);(WRCC 1998). In Mill Creek, early irrigation withdrawals dewatered much of the spawning gravels during the first two weeks of August, coinciding with the probable Yellowstone cutthroat trout egg incubation and early emergence period (Hennessey 1998, Roulson 1998). In fact, flows dropped below lease level as early as August 2, and irrigation diversion headgates had to be adjusted by the Mill Creek water lease enforcement contact on at least three occasions in August to maintain flows at or above lease levels. Even with flows restored to the quantifiable lease level of 4.4 cfs (0.12 m^3/s) at the East River Road bridge, much of the spawning-quality gravels in the section nearest the creek mouth remained exposed throughout August. Since salmonid eggs and newly emerged fry require a moist environment and flowing water to maintain their development, it is highly likely that redds in the dewatered portions of Mill Creek did not produce fry in 1999 (Benson 1960, Clancy 1988).

As stated in the 1998 report, the Mill Creek lease is intended to provide in-stream flows sufficient to allow the creek to connect with the Yellowstone River in 8 out of 10 years (Shepard 1990). Furthermore, the intent of water leases is to "maintain and enhance streamflows for the benefit of fisheries" (Spence 1996, EQC 1998). Judging from the fry trapping results of 1998 and 1999, the quantifiable lease level at the East River Road bridge may not be adequate to prevent large Yellowstone cutthroat trout fry losses in low to average water years (Roulson 1998). Mill Creek is a wide, flat, cobble and gravel-bottomed creek, and the amount of water necessary to ensure specific levels of streambed coverage or redd success has not been quantified. Since spawning surveys in Mill Creek are often hampered by high, turbid flows in the spring, an evaluation of the minimum amount of water required to cover a prescribed wetted perimeter would be a useful management tool. If it becomes apparent that 4.4 cfs is insufficient to reliably benefit the fishery, then the leased flows should be reevaluated, and increased if possible. An increase in in-stream flows would not be necessary for the entire lease period, but would be most effective during the 3-5 week period from mid-July until the end of August, and might be able to be accommodated in most years without disrupting the irrigation season.

After 5 years of lease implementation, numbers of Yellowstone cutthroat trout fry outmigrating from Mill Creek increased dramatically in 1997, a record water year, only to progressively decline in 1998 and 1999 (Hennessey 1998, Roulson 1998). If the Mill Creek population of Yellowstone cutthroat trout is to continue to recover, it is imperative that flows for incubation and outmigration be maintained (Clancy 1988; Hennessey 1998, Roulson 1998). Next year will be the first year when spawners from the 1997 year class will begin to return to Mill Creek, potentially generating a record fry outmigration. It would be a great loss to the Yellowstone fishery if flows are not sufficient to support the fry of this prospectively important year class.

Cedar Creek had a similar pattern of flow reductions and lease enforcement to that seen in Mill Creek in early August. Flows dropped below lease level on Cedar Creek on August 9, 14, and 16; and ditch adjustments were necessary to restore flows on several occasions. However, Cedar Creek fry outmigration increased from 1998 levels, probably because the total time and severity of flow reductions during the critical incubation period lasted for less than 24 hours on each occasion in 1999, compared to the 7 day long period in 1998 (Figure 8). Cedar Creek has a restricted, u-shaped channel and small changes in flow increase its wetted perimeter much more drastically than in Mill Creek. Byorth (1990) showed that maintaining flows of 1.0 cfs protects approximately 79% of Yellowstone cutthroat trout redds, but increasing flows by only a third of cubic foot per second, to the current quantifiable lease level of 1.3 cfs, prevented the dewatering of an additional 20% of redds, bringing the total protected close to 100%.

Timeliness of lease enforcement is critical, particularly from July to early August when Yellowstone cutthroat trout eggs hatch out and fry are still in the gravel. Becker et al. (1983) found that alevins or "sac-fry" of chinook salmon (*Onchorynchus tshawytscha*) were more sensitive to dewatering than the developing eggs which have a protective layer or chorion that can prevent dessication. Most stages of development can withstand short-term dewatering since gravels hold some water in the interstitial spaces, if leases are enforced quickly when inadequate flows are reported, then losses can be minimized. However, when long-term dewatering occurs, as it did in Cedar Creek in 1998 and this year in Mill Creek, extensive losses should be expected. Because of the many water right holders on each stream, water lease administration is often complicated. Consistent monitoring is necessary, as is good communication and cooperation between lessors and lease enforcement contacts.

In both Mill and Cedar creeks water lease administration was much more active and consistent an issue this year than in the past. Both enforcement contacts were very cooperative when notified about low water levels. It should be acknowledged that water lease enforcement often involves changing water availability during times of peak demand, and can be a very controversial job. On Mill Creek, the first attempt at enforcement was thwarted by an individual water right holder who raised the headgate soon after the enforcement contact had lowered it to restore lease-level flows. The enforcement contact had to resort to locking the headgate to insure consistent flow management. Additionally, the enforcement contact was unclear as to whether the lease was in effect during July and did not expect to have to manipulate flows until later on in the summer. However, overall administration of the lease went smoothly and there were few conflicts on Cedar Creek this year.

Misunderstandings and miscommunications can lead to friction in lease administration. It would be beneficial for FWP to train water lease enforcement contacts each year to ensure that lease levels are accurately maintained and that enforcement contacts can correctly advise water right holders and lessors on when and how water levels may be adjusted. It is important that staff gauge readings be verified annually to insure accurate flow manipulation, and that adequate flow monitoring be made part of water lease maintenance.

This year was the first year that FWP implemented Hennessey's sampling protocol and it worked well as an alternative to sampling every day throughout fry outmigration. The protocol was able to detect the beginning of the ascending limb in Cedar and Mol Heron creeks (Figures 13 and 14). Judging from the shape of the graphs of outmigration, the protocol managed to sample the majority of the peak region for both Cedar and Mol Heron, and suspended trapping once trap catch had declined significantly (Hennessey 1998); (Figures 13 and 14). However, the protocol did not identify an ascending limb during the extremely short outmigration seen in Mill Creek in 1999 (Figure 11). GANDA recognized that fry outmigration was not progressing normally in Mill Creek and increased sampling to every day once fry were caught in order to better document the outmigration. Although Hennessey's protocol is effective in most years, professional judgement should be used when conditions such as those seen in 1999 in Mill Creek arise.

GANDA tested Hennessey's protocol on the Big Creek data from 1999 and found that it would have sampled 95.7% of the total fry caught and reduced trapping effort by 37%, from 35 days to 22 days. This demonstrates the potential suitability of Hennessey's protocol to other tributary streams with Yellowstone cutthroat trout populations. However, it would be wise to collect at least one more season of complete data on Big Creek to confirm the outmigration pattern before employing the protocol's shortened sampling schedule. Given the results from Cedar, Mol Heron, and Big creeks, GANDA recommends that FWP adopt Hennessey's protocol for use in future monitoring efforts on Cedar and Mol Heron creeks, and on Big Creek after confirming the outmigration pattern. The protocol may be continued on Mill Creek as well, but more frequent monitoring may be required if outmigration appears inconsistent or during low flow years.

The 1999 sampling season was considerably shorter than in 1997 or 1998 because of the use of Hennessey's protocol. This translated into savings for FWP in terms of labor and monitoring costs, but also changed some of the data gathered. Because the descending limbs of fry outmigrations were not monitored, data on fry lengths may have truncated. If FWP wants to collect information on the life history of Yellowstone cutthroat trout fry concerning their residence time in natal tributaries, then this late-season data may be valuable. Should further research on fry residence time become a priority, it would be important to sample the latter end of outmigration and perhaps sample well into late September or October to ensure that late moving fry are documented.

Based on the results from this survey and a review of results from 1996-1998, GANDA recommends the following management actions to secure continued protection of Yellowstone cutthroat trout populations in the four Yellowstone FWP water leasing project streams:

1. Maintain the water leases on all four Yellowstone FWP water leasing project streams and pursue renewal for the maximum time allowed when available;

2. Determine the flows necessary in Mill Creek to preserve 25%, 50%, and 75% or more of the wetted streambed perimeter in the section up to ½ mile from the mouth of the creek, and compare these flows with the current lease level;

3. Explore potential expansion of the Mill Creek lease to allow higher flows during the critical incubation and early emergence period (late July to mid August). If possible, secure flows that meet the 50% to 75% wetted perimeter requirement as defined by recommendation 2 above;

4. Continue annual monitoring of fry outmigration from all four Yellowstone water leasing project streams using Hennessey's protocol on Mill, Cedar, and Mol Heron creeks;

5. Collect at least one more complete season of daily trapping data from Big Creek before implementing Hennessey's protocol for annual monitoring;

6. Institute an annual training and site-specific information sharing for water lease enforcement contacts and lessors;

7. Continue to pursue active and close coordination with water lease enforcement contacts to ensure continuity and consistency of administration; and

8. Pursue additional water leases on other Yellowstone cutthroat trout spawning streams to further protect the species.

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8.0 Appendix: Staff Gauge Rating Curves Used to Quantify Flows in 1999

The following are reproductions of staff gauge rating curves that were verified by GANDA at the beginning of the 1999 field season. It should be noted that each gauge may require a correction factor or "shift" when converting the gauge reading as seen in the field to a flow measurement on the rating curve. For example, the Cedar Creek gauge required a +0.04 shift to make the 1998 rating curve read 1999 flows accurately. This requires that a gauge reading of 1.00 be translated to 1.04 as read off the 1998 rating curve or chart to quantify the flow on the creek.

8/26/99

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION

EXPANDED RATING TABLE

DATE PROCESSED: 10-01-1999 @ 10:43 BY slynn

PAGE 1

TYPE: LOG

06192050

MILL CREEK NEAR MOUTH, NEAR PRAY, MT

OFFSET: .40

DD: 1 TYPE: 001 RATING NO: 5.0

START DATE/TIME: 04-01-1999 (0015)

BASED ON ______ DISCHARGE MEASUREMENTS, NOS ________, AND ________, AND IS ______ WELL DEFINED BETWEEN ______ AND ______ CFS

COMP BY ______ DATE ________ CHK. BY ______ DATE ________

STAFF GAGE WITH 1999 REVISED DATUM.

DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION)

GAGE HEIGHT (FEET)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH FT
.70	3.8*	4.1	4.3	4.6	4.9	5.1	5.4	5.7	6.1	6.4	2.9
.80	6.7	7.0	7.4	7.7	8.1	8.4	8.8	9.2	9.6	10.0	3.7
.90	10.4	10.8	11.2	11.6	12.1	12.5	13.0	13.4	13.9	14.4	4.5
1.00	14.9	15.4	15.9	16.4	16.9	17.4	17.9	18.5	19.0	19.6	5.2
1.10	20.1	20.7	21.3	21.9	22.5	23.1	23.7	24.3	24.9	25.5	6.1
1.20	26.2	26.8	27.5	28.1	28.8	29.5	30.2	30.9	31.6	32.3	6.8
1.30	33.0*	33.7	34.5	35.2	36.0	36.7	37.5	38.3	39.1	39.9	7.7
1.40	40.7	41.5	42.3	43.1	43.9	44.8	45.6	46.5	47.4	48.2	8.4
1.50	49.1	50.0	50.9	51.8	52.7	53.6	54.6	55.5	56.4	57.4	9.3
1.60	58.4	59.3	60.3	61.3	62.3	63.3	64.3	65.3	66.3	67.3	10.0
1.70	68.4	69.4	70.5	71.5	72.6	73.7	74.8	75.9	77.0	78.1	10.8
1.80	79.2	80.3	81.5	82.6	83.7	84.9	86.1	87.2	88.4	89.6	11.6
1.90	90.8	92.0	93.2	94.4	95.7	96.9	98.1	99.4	101	102	12.2
2.00	103	104	106	107	108	110	111	112	114	115	13.0
2.10	116	118	119	120	122	123	125	126	127	129	14.0
2.20	130	132	133	135	136	138	139	141	142	144	15.0
2.30	145	147	148	150	151	153	154	156	157	159	16.0
2.40	161	162	164	165	167	169	170	172	174	175	16.0
2.50	177	179	180	182	184	185	187	189	190	192	17.0
2.60	194	196	197	199	201	203	205	206	208	210	18.0
2.70	212	214	215	217	219	221	223	225	227	229	18.0
2.80	230	232	234	236	238	240	242	244	246	248	20.0
2.90	250	252	254	256	258	260	262	264	266	268	20.0*
3.00	270*										

Mill Creek at Mouth

10-30-97

Upper gauge

06191600
CEDAR CR AT OTO RANCH NEAR CORWIN SPRINGS, MT
OFFSET: .30

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION
EXPANDED RATING TABLE
DATE PROCESSED: 10-30-1997 @ 10:03 BY slynn

PAGE 1
TYPE: LOG
DD: 1 TYPE: 001 RATING NO: 2.0
START DATE/TIME: 04-01-97 (0015)

BASED ON _______ DISCHARGE MEASUREMENTS, NOS ________, AND ________, AND IS ______ WELL DEFINED BETWEEN ______ AND ______ CFS
COMP BY _____ DATE ________ CHK. BY _____ DATE ________

DISCHARGE IN CUBIC FEET PER SECOND (STANDARD PRECISION)

GAGE HEIGHT (FEET)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH FT
.80	4.0*	4.3	4.6	4.9	5.2	5.5	5.8	6.2	6.5	6.9	3.3
.90	7.3	7.7	8.2	8.6	9.1	9.5	10.0	10.6	11.1	11.6	4.9
1.00	12.2	12.8	13.4	14.0	14.7	15.3	16.0	16.7	17.5	18.2	6.8
1.10	19.0*	19.8	20.6	21.5	22.4	23.3*	24.4	25.5	26.6	27.8	10.0
1.20	29.0*	30.4	31.9	33.4	35.0	36.6	38.3	40.0	41.8	43.7	16.6
1.30	45.6	47.6	49.7	51.8	54.0	56.3	58.6	61.1	63.5	66.1	23.2
1.40	68.8	71.5	74.3	77.2	80.2	83.3	86.4	89.7	93.0	96.5	31.2*
1.50	100*										

1999

+0.03 shift

UPPER GAUGE: CEDAR CREEK AT OTO RANCH 1997

Middle Gauge

TED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION
EXPANDED RATING TABLE
DATE PROCESSED: 07-22-1999 @ 10:03 BY slynn

PAGE 1
TYPE: LOG

06191610
CEDAR CR AB DIVERSION ERWIN SPRINGS, MT
OFFSET: -.20

DD: 1 TYPE: 001 RATING NO: 2.0
START DATE/TIME: 07-01-1997 (0015)

BASED ON ______ DISCHARMEASUREMENTS, NOS ________, AND ________, AND IS ______ WELL DEFINED BETWEEN ______ AND ______ CFS
COMP BY _____ DATE ________ CHK. BY _____ DATE ________

GAGE HEIGHT (FEET)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH FT
		DISCHARGE IN CUBIC FEET PER SECOND					(EXPANDED PRECISION)				
.70	8.000*	17	8.580	8.881	9.188	9.503	9.826	10.16	10.49	10.84	3.190
.80	11.19	15	11.92	12.29	12.68	13.07	13.47	13.88	14.30	14.72	3.970
.90	15.16	11	16.05	16.52	16.99	17.46	17.95	18.45	18.96	19.47	4.840
1.00	20.00*	21	21.24	21.88	22.53	23.20	23.88	24.58	25.29	26.01	6.750
1.10	26.75	21	28.28	29.06	29.87	30.68	31.52	32.37	33.24	34.12	8.270
1.20	35.02	31	36.87	37.83	38.80	39.78	40.79	41.81	42.86	43.92	9.980*
1.30	45.00*										

Middle Gauge : Cedar Creek above diversion 1999.

lowest

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION

EXPANDED RATING TABLE

TYPE: LOG

06191620

DATE PROCESSED: 08-28-1998 @ 14:21 BY slynn

CEDAR CR AT MOUTH NR CORWIN SPRINGS, MT

OFFSET: .00

DD: 1 TYPE: 001 RATING NO: 4.0

START DATE/TIME: 04-01-98 (0015)

BASED ON ______ DISCHARGE MEASUREMENTS, NOS ________, AND ________, AND IS ______ WELL DEFINED BETWEEN ______ AND ______ CFS

COMP BY _____ DATE _________ CHK. BY _____ DATE _________

GAGE HEIGHT (FEET)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN Q PER TENTH FT
			DISCHARGE IN CUBIC FEET PER SECOND				(EXPANDED PRECISION)				
.30	.400*	.436	.474	.515	.557	.601	.648	.696	.747	.800	.456
.40	.856	.914	.974	1.036	1.101	1.168	1.238	1.311	1.386	1.464	.688
.50	1.544	1.627	1.712	1.801	1.892	1.986	2.083	2.183	2.286	2.391	.956
.60	2.500*	2.615	2.733	2.854	2.979	3.107	3.239	3.374	3.512	3.654	1.300
.70	3.800*	3.960	4.124	4.292	4.465	4.643	4.825	5.012	5.203	5.399	1.800
.80	5.600*	5.815	6.035	6.260	6.492	6.729	6.971	7.219	7.474	7.734	2.400
.90	8.000*	8.295	8.597	8.907	9.224	9.550	9.883	10.22	10.57	10.93	3.300
1.00	11.30	11.67	12.05	12.44	12.84	13.25	13.67	14.10	14.53	14.98	4.130
1.10	15.43	15.90	16.37	16.86	17.35	17.85	18.37	18.89	19.42	19.97	5.090
1.20	20.52	21.09	21.66	22.25	22.85	23.46	24.08	24.71	25.35	26.01	6.150
1.30	26.67	27.35	28.04	28.74	29.46	30.18	30.92	31.67	32.44	33.21	7.330*
1.40	34.00*										

1999 use + 0.04 shift

LOWER GAUGE: CEDAR CREEK AT MOUTH 1998

Mol Heron Rating Curve 1999

gauge height	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	Δ in Q / Tenth of a foot
1.2	17.111	17.841	18.595	19.375	20.181	21.014	[21.874	22.762	23.678	24.624	8.490
1.3	25.600	26.607	27.645	28.716	29.819	30.956	32.128	33.335	34.578	35.857	11.575
1.4	37.175	38.531	39.926	41.362	42.838	44.357	45.918	47.524	49.173	50.869	15.436
1.5	52.611	54.400	56.238	58.125	60.063	62.052	64.093 *]	66.188	68.338	70.543	20.194
1.6	72.805	75.124	77.502	79.941	82.440	85.002	87.627	90.316	93.072	95.894	25.980
1.7	98.784	101.744	104.775	107.877	111.053	114.303	117.629	121.031	124.513	128.074	32.932
1.8	131.716	135.441	139.250	143.144	147.125	151.194	155.353	159.603	163.946	168.383	41.199
1.9	172.916	177.545	182.274	187.103	192.034	197.069	202.209	207.456	212.811	218.276	50.938
2	223.854	229.545	235.351	241.275	247.317	253.480	259.766	266.176	272.712	279.376	—

equation ⇒ $\log_{10} cfs = 0.8347 + 5.0336 (\log_{10} gauge)$

1.56 = highest actual measured discharge

MOL HERON RATING CURVE 1999