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Applegate Dam Completion Report

Effects of Applegate Dam on Steelhead in the Applegate River and Recommendations for Dam Operations

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Effects of Applegate Dam on Steelhead in the Applegate River and Recommendations for Dam Operation

Rogue Basin Fisheries Evaluation Program
Applegate Dam Studies
Completion Report

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SUMMARY

Applegate Dam was completed in 1980 in the headwaters of the Applegate River in southwest Oregon. It was built as part of a three-dam project by the United States Army Corps of Engineers (USACE) to control flooding and provide other benefits in the Rogue River basin. Fishery enhancement benefits were ranked second only to flood control benefits from Applegate Dam. The purpose of this report is to present results and recommendations from research done by the Oregon Department of Fish and Wildlife on steelhead *Oncorhynchus mykiss* populations and fisheries in the Applegate River. Data were collected during 1979-85 with funds from USACE. The research addressed four objectives:

1. Determine the effects of Applegate Dam on downstream changes in flow, temperature, and turbidity in the Applegate River.
2. Determine the effects of Applegate Dam and develop criteria for its operation as related to the sport fishery for steelhead.
3. Determine the effects of Applegate Dam and develop criteria for its operation as related to the biology of wild adult steelhead.
4. Determine the effects of Applegate Dam and develop criteria for its operation as related to the biology of wild juvenile steelhead.

Applegate Dam is located 75 km upstream from the confluence of the Applegate River with the Rogue River, which is 10 km downstream from Grants Pass. The reservoir has a storage capacity of 82,000 acre-ft, of which 65,000-75,000 acre-ft are released during the summer and fall. The volume and temperature of water released from the reservoir is normally controlled through an intake structure with ports at 6 different elevations.

The largest percentage effect of Applegate Dam on river flow during 1981-84 was during July through October when augmentation from storage increased average flow throughout the river by 40%-86%, depending on month and location. August was the month of lowest average flow (211 cfs) and December was the month of highest average flow (2,895 cfs) during the 4-year period. The dam reduced average flow throughout the river each month by 14%-44% from February through April when the reservoir was refilled. The dam reduced peaks in winter flow, reducing the highest potential peak flow at a point 31 km downstream by over 50% each season.

During the first 4 years of operation, maximum outflow temperature was reduced below maximum inflow temperature from mid-May through mid-September with the largest average difference ($11^{o}C$) being in August. At a point 31 km downstream, the biggest reduction from natural maximum temperature during 1981-84 was estimated to be an average of $3.1^{o}C$ during 16-31 July. This was also the period of highest average in maximum temperature ($19.7^{o}C$) at this middle river location. The period 1-15 January had the lowest average in maximum temperature ($5.6^{o}C$) during the 4-year period. During October through December, maximum outflow temperature exceeded maximum inflow temperature by several degrees because of heat storage in the reservoir. At a point 31 km downstream, the biggest increase from natural maximum temperature during 1981-84 was estimated to be an average of $2.0^{o}C$ during 1-15 November. Increases of 0.3^{o}-$0.8^{o}C$ in the maximum temperature at this location were also estimated

during January through April, possibly because reductions in flow when the reservoir was being refilled allowed greater daytime warming downstream.

Because of difficulties we had in sampling juvenile steelhead, analyses were restricted to examining rearing distribution and growth in the main river. In the postimpoundment period, population density of subyearling steelhead on riffles in summer was highest in the upper river (57-71 fish/m^2) whereas population density of yearling steelhead in pools was similar throughout the river (0.40-0.56 fish/m of pool length). We had inadequate data to determine if the dam changed the rearing distribution. Decisions on temperature and flow releases from the dam will need to consider the high population density of subyearling steelhead close to the dam during summer.

In the upper river, the growth rate of subyearling steelhead increased slightly ($P \leq 0.1$) whereas fork length achieved by September (6-7 cm) tended to be smaller after closure of Applegate Dam. Apparently the increased growth rate attributed to cooler water in summer was offset by delayed emergence because of cooler water in the spring. Growth rate of subyearlings in the middle river did not show a significant increase, even at $P \leq 0.1$, although the means increased by 7%-10% in July, August, and September. Unlike the tendency toward smaller fish at the end of the season in the upper river, length of fish in the middle river tended to increase after dam closure and length was correlated to growth rate indexes in the middle river (r ranged from 0.777 to 0.981). The tendency towards larger subyearlings after Applegate Dam was completed suggests an improvement in growth rate in the middle river that resulted from increased flow that keeps temperature lower and may provide other benefits, such as reduced crowding.

Scales of subyearling steelhead sampled in summer demonstrated that growth rate indexes in the upper river were negatively correlated to river temperature over the range of 11°-22°C (r = -0.799 to -0.953). The correlations of the indexes to flow over the range of 52-575 cfs were not as good (r = 0.722 to 0.762). However, farther below the dam in the middle river where flow begins to affect temperature, the correlations of growth rate indexes to flow were sometimes greater than the correlations to temperature.

Because of difficulties we had in sampling adult steelhead, analyses were few. Scale analyses showed that first-spawning migrants (mature adults that had made a previous migration as nonspawning half-pounders) were the most abundant life history type, whereas two-salt spawners were the most abundant life history type among Rogue River winter steelhead. Because of the high percentage of first-spawning migrants, mortality and harvest of half-pounder steelhead that enter the Rogue River in summer may affect abundance of adult winter steelhead in the Applegate River. We saw a slight time trend toward a lower percentage of first-spawning migrants. This may be tied to the slight time trend toward older age at smolting because first-spawning migrants have a younger smolt age composition compared with two-salt spawners (mature adults on first migration after spending two summers in the ocean). If these trends continue, we may see a shift towards larger adults and a higher percentage of two-salt spawners produced by the Applegate River population. Steelhead that did not make a half-pounder migration before spawning were larger as adults, as were fish that smolted at an older age.

Annual sport catch of adult steelhead from the Applegate River decreased from 1,274 fish to 660 fish after completion of Applegate Dam ($P = 0.053$). Because we did not have a reliable measure of steelhead abundance, and because postimpoundment catch was largely on broods produced before completion of the dam, the role of the dam in this decline of catch can not be inferred. However, the dam may adversely affect water conditions for winter steelhead angling unless alternative schedules for refilling the reservoir (such as faster refilling before 15 February, the date when steelhead abundance and angling success increased historically) can be adopted for years with relatively low runoff. Catch during January through March was highest when mean flow for the same time period was 800-1,200 cfs, and decreased at a mean flow above or below this range. Average flow during the fishery was less than 1,000 cfs in 62% of the years preceding dam closure (1939-80). Flow will be further reduce to refill the reservoir.

Recommendations for dam operation and steelhead research were developed and are provided at the end of this report (*see* pages 35-37).

INTRODUCTION

Applegate Dam was completed in 1980 as part of a three-dam project by the United States Army Corps of Engineers (USACE) to control flooding and provide other benefits in the Rogue River basin. Fishery enhancement benefits were ranked second only to flood control benefits from Applegate Dam. To produce the proposed anadromous salmonid benefits, USACE took the following actions:

1. They constructed a multiport withdrawal system at the dam to provide a range of water temperature with which to benefit fish downstream.

2. They provided an adult collection facility at the base of the dam (and fish culture space at Cole M. Rivers Hatchery) to mitigate for steelhead *Oncorhynchus mykiss* spawning areas blocked by the dam.

3. They funded modifications to improve fish passage at two 10-15 ft high irrigation dams downstream from Applegate Dam.

4. They funded the Oregon Department of Fish and Wildlife (ODFW) to conduct studies to determine the effects of Applegate Dam on anadromous salmonids in the Applegate River and to recommend operating criteria for the dam that would enhance anadromous salmonid production and increase fishery benefits.

Results from the first phase of a similar study by ODFW on the effects of Lost Creek Dam on anadromous fish in the Rogue River were presented to USACE in 1985 (Cramer et al. 1985). Lost Creek Dam provided higher flow, increased rearing habitat, and reduced summer temperature for steelhead rearing in the Rogue River (Cramer et al. 1985). Growth rate of juvenile steelhead increased 40% in the lower 210 km of the river, and fish that had a higher growth rate tended to smolt at age 1 instead of age 2 or older. Abundance of steelhead fry increased when peaks in winter flow were cropped by Lost Creek Dam.

Cole M. Rivers was the first person to extensively study steelhead populations of the Rogue River, of which the Applegate River is a tributary at river kilometer 152. Rivers (1961) claimed that the Rogue River basin had 3 separate runs of steelhead; a spring run that entered the river when temperature started to rise, a fall run that started up the river in August when temperature started to decline, and a winter run that entered the river just prior to spawning. Everest (1973) found that members of the "spring" and "fall" runs spawned simultaneously in the same areas. He believed they were members of a common race of summer steelhead. ODFW now views the Rogue River basin as having two runs of steelhead: a summer run that generally enters the Rogue River from April through October; and a winter run that generally enters from November through March. Steelhead counted as they ascend Gold Ray Dam at river kilometer 202 of the Rogue River (50 km above the mouth of the Applegate River) are classified by ODFW as summer steelhead from 16 May through 31 December, and classified as winter steelhead from 1 January through 15 May. Rivers (1961) believed that the winter run made up the largest part of the Rogue River basin's steelhead population. The Applegate River is used primarily by winter steelhead.

Steelhead usually return to spawn at age 4; however, many Rogue River steelhead and some Applegate River fish return at age 2 or 3 as "half-pounders" on a nonspawning migration in the summer after 3 to 5 months at sea (Rivers 1961). Less than 5% of these small steelhead actually spawn before returning to the ocean the following spring (Everest 1973). This half-pounder life history is found only among populations of the Rogue River basin and two northern California river basins (Everest 1973). Nearly all summer steelhead spawners and a portion of winter steelhead spawners in the Rogue River make a prior migration as half-pounders (Cramer et al. 1985). Half-pounders grow little during their 4-9 months in freshwater, so adults with this life history are smaller than other adults at a given post-smolt age (Everest 1973).

Rogue River basin steelhead are primarily tributary spawners that use the main river when denied access to tributaries by low flow (Rivers 1963). Steelhead spawn in the Applegate River and its tributaries, with the summer run using many of the smallest tributaries and the winter run using the main Applegate River to some extent (Appendix Table A-1). Everest (1973) observed that the preferred spawning habitat of summer steelhead included small streams with less than 25 square miles of watershed and with less than 50 cfs winter streamflow. Most of these streams become intermittent in early summer.

Spawning of summer steelhead in the middle Rogue River tributaries (including the Applegate River) starts in early January, peaks in late January, and is completed by the middle of March (Everest 1973). Peak time of spawning for winter steelhead in the Applegate River ranges from mid to late April with stragglers that spawn into May in the colder headwaters (Rivers 1963).

Everest (1973) observed that summer steelhead fry emerge from the gravel during April and May, and juveniles migrate out of the small streams before flow becomes too low in June or July. The pattern of rearing in the tributaries in winter and in the main river in summer continues for one to three winters until the juveniles migrate to the sea during March through June. Everest concluded that if steelhead were to survive in the basin, these tributaries would have to be protected to insure the availability of water and suitable habitat for spawning and rearing.

Rivers (1963) described human activities that he believed were the cause of declines in the fish populations of the Rogue River basin prior to 1941. Gold mining operations increased silt intermittently in the Applegate River from 1890 through 1910. During periods when mining activity was heaviest, the Applegate River was "brick red." Layers of silt 1/8- to 1/4-inch thick covered banks and gravel bars at low summer flow. Rivers (1963) observed that the decline in migratory fish runs closely paralleled years of hydraulic and placer mining (1890-1910), and that the decline in the fishery caused by irrigation after 1900 was even greater than loss from mining. Flow was reduced during the critical summer period, juvenile fish were diverted into canals and fields, and upstream passage to wintering and spawning areas was impeded or blocked by irrigation diversion structures.

Rivers (1963) believed that the most serious problem for fisheries in the Applegate River was the dam built at the mouth of Jackson Creek (km 13) in 1899. It was used for irrigation in the summer and as an egg-take station by the United States Bureau of Fisheries from October through April. Eggs from most of the steelhead captured were sent to other parts of the world. The station was operated for only 5 or 6 years in a row because fish became too scarce in the system. It was run intermittently from 1912 through 1933.

Everest (1973) predicted some potential effects of Lost Creek Dam on summer steelhead. Extrapolation of his predictions indicates that Applegate Dam would contribute to some of these potential effects on summer steelhead, and perhaps winter steelhead, by its effects on the Applegate River and on the Rogue River below the confluence. Thus, higher flow and cooler water in summer from Applegate Dam might reduce disease problems in summer, expand rearing areas, and thereby increase production of wild smolts, although fewer fish would smolt at age 1 because of reduced growth rate in the cooler summer water. Reductions in the level of flood peaks in winter might increase survival of juvenile steelhead near the dams.

Our report summarizes the results of research done by ODFW from 1979 through 1985 to determine the effects of Applegate Dam on steelhead populations in the Applegate River. It provides operating recommendations for Applegate Dam designed to enhance steelhead production and the steelhead fishery in the Applegate River. We have also made recommendations for future research that could provide ODFW with better information for managing steelhead populations in the Applegate River.

Our study included four objectives:

1. Determine the effects of Applegate Dam on downstream changes in flow, temperature, and turbidity in the Applegate River.

2. Determine the effects of Applegate Dam and develop criteria for its operation as related to the sport fishery for steelhead.

3. Determine the effects of Applegate Dam and develop criteria for its operation as related to the biology of wild adult steelhead.

4. Determine the effects of Applegate Dam and develop criteria for its operation as related to the biology of wild juvenile steelhead.

STUDY AREA

The Applegate River is located in southwest Oregon and northern California with its headwaters in the Siskiyou Mountains (Figure 1). The drainage area of the Applegate River basin is 1,236 km^2 with 15% in California. The Applegate River originates at 2,256 m above sea level and flows north and west 93 km to its confluence with the Rogue River 10 km downstream from Grants Pass, Oregon, at 268 m above sea level.

Applegate Dam is located 75 km upstream from the mouth of the river at a stream elevation of 534 m above sea level, with 29% (359 km^2) of the basin draining into the reservoir. The dam, which is 73.8 m high (242 ft) and has no fish passage facilities, has a permanent structure at the base of the dam for collecting upstream migrants for hatchery broodstock and other fish management purposes. The reservoir has a total storage capacity of 82,000 acre-ft, and 65,000 acre-ft of this is released sometime during the conservation release season of 1 May through 15 November to bring the reservoir down to 17,000 acre-ft (minimum flood control pool) for flood control. An additional 10,000 acre-ft of storage is available to meet downstream water requirements in years of low runoff, and if used, the reservoir is lowered to 7,000 acre-ft of inactive storage. The volume and temperature of water released from the reservoir is normally controlled through an intake structure with ports at 6 different elevations, including the regulating outlet near the bottom. Opportunity exits for mixing water withdrawn from different elevations to achieve a desired release temperature. This is maximized when the reservoir is near full and is thermally stratified in early summer. At minimum flood pool, the upper four ports are above water.

The Applegate River basin is dominated by a maritime climate that contributes to mild, wet, winters and warm, dry, summers. Annual precipitation above the damsite ranges from 76 to 152 cm. About 75% of the annual precipitation falls between November and March, mostly as snow above the damsite, with less than 2% falling during July through August. Snow in the headwaters is the principal source of runoff from late spring through summer. Runoff to the damsite averages 317,000 acre-ft. Reservoir inflow ranges from 13 to 29,000 cfs. Evaporation depletes approximately 2,000 acre-ft of stored water per year from the reservoir. Maximum daily air temperature at the river mouth averages 32^o to 35^oC in July and August and 8^o to 10^oC in December and January.

Salmonid fishes in the Applegate River basin include large populations of fall chinook salmon *O. tshawytscha* and winter steelhead. Small populations of cutthroat trout *O. clarki*, summer steelhead, and coho salmon *O. kisutch* are also present in the Applegate River.

METHODS

Hydrologic Sampling and Modeling

Data on river flow, temperature, and turbidity were obtained from the United States Geological Survey (USGS). Data on air temperature and photoperiod were obtained from the National Oceanic and Atmospheric Administration (NOAA).

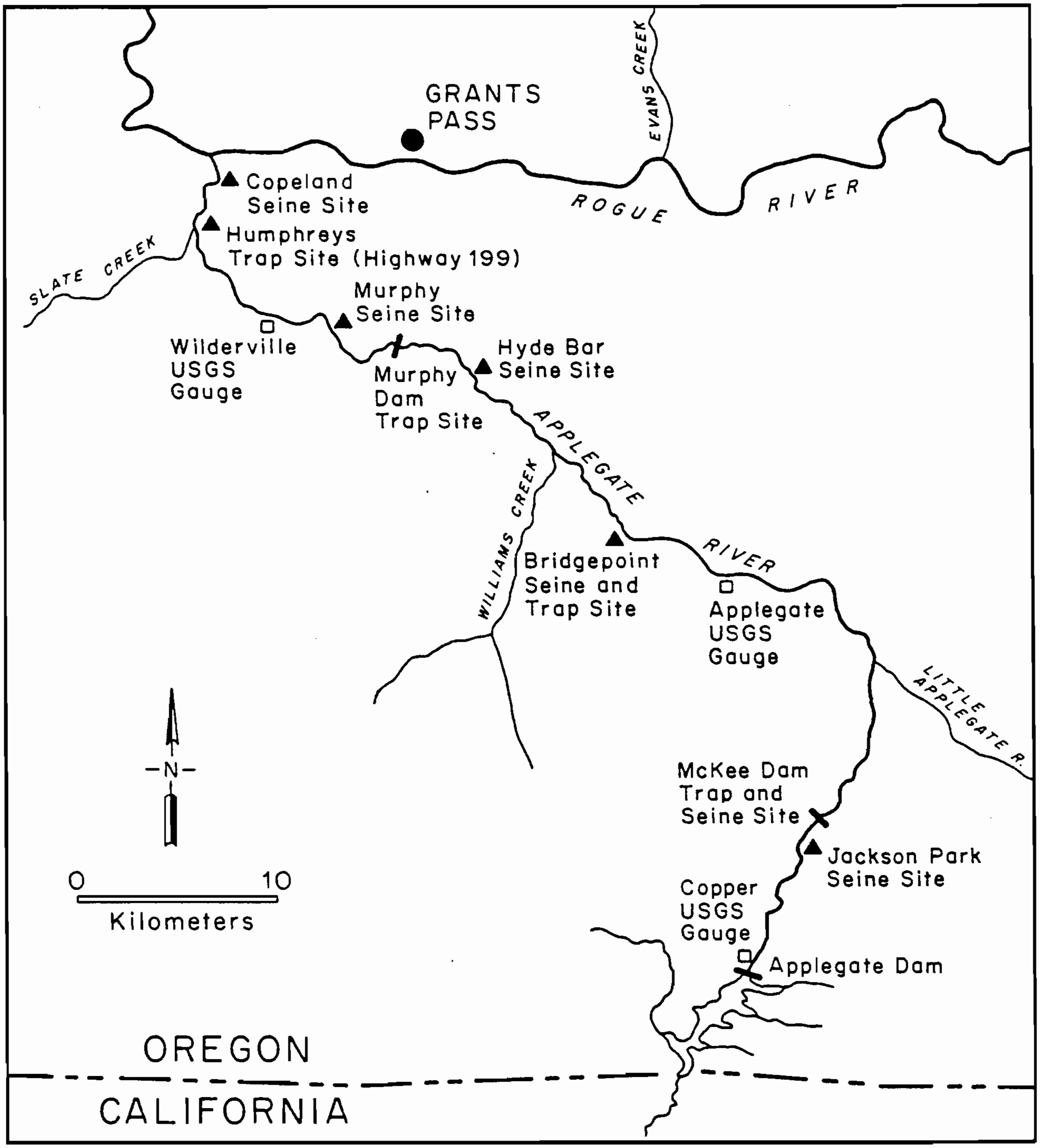

Figure 1. Map of the Applegate River basin.

We assessed the dam's effects on river flow by monitoring flow at USGS gauges located near Copper (km 74), Applegate (km 44), and Wilderville (km 13). Inflow to the reservoir was estimated by summing daily mean flow recorded in the three major tributaries to the reservoir (Carberry Creek, Middle Fork Applegate River, and Elliott Creek).

Mean water temperature for each day was not published by USGS for the early years of our study (only maximum and minimum were published for each USGS thermograph). We chose to use maximum temperature for each day, and weekly or monthly averages of these daily maximum values in our analyses, because because of the sensitivity of salmonids to high temperature and because of past problems with salmonid survival in the warm water of the Applegate and Rogue rivers.

The daily maximum inflow temperature (DIT) to the reservoir was estimated from the daily maximum water temperature of Carberry Creek, the Middle Fork Applegate River, and Elliott Creek weighted by stream flow as follows:

$$\mathrm{DIT} = \left(\sum_{i=1}^{3} t_i f_i\right) / \sum_{i=1}^{3} f_i$$

where

t_i = daily maximum water temperature in stream i, and
f_i = daily mean flow in stream i.

Effects of the dam on downstream water temperature were assessed by predicting what Applegate River temperature would have been without the dam during years when Applegate Dam was in operation (1981-84) and comparing the predicted temperature with actual temperature. We used multiple regression analysis to construct models that would predict daily maximum water temperature at the USGS gauge near Applegate from independent variables that were not affected by the construction of Applegate Dam. Variables tested for inclusion in the models are listed in Appendix Table A-2. The gauging station near Applegate was selected because it had the longest period of temperature record (January 1974-October 1980) and thus provided the largest database from which to develop models. We developed separate regression models for each of three time periods encompassing the entire year: 1 January-15 May, 16 May-15 September, and 16 September-31 December. These time periods were selected because they yielded the best overall correlation between river temperature and independent variables.

We used daily values of dependent and independent variables to construct models (Appendix Table A-3). Because of the large size of the data set (N = 2,494), we subsampled by using values from every fourth day. Completed models are listed in Appendix Table A-4.

To validate the regression models, we determined how close these models predicted temperature that existed during the time period used to construct the models, but for days other than those used to construct the models. This was done by predicting temperature for the first day following each day used to construct the models and comparing the predicted temperature with the temperature that actually occurred. These values were averaged by 2 week intervals. Generally, the models predicted temperature within $0.5^{o}C$ of actual value; however, in 6 out of 24 cases, the predicted temperature differed significantly from the actual temperature at $P \leq 0.05$ (Appendix Table A-5). The models tended to underestimate temperature during 16 February-15 March and during 1 July-15 August. Based on this analysis we feel the models are accurate within $1^{o}C$ and may underestimate temperature by $0.5^{o}C$ during the early spring and late summer.

Turbidity samples were collected by USGS at their gauge near Copper starting in October 1980. We examined mean daily and hourly turbidity readings to determine whether or not operation of the dam increased the amount or duration of downstream turbidity.

Juvenile Sampling

We captured juvenile steelhead with beach seines and traps. Sites sampled prior to 1979 as controls for the Lost Creek Dam evaluation and sites sampled during the present study are listed in Table 1. Crews made two seine sets per week at each site when juveniles were available for capture. The first set was started part way up a riffle and completed in the head of a pool to catch larger fish living in the faster moving water. The second set was made in the slower part of the pool. Flow was sometimes so low that one set covered an entire site. Crews occasionally made additional sets to verify findings, or to meet goals for the number of fish to be sampled for length, weight, or scales.

Our most useful data on juvenile steelhead were gathered at McKee and Murphy ditches where we trapped juveniles after they migrated a short distance down irrigation ditches and were being bypassed back to the river. The traps were screened boxes that averaged 2 x 1 x 0.5 m. The traps fished continuously and were checked as often as needed to insure survival of trapped fish. Water was diverted into the irrigation ditches from about 1 May to 15 October each year.

Catch from each site and sampling technique was segregated by species and age class. We anesthetized juveniles with a mixture of tricane methanesulfonate (MS-222) and quinaldine (Schoettger and Steucke 1970) or benzocaine prior to handling. For each age class of each salmonid species at each site, we measured 30 fish per week to the nearest 0.1 cm fork length and weighed 25 fish per month to the nearest 0.1 g. The age of juveniles was estimated based upon length-frequency distributions that were periodically verified by analysis of scales. For age and growth analyses, we sampled scales from 20 juvenile steelhead each week at two traps along the main river. Approximately 10 scales were removed from the left side of the fish about four rows above the lateral line and immediately posterior to the dorsal fin.

Growth of juvenile steelhead was determined from scale measurements (*see* page 11) and from fork length in September. We assessed growth rate from scales collected at traps only, because we were unable to capture an adequate number of juvenile steelhead at seining sites.

Table 1. Details of sampling for juvenile salmonids in the Applegate River basin.

Station			Period sampled	Sampling frequency	Gear	Years sampled
Name	Km	Mile				
Applegate River:						
Jackson Park	66	41	01/01-08/01	Weekly	(a)	1982-85
McKee Dam	64	40	01/01-10/17	Weekly	(a)	1976-85
McKee ditch	63	40	05/01-09/30	Continuously	(b)	1979-85
Bridgepoint	37	23	01/01-08/24	Weekly	(b,c)	1976-81
Hyde Bar	29	18	01/01-08/24	Weekly	(c)	1982-85
Murphy Dam	21	13	05/01-07/14	Continuously	(d)	1982
Murphy ditch	21	13	05/01-10/21	Continuously	(b)	1979-85
Murphy seine	18	11	01/01-07/25	Weekly	(c)	1976-85
Highway 199	5	3	03/02-07/15	4 days per week	(e)	1979-85
Copeland	1	1	01/01-07/25	Weekly	(c)	1976-85
Tributaries:						
Little Applegate River	54	34	01/01-09/26	Weekly	(a)	1979-83
Slate Creek	5	3	01/01-07/09	Weekly	(a)	1979-85

[a] *25 x 8 ft floating seine.*
[b] *Trap in irrigation ditch bypass (*see *page 9 for more details).*
[c] *50 x 8 ft floating seine.*
[d] *Fyke and box trap at lowhead dam spillway to capture steelhead smolts.*
[e] *Humphreys trap (inclined plane between pontoons; had traveling screen driven by a paddle wheel).*

Because of uncertainty of the effect of flow variation on juvenile steelhead catch in seines and traps, we used a combination of snorkeling and electrofishing in areas that typified the upper, middle, and lower river to determine rearing distribution. The sampling was done in late August of 1983-85 when flow was lowest and the subyearling steelhead had all emerged.

Shallow edges of representative riffles were sampled with a backpack electrofisher to bring subyearling steelhead up out of the cobble. Three riffles were sampled in each of the upper (km 66-67), middle (km 39-41), and lower (km 3-13) sections of the river. Electrofishing became ineffective as depth approached 0.3 m. Therefore, we were limited to sampling the edges of the riffles, making a sweep in an upstream direction to sample a 1 x 30 m area. The results were calculated in number of fish per square meter, and the same three riffles in each area of the river were sampled each year.

A diver counted the number of yearling steelhead along a transect in pools immediately below riffles that were electrofished. The diver wore a wetsuit, mask, and snorkel to make three downstream passes through the center of each pool. No pattern of change in fish numbers was evident on second and third passes, so the three counts were averaged and expressed as the number of fish per lineal foot.

Adult Sampling

To index abundance, determine growth, and estimate life history composition of winter steelhead adults, we electrofished from a 16 ft driftboat or a 14 ft inflatable raft in the middle section of the Applegate River (km 41-21) at approximately weekly intervals from 15 February until 1 May. A 2,500 watt generator and a converter provided pulsed direct current at 150-300 volts and 1.5-2.5 amperes.

Flow during the electrofishing period fluctuated from a few hundred to several thousand cubic feet per second. Our efforts were most productive when flow was 500-1,800 cfs and turbidity was less than 6.0 JTU.

Captured fish were momentarily held in a 68-quart ice chest containing river water until the boat could be stopped in quiet water. To limit further stress, captured fish were handled while still stunned. All steelhead captured were measured to the nearest 1 cm fork length, examined for sex, and checked for hatchery fin clips or other marks. Approximately 10 scales were removed from each side of the fish in the first four rows above the lateral line and immediately posterior to the dorsal fin. We used a paper punch to mark all fish with a hole in the left operculum so we could identify recaptured individuals.

In 1981, a trap was placed in the fish ladder at Murphy Dam (km 21) from 15 February through 1 May in an attempt to capture adult steelhead. However, of 163 adults captured, 90% were kelts. Because the sample of upstream migrants was small and many fish were seen jumping the dam, we discontinued this sampling.

Angler Catch Sampling

We estimated annual sport catch of winter steelhead in the Applegate River by using monthly catch estimates for January through March that were derived from salmon-steelhead catch cards returned by anglers each year since 1967.

Scale Analysis

Scales from juvenile fish were mounted on glass slides with a solution of 5% glycerin and 95% sodium silicate. We mounted up to 10 scales per fish and analyzed two of the larger, nonregenerated, and regular-shaped scales. Scales were analyzed at a magnification of 88X projected on a screen. Circuli counts and scale measurements were made directly on the screen along the longest line in the anterior region at a 20° angle from the longitudinal midline of the scale. We counted circuli and measured radii (to the nearest 0.5 mm) from the nucleus center to each annulus and to the outer edge of the scale. The average spacing of circuli on each scale was computed from these data as an index of growth rate from the time of earliest scale formation until capture. To measure very recent growth in juvenile steelhead, we also measured the width of outer band I (the first two intercircular spaces contained between the first and third circuli inward from the outer edge of the scale), and the width of outer band II (the two intercircular spaces contained between the third and fifth circuli inward from the outer edge of the scale).

The freshwater (juvenile) portion of scales from adults that returned to the river were similarly analyzed, except that no outer band widths were measured. Additionally, we counted circuli and measured radii from the nucleus center to the point of ocean entrance. Generally, four of the larger, nonregenerated, and regular-shaped scales from each adult fish were mounted on gummed cards and impressed on acetate at approximately 100°C under 5,000 psi for 3 minutes to provide a permanent record of scale characteristics. Counts and measurements were taken from the projected image of the acetate impression. Counts and measurements were averaged from two scales for each adult steelhead.

The most common types of adult steelhead life history seen in the Applegate River are defined in Table 2.

Table 2. Descriptions of the most common life history types among adult steelhead in the Applegate River.

Life history type	Description
First-spawning migrant	Adult on its first spawning migration after completing a previous migration as a half-pounder.[a]
Second-spawning migrant	A first-spawning migrant that survived to make a second spawning run.
One-salt spawner	Adult on its first spawning migration after spending one summer in the ocean.
Two-salt spawner	Adult on its first spawning migration after spending two summers in the ocean.
Two-salt repeat spawner	A two-salt spawner that survived to make a second spawning run.

[a] *A half-pounder returns to freshwater during summer or early fall after it first migrated to the ocean, is usually immature, usually does not enter spawning areas or spawn, and then returns to the ocean the following spring.*

Analytical Methods

Data were split into preimpoundment and postimpoundment sets based on the date of dam closure (December 1980). The reservoir was only two-thirds filled in the first winter (1980-81) because of a drought, but enough storage was in the reservoir to substantially affect flow in each season of 1981, so we used 1981 as part of our postimpoundment data set.

We originally intended to use tributary streams as controls for our statistical comparisons. However, we found that substantial parts of the life cycles of tributary populations were completed in the main river. Thus, tributary streams had little use as controls in our analyses.

We used two-tailed *t* tests to compare annual values before impoundment with those after impoundment. We used Bartlett's test (Snedecor and Cochran 1967) to test for homogeneity of variances between years and impoundments before applying *t* tests or analysis of variance if variances differed substantially between data sets being compared. When applying the *t* test to data with variance that could not be stabilized or to data that had unequal sample sizes, we used formulas from Snedecor and Cochran (1967). We also used *t* tests to compare predicted values from regression equations for the years after closure with those from before closure.

We calculated the minimum detectable difference (MDD) from the preimpoundment mean as the difference needed to provide an 80% chance of detecting a statistically significant change at the 0.05 significance level (Lichatowich and Cramer 1979). The MDD was used to assess the probability of a Type II error in the analyses (one in which we found no statistical difference, when in fact, a difference existed and we had insufficient data to detect it). The MDD was expressed as the percent change from the preimpoundment average.

It is unrealistic to assume fishery parameters are influenced by only one variable. We recognized that we were stretching the use of multiple regression beyond customary guidelines for minimum sample size, but we did the best we could to determine factors affecting fisheries with the data we had. Because many comparisons and correlations suffer from small sample sizes (years), some conclusions and recommendations may change with additional data.

Because a primary purpose of this study was to determine operating criteria for Applegate Dam that would optimize fishery benefits, our analyses focused on identifying relationships between biological and environmental variables (primarily river flow, temperature, and turbidity). In multiple regression analyses, we only tested independent variables for which we could hypothesize a causal relationship to the dependent variable. We chose the "best" multiple regression equations based on the combination of variables that was intuitively most logical and accounted for the most variation in the dependent variable (provided the highest R^2 value). Independent variables whose partial correlation to the regression residuals had a significance probability of less than 0.05 were generally excluded from the regressions. At each step of the multiple regression, the residuals were plotted against independent variables of interest to determine if mathematical transformations were appropriate.

We transformed variables when necessary to achieve normality. We used the angular transformation (arcsin $[\text{percentage}]^{1/2}$) (Snedecor and Cochran 1967) on proportional or percentage data before using *t* tests or analysis of variance. We used the logit transformation ($X = \log_e p/(1-p)$) on all percentage or proportional data used in regressions so that independent variables could be linearly related to the full range of proportions from 0 to 1 or percentages from 0% to 100% (Bickel and Dokson 1977). We used a square root transformation on data that followed a Poisson distribution.

RESULTS AND DISCUSSION

Effects of Applegate Dam on Downstream Flow

Applegate Dam stores 82,000 acre-ft of which 65,000-75,000 acre-ft is released annually. The reservoir is refilled during February through April and gradually drawn down during June through November (Figure 2).

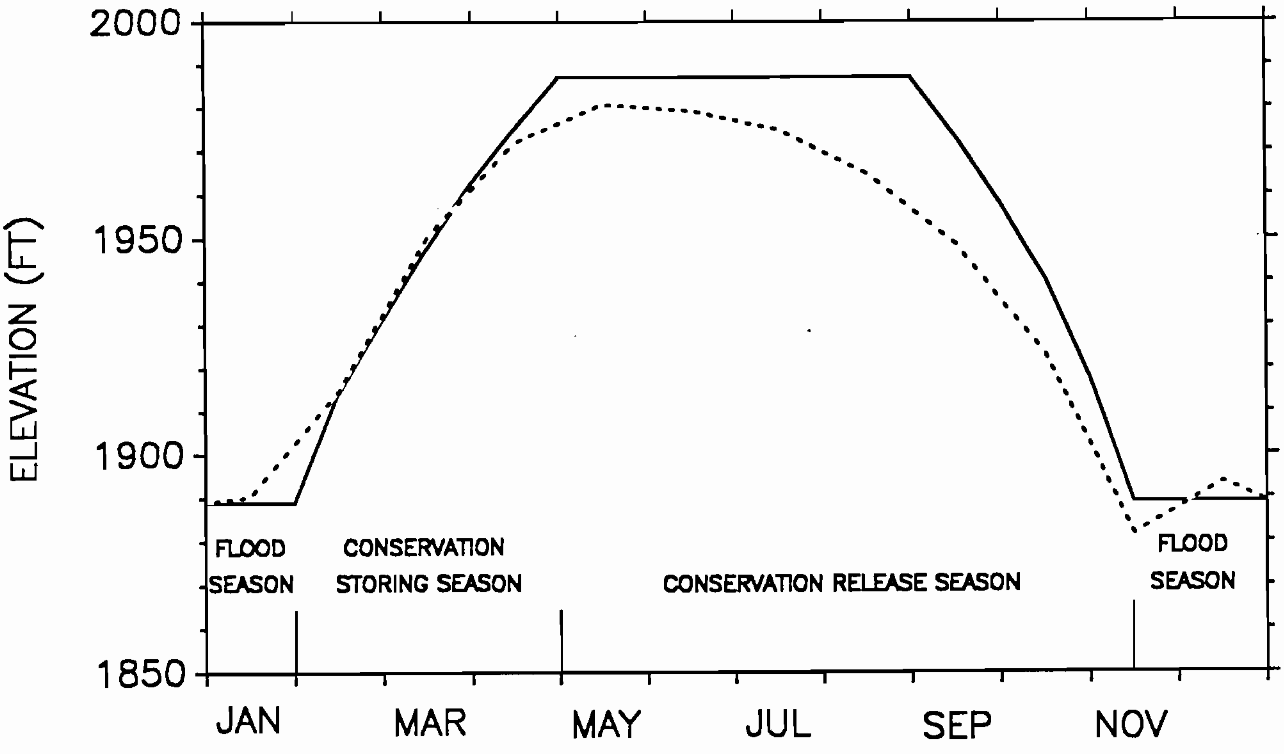

Figure 2. Rule curve for Applegate reservoir (solid line) and average monthly reservoir elevation for 1981-84 (broken line).

Runoff in the Applegate River peaks during December through March (Figure 3). During this period, mean monthly flow is approximately twice as high near the mouth of the Applegate River (Wilderville) as at the damsite (Copper). Runoff is lowest during July through September, with flow lowest near the river mouth because of irrigation withdrawals, evaporation, and groundwater losses. Mean monthly values of natural flow in the basin during the first four years of operation of the dam averaged higher than historic values.

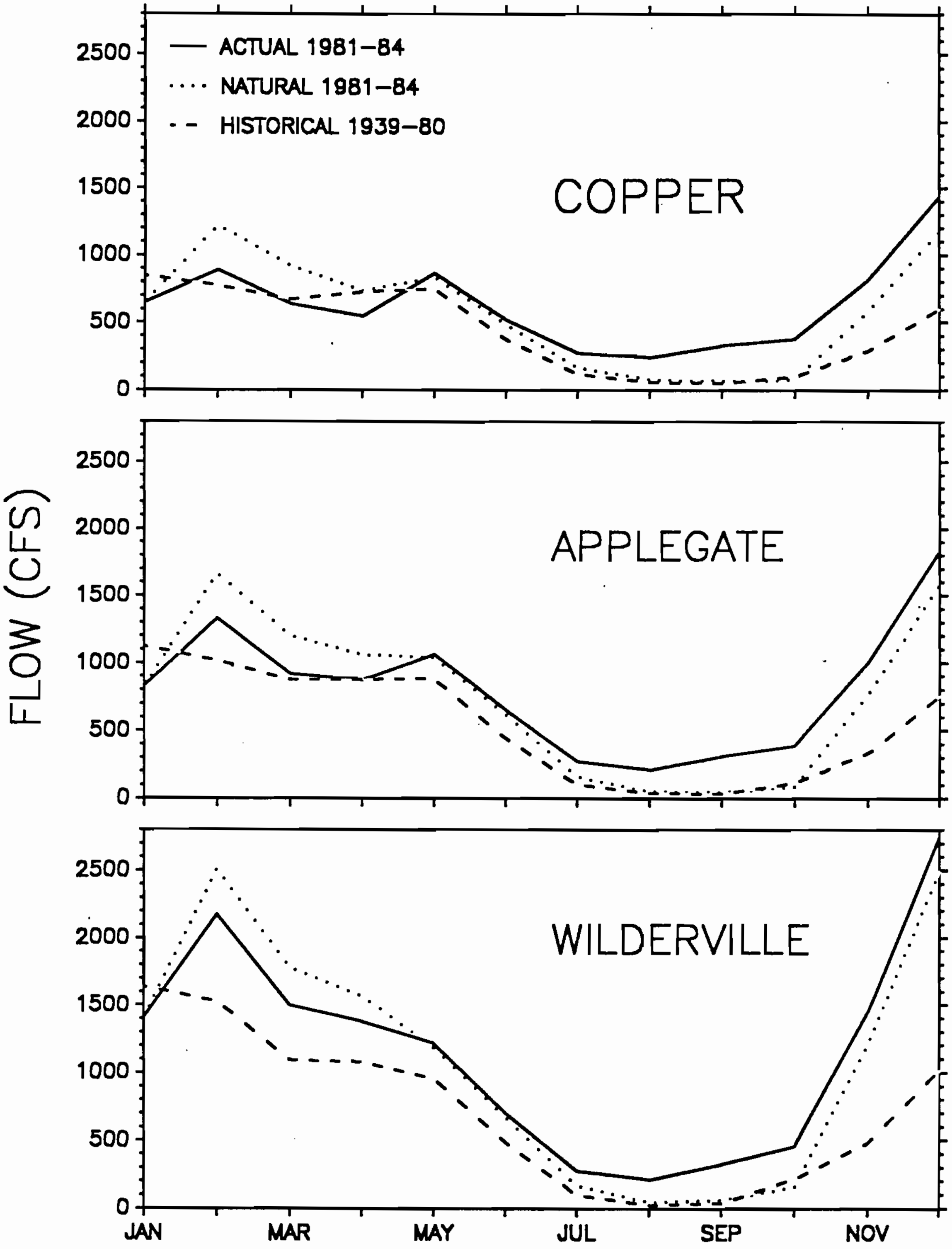

Figure 3. Estimated mean monthly flow near Copper, Applegate, and Wilderville. Historical flow for Wilderville is from 1939-55 and 1978-80.

Applegate Dam affected average monthly flow in all months except January, May, and June (Figure 3). Average monthly flow was increased with water released from Applegate Dam during July through December. Maximum augmentation occurred in October when Applegate Dam increased river flow by an average of 304 cfs near Copper (the damsite). Flow was reduced by the dam from February through April while the reservoir was refilled. Maximum reduction was during February when Applegate Dam reduced flow by an average of 333 cfs.

The relative effect of Applegate Dam on discharge in the Applegate River basin measures the importance of the dam on seasonal river flow. The largest effect of Applegate Dam on river flow occurred during July through October when augmentation from storage was a substantial percentage of the flow throughout the river (Table 3). For example, during September of 1981-84 an average of 81.1%, 85.6%, and 81.7%, of the flow near Copper, Applegate, and Wilderville, respectively, cam from storage.

Table 3. Percentage of flow attributable to storage released or retained by Applegate Dam at three locations in the Applegate River, 1981-84. Negative values indicate reductions.

Location	January	February	March	April	May	June
Copper	0.3	-37.4	-44.3	-34.7	3.3	6.5
Applegate	0.4	-25.0	-30.8	-21.8	2.7	5.2
Wilderville	0.2	-15.3	-18.9	-13.7	2.4	4.8

Location	July	August	September	October	November	December
Copper	40.4	67.3	81.1	79.7	28.6	17.7
Applegate	40.6	76.6	85.6	77.4	23.3	13.9
Wilderville	39.8	76.9	81.7	66.4	16.2	9.2

Because of flow from tributaries below the dam, the effect of Applegate Dam on monthly flow during refilling (February through April) was substantially less than during drawdown (Table 3). The dam affected flow in the upper reach of the river more than it affected flow in the middle or lower reaches of the river. The small effect of Applegate Dam on river flow (13.7%-44.3%) during the period when the reservoir was refilling was caused by above-average flow from precipitation during the first 4 years after closure of the dam. Natural flow in November through May of 1981-84 was substantially higher than flow in November through May of 1939-80 (Figure 3). Refilling of Applegate Dam will have a greater effect on flow during average or below average flow years.

Applegate Dam had a major effect on river flow during peak flood events. The amount of reduction in daily peak flow during the flood seasons of 1981-84 corresponded to the intensity of the flood (Figure 4). Reductions generally exceeded 50% of the potential peak flow.

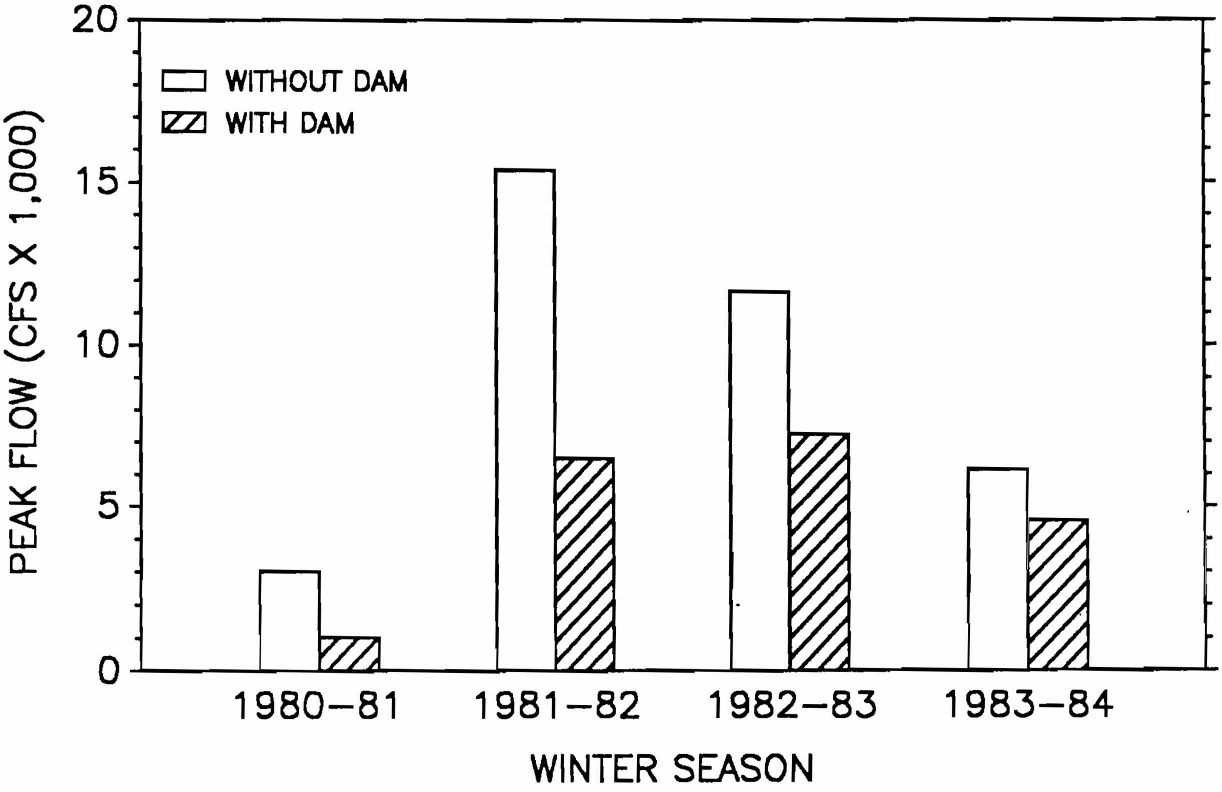

Figure 4. Reduction in the highest daily flow of the Applegate River near Applegate caused by Applegate Dam each year, 1981-84.

For use with the data that we present here from our fish sampling that began in 1979, flow in the two years before closure (1979-80) was compared with flow after closure (Appendix Table A-6). Near Copper and Applegate, mean monthly flow was significantly higher after closure than before closure during June through December ($P \leq 0.05$ for June and $P \leq 0.01$ for July-December). Near Wilderville, mean monthly flow after closure was significantly higher than before closure during July through December ($P \leq 0.01$). Mean monthly flow after closure was not significantly lower than flow before closure for the period when most of our fishery data were gathered. The lack of significantly lower winter flow after closure was caused by natural winter flow that was above average in 1981-84 (Figure 3), and caused by higher variation between years for winter flow compared with summer flow.

Effects of Applegate Dam on Downstream Temperature

During 1981-84, reservoir inflow temperature exceeded outflow temperature from mid-May through mid-September (Figure 5). The largest difference (11.0°C) was in August. During October through December, outflow temperature always exceeded inflow temperature because of heat storage in the reservoir.

We estimated that the dam reduced maximum daily river temperature 31 km downstream near Applegate by an average of 3.1°C during 16-31 July (Figure 5; Table 4). Cooling began in June and continued through September. The dam increased river temperature near Applegate from mid-October through mid-April. Warming was most intensive during the first two weeks of November when river temperature was increased by an average of 2.0° C. The apparent increase in river temperature near Applegate during January through April, though slight, is puzzling. Applegate Dam does not increase outflow temperature during this time of the year, but does reduce outflow to fill the reservoir. By reducing flow, the dam may promote warming of the river by allowing more heating from solar radiation as the water travels downstream in January through April. However, flow was not a significant variable in the model that we developed to predict temperature for this time of the year. This indicates that changes in outflow should not affect river temperature during January through April. The apparent increase in river temperature could also be attributed in part to the model's under-prediction of temperature during this time of year.

Compared with historic temperature (1974-79), predicted natural temperature near Applegate in 1981-84 was below average during March through July (Figure 5). Thus, the effect of the dam on river temperature near Applegate during March through July 1981-84 may not be typical of the dam's effect on river temperature under average conditions.

For use with the data that we present here from our fish sampling that began in 1979, river temperature in the two years before closure (1979-80) was compared with temperature after closure (Appendix Table A-7). Postimpoundment temperature was significantly lower than preimpoundment temperature at $P \leq 0.05$ during March through September near Copper, during June through September near Applegate, and during July through September near Wilderville. Maximum differences in temperature between preimpoundment and postimpoundment periods were in July when maximum temperature averaged 10.3°C, 4.2°C, and 2.5°C lower near Copper, Applegate, and Wilderville, respectively. Maximum river temperature after closure did not significantly exceed maximum river temperature before closure except during January near Applegate (1.1°C, significant at $P \leq 0.05$).

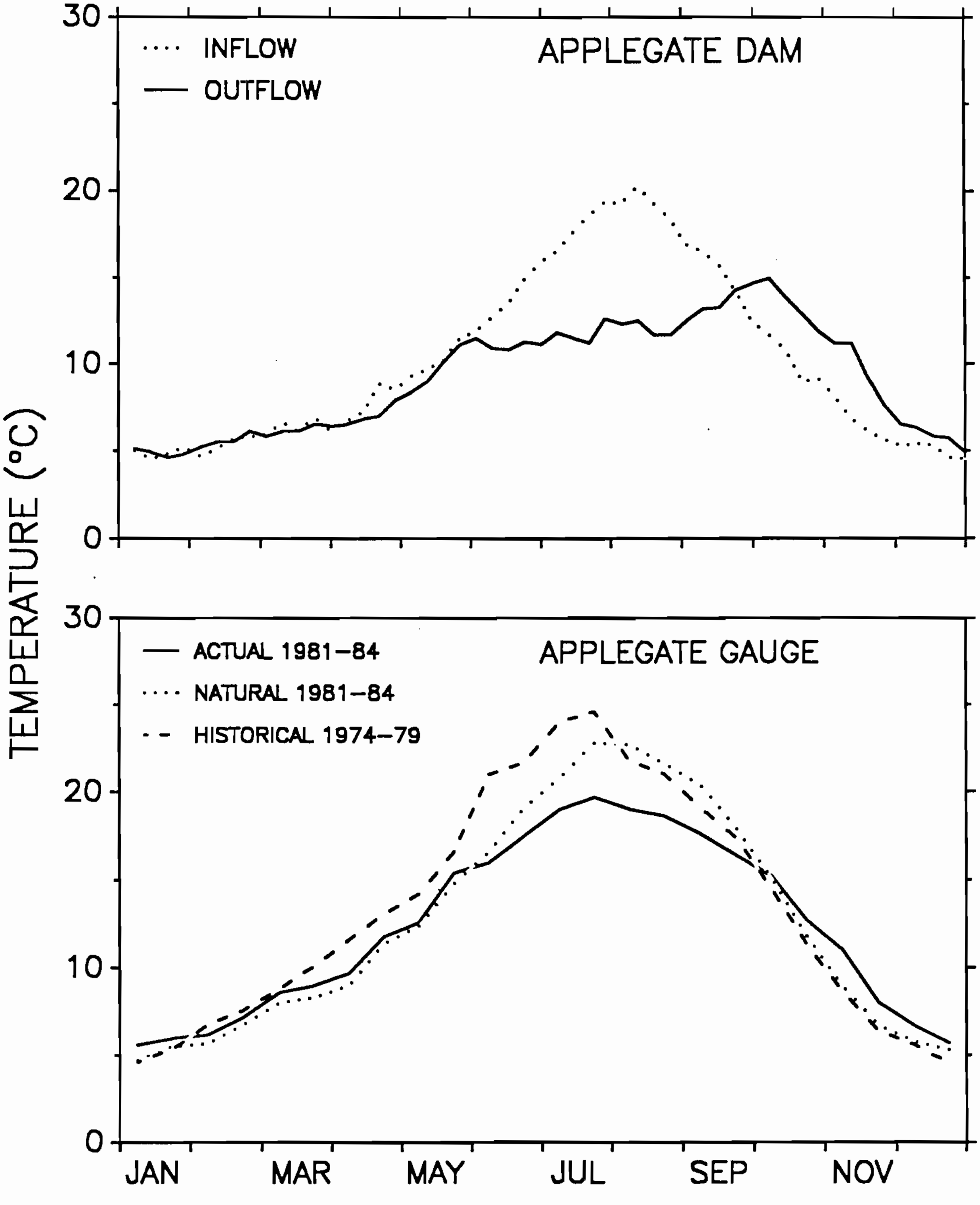

Figure 5. Mean biweekly maximum water temperature at inflow and outflow of Applegate Dam during 1981-84 and near Applegate during 1974-79 and 1981-84.

Table 4. Daily maximum water temperature (^{o}C) near Applegate averaged by 2-week intervals, 1981-84 (* = $P \leq 0.05$; ** = $P \leq 0.01$). CI = confidence interval.

Time period	Predicted natural	Actual	Difference[a] ± 95% CI
01-15 January	4.7	5.6	0.8 ± 0.14*
16-31 January	5.5	6.0	0.3 ± 0.16*
01-15 February	5.7	6.2	0.4 ± 0.13*
16-28 February	6.8	7.2	0.5 ± 0.28*
01-15 March	8.0	8.6	0.5 ± 0.20*
16-31 March	8.3	9.0	0.5 ± 0.16*
01-15 April	9.0	9.7	0.8 ± 0.26*
16-30 April	11.4	11.8	0.4 ± 0.27*
01-15 May	12.4	12.6	0.2 ± 0.24
16-31 May	14.8	15.4	0.6 ± 0.23
01-15 June	16.6	16.0	-0.5 ± 0.42*
16-30 June	19.1	17.5	-1.0 ± 0.21**
01-15 July	20.8	19.0	-1.9 ± 0.30**
16-31 July	22.8	19.7	-3.1 ± 0.16**
01-15 August	22.7	19.0	-2.8 ± 0.20*
16-31 August	21.6	18.6	-3.4 ± 0.22*
01-15 September	20.5	17.6	-2.8 ± 0.20**
16-30 September	17.9	16.4	-1.5 ± 0.34**
01-15 October	15.1	15.2	0.1 ± 0.22
16-31 October	11.8	12.7	0.9 ± 0.22**
01-15 November	8.9	11.0	2.0 ± 0.18**
16-30 November	6.7	8.0	1.4 ± 0.16**
01-15 December	5.8	6.7	0.9 ± 0.18**
16-31 December	5.3	5.7	0.5 ± 0.18*

[a] *Biweekly average of daily difference between actual and predicted natural temperature.*

Effects of Applegate Dam on Downstream Turbidity

We were unable to determine the effect of Applegate Dam on turbidity because sampling at the damsite was started only 3 months before closure of Applegate Dam. No turbidity data were collected above the reservoir site or in the lower river before or after closure of Applegate Dam. We split the existing data set (1 October 1980 to 30 September 1984) into three periods; 15 June to 15 October (the summer low flow period), 15 October to 30 March (the winter storm period), and 1 April to 15 June (the spring runoff period). The range of daily mean turbidity values was 0-25 JTU during the summer low flow period, 0-1,000+ JTU during the winter storm period before dam closure (October-December 1980), 0-480 JTU during the winter storm period after dam closure, and 0-80 JTU during the spring runoff period. On 3 May 1984 the regulating outlet was opened for a short period of time and turbidity near Copper was increased to 670 JTU. Peak turbidity during the winter storm period before dam closure (1,000+ JTU) and peak turbidity during the spring runoff period (670 JTU) occurred during weeks when flow increased 700-1,000 cfs at the dam. Without data from above the damsite on 3 May 1984, we are unable to determine if turbidity would have reached 670 JTU near Copper in the absence of the dam.

Effects of Applegate Dam on Juvenile Steelhead

Our analyses were restricted to examining growth and rearing distribution in the main river because of the difficulties we had in sampling juvenile steelhead. We were unable to determine dates of first emergence or emergence completion for steelhead because of difficulties we had in seining on shallow riffles where steelhead fry reside. Our sporadic catch of emergent-sized steelhead fry indicated that they were emerging from May through June. This corresponds with the estimate that peak spawning of Applegate River winter steelhead occurs between mid-April and mid-May, based on wild adults that were spawned as hatchery broodstock (telephone interview in June 1987 with Michael D. Evenson, ODFW, Cole M. Rivers Hatchery, Trail, Oregon).

We were unable to determine the effects of Applegate Dam on juvenile steelhead abundance and migration because catch dropped about 10-fold when summer flow increased after completion of Applegate Dam, and too few steelhead were captured to provide reliable estimates of trap efficiency at different flow levels. Steelhead smolts were the most difficult to capture, but our limited catch indicates that they were migrating out of the river from mid-March through mid-June, with peak migration in April or May. Our catch indicates that many steelhead parr (mostly age 1 fish) migrated out during May and June, consistent with the findings of Everest (1973), but some remained in the Applegate River with age 0 steelhead throughout the summer.

Growth

Annual measurements of growth of subyearling steelhead are given in Appendix Tables A-8 and A-9. Comparison of annual measurements collected before and after closure of Applegate Dam indicates that growth rate tended to increase by about 30% in the upper river (only significant at $P \leq 0.1$); however, the length of fish in September had not increased (Table 5). The postimpoundment increases in growth rate were greater before 1985 data were included because growth rate in 1985, with the release of warmer water (15^{o}-$17^{o}C$ in 1985 compared with 10^{o}-$12^{o}C$ in 1981-84), was as low as the growth rate during the preimpoundment years (Appendix Table A-8). The increases in width of outer band I, outer bands I + II, and circuli spacing were all highly significant at $P \leq 0.001$ using data through 1984. Although fish length in September showed a larger postimpoundment decrease if the year of warmer release water (1985) was excluded, the difference from the preimpoundment period was still not significant, even at $P \leq 0.1$. The minimum detectable differences for changes in circuli spacing and fish length were 54% and 27%, respectively (Table 5).

Table 5. Comparisons of subyearling steelhead growth measurements in September at McKee ditch trap before and after closure of Applegate Dam. MDD = minimum detectable difference.

Growth measurement	1979-80	1981-85	Difference	*P*	MDD (%)
Outer bands I + II (mm at 88X)	5.57	7.10	1.53	0.031	--
Average circuli spacing (mm at 88X)	1.71	2.26	0.55	0.063	54
Fish length (cm)	7.2	6.6	-0.6	0.285	27

We believe that the increase in growth rate in the upper river without a corresponding increase in fish length resulted from releases of cool water from the dam. We think that the lower temperature delayed completion of steelhead emergence and development in June, but provided better growth conditions than before dam closure during the rest of the summer. Because tributaries between Applegate Dam and McKee are few and small, most subyearlings above McKee are probably from redds in the main river and would have been affected by the dam starting at the egg stage.

Growth rate of subyearlings in the middle river, based on the width of outer band I on scales sampled at the Murphy ditch trap during 1979-85, did not show a significant increase, even at $P \leq 0.1$, although the mean band width increased by 7%-10% in July, August, and September. Similarly, the 4% increase in growth rate based on average spacing of circuli deposited by September of each year was not significant, even at $P \leq 0.1$. However, all of these growth rate indexes in 1985, when release temperature was increased, were as low as the indexes during the preimpoundment years (Appendix Table A-9). With 1985 data excluded, the increases in growth rate indexes after the dam was completed were larger (8%-11%), but were still only significant at $P \leq 0.1$. The minimum detectable differences of the growth rate indexes ranged from 21% to 38%. Unlike the tendency toward smaller fish at the end of the season in the upper river, the length of fish at Murphy had increased by 15%; however, this was still not significant at $P \leq 0.1$. The minimum detectable difference was 36%.

We think the reason for a slight postimpoundment tendency toward larger size in the middle river (contrasted with the tendency toward smaller size seen in the upper river) is that a substantial (but unquantified) portion of subyearlings sampled at Murphy emerge from redds in the larger tributaries of the Applegate River between McKee and Murphy (Little Applegate River, Thompson Creek, and Williams Creek). So, unlike the fish above McKee, their emergence time and earliest development should not have been delayed by cool water released from the dam, and when declining tributary flow forced them into the main river, slight postimpoundment increases in growth during July-September tended to produce slightly larger fish by September. Additionally, cool water released from the dam should have affected emergence time and early development of fish from redds in the middle river less than it affected fish from redds above McKee.

We wanted to investigate logical environmental and biological factors to determine how our growth measurements for subyearling steelhead were related to these factors. However, our data on emergence timing, juvenile abundance, and rearing distribution of subyearling steelhead were not adequate in most years. So, we concentrated on how temperature and flow of the river affected growth indexes of subyearling steelhead. We recommended and achieved higher temperature of release water in 1985 (15°-17°C) than in other years (10°-12°C) in an attempt to decorrelate temperature and flow to determine which factor had a greater effect on growth. Also, we had noted that subyearlings in the upper river tended to be smaller in 1981-84 than in preimpoundment years, and we were concerned that water released at 10°-12°C might be suboptimal for growth.

In the upper river, temperature was correlated higher than flow to the monthly growth rate indexes (Table 6). All three growth rate indexes were negatively correlated each month to river temperature for fish sampled in August and September. Flow was correlated to only two of the three indexes, only in September, and only at significance levels of $P \leq 0.05$ to 0.1. We were able to establish the relative importance of temperature by decorrelating temperature and flow through releases of flow similar to other postimpoundment years, but at a temperature mid-way between the levels observed in the first four postimpoundment years and the high levels observed in the preimpoundment years of 1979 and 1980 (Figure 6).

Our hypothesis was that growth rate in 1985 would be higher than in any other year because temperature would be nearest the optimum for growth. This was not the result (Figure 6). The temperature to which most fish above McKee are exposed may be several degrees higher than the data from Copper (10 km upstream) indicate. This means that releases of 10°-12°C water from the dam (1 km above the Copper thermograph) may provide a temperature closest to the optimum for growth of subyearling steelhead above McKee, where their concentration in the main river appears to be greatest (*see* page 28).

We attempted to incorporate temperature and flow into a multiple regression model of factors that affect growth rate of subyearlings above McKee by using the mean of outer band width from each of the 3 months in each of the 7 years, but flow was not a significant variable (Table 7). Band width was greatest early in the summer and smallest late in the summer at a similar temperature level, so we hypothesized that longer photoperiod in the early summer was promoting growth, possibly through higher quantity or quality of food production or more hours of feeding. We examined photoperiod and found that it was a highly significant variable in the models ($P \leq 0.001$) (Table 7). We had no measurements of food production or feeding activity to test for correlations to fish growth. The models indicate that for each 1°C increase in temperature above 11°C at Copper from mid-June through mid-September, growth rate is decreased by 3%-4%.

Table 6. Correlations between growth indexes on scales of subyearling steelhead captured in the McKee ditch trap and river temperature and flow near Copper, 1979-85.

Month, independent variable, growth index	Number of years	Range in independent variable	*r*	*P*
AUGUST				
Temperature:				
Outer band I	6[a]	10.9°-22.4°C	-0.892	0.011
Outer bands I + II	6[a]	11.0°-22.3°C	-0.860	0.020
Circuli spacing	6[a]	10.8°-20.8°C	-0.799	0.045
SEPTEMBER				
Temperature:				
Outer band I	7	12.2°-19.6°C	-0.930	0.001
Outer bands I + II	7	11.4°-20.6°C	-0.953	<0.001
Circuli spacing	7	11.2°-20.5°C	-0.935	<0.001
Flow:				
Outer bands I + II	7	52-284 cfs	0.762	0.039
Circuli spacing	7	105-575 cfs	0.722	0.058

[a] *No scales were collected at McKee until September 1979.*

Table 7. Statistics for multiple regression analyses of environmental factors correlated with outer band widths on scales of subyearling steelhead captured at McKee ditch trap throughout each July-September, 1979-85. Mean values from each month (July-September) were used, contributing 3 values in most years for a total sample size of 18 monthly means for the 7 years.

Dependent variable	R^2	Independent variable	Regression coefficient	Standard error	*P*
Band I	0.78	Constant	0.1403	1.3483	0.919
		Temperature (°C)	-0.1107	0.0207	<0.001
		Photoperiod (hours)	0.3697	0.0900	<0.001
Bands I + II	0.83	Constant	-3.0764	3.4773	0.390
		Temperature (°C)	-0.2598	0.0424	<0.001
		Photoperiod (hours)	1.0169	0.2282	<0.001

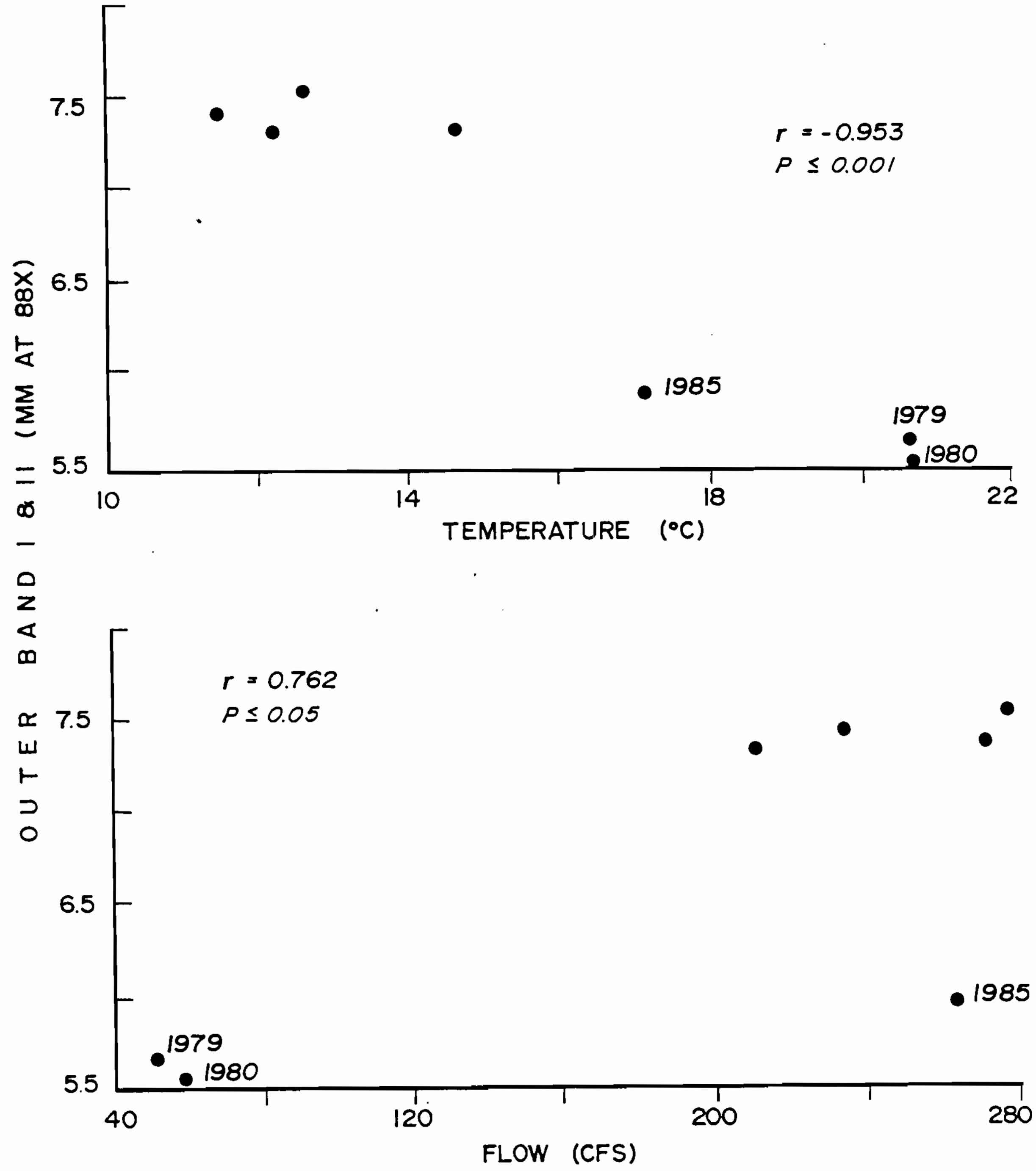

Figure 6. The width of outer bands I + II on scales of subyearling steelhead captured each September at McKee ditch trap plotted on river temperature and on flow near Copper averaged for the 6 weeks preceding fish capture, 1979-85.

With only 7 years of data on length of subyearlings at the end of sampling in September, we were unable to build a mathematical model that would incorporate temperature or flow from the dam in predicting length of fish that could be produced. The tendency toward production of smaller fish in the upper river with the dam in place is not statistically significant, even at $P \leq 0.1$, and we do not know if the production of slightly smaller subyearlings growing at a faster rate each September would have an effect on adult production.

Growth rate indexes from middle river fish were correlated to middle river temperature and flow (Table 8). Temperature was less correlated than flow in the early summer and more correlated than flow in the late summer. Temperature in the middle river (Table 8) was higher and had a narrower range than in the upper river (Table 6). Temperature was probably so high that growth rate began to level out with each degree increase in temperature. The lack of significant correlations, even at $P \leq 0.1$, between growth rate and flow in late summer may be attributed to the fact that flow has not exceeded 390 cfs in late summer compared with 679 cfs in the early summer (Table 8). Weather conditions become increasingly important in determining temperature of the middle river at lower flow.

Multiple regression models of factors that affect the growth rate of subyearling steelhead in the middle river included flow and temperature as variables significant at $P \leq 0.05$ (Table 9). The models that included flow had R^2 values that were nearly as high as the models that included temperature. The models indicate that for every 10 cfs increase in flow, outer band I increases by 4% with flow up to 400 cfs, and outer bands I + II increases by 0.5% with flow up to 679 cfs. Our interpretation of these results is that temperature is a more important factor than flow in directly affecting growth rate, whereas flow is an important determinant of temperature in the middle river in summer and may provide other benefits to growth (e.g., reduced rearing density). The strong dependence of steelhead growth on temperature has been demonstrated in the laboratory by Wurtsbaugh and Davis (1977).

As with the upper river data, we were unable to build a mathematical model to predict fish length at Murphy in September with only 7 years of data. However, length in September was correlated to all three growth rate indexes (r ranged from 0.777 to 0.981; P ranged from 0.0002 to 0.057). We believe that the slight tendency towards larger subyearlings since Applegate Dam was completed reflects an improvement in growth rate in the middle river that has resulted from increased flow that keeps temperature lower and provides other benefits, such as reduced crowding. These changes could be beneficial to adult steelhead production. Studies in the Rogue River and other rivers have shown that faster growing steelhead will smolt at younger ages (Kesner 1969; Everest 1973; Hoar 1976; Cramer 1986). A younger age at smolting should increase population productivity by reducing the number of years steelhead must survive before spawning. However, there may be counteracting effects if a shift towards smaller mature females or a shift towards more males than females at maturity is caused by faster growth and younger age at smolting.

Table 8. Correlations between growth indexes on scales of subyearling steelhead captured in the Murphy ditch trap and river temperature and flow near Applegate, 1979-85.

Growth index, independent variable	Number of years	Range in independent variable	*r*	*P*
JULY				
Temperature:				
Outer band I	7	17.2°-23.3°C	-0.673	0.088
Outer bands I + II	7	16.2°-22.3°C	-0.767	0.037
Circuli spacing	7	14.6°-20.1°C	-0.710	0.065
Flow:				
Outer band I	7	62-412 cfs	0.761	0.039
Outer bands I + II	7	104-679 cfs	0.805	0.023
AUGUST				
Temperature:				
Outer bands I + II	7	17.8°-24.6°C	-0.692	0.076
Flow:				
Outer bands I + II	7	29-390 cfs	0.664	0.095
SEPTEMBER				
Temperature:				
Outer bands I + II	6[a]	18.6°-23.0°C	-0.902	0.009
Circuli spacing	6[a]	16.5°-21.0°C	-0.820	0.035

[a] *No scales were collected at Murphy in September 1982.*

Table 9. Statistics for multiple regression analyses of environmental factors correlated with outer band widths on scales of subyearling steelhead captured at Murphy ditch trap during each July-September, 1979-85. Mean values from each month (July-September) were used, contributing 3 values each year except 1982 for a total sample size of 20 monthly means for the 7 years.

Dependent variable	R^2	Independent variable	Regression coefficient	Standard error	P
Band I	0.64	Constant	0.3094	0.9727	0.754
		Temperature (^oC)	-0.0765	0.0247	0.007
		Photoperiod (hours)	0.3188	0.0638	<0.001
Band I	0.58	Constant	-0.3836	0.9887	0.703
		Flow (cfs)	0.0126	0.0052	0.028
		Photoperiod (hours)	0.2402	0.0712	0.004
Bands I + II	0.78	Constant	0.1681	2.7370	0.951
		Temperature (^oC)	-0.2402	0.0502	<0.001
		Photoperiod (hours)	0.7939	0.1616	<0.001
Bands I + II	0.73	Constant	-2.4997	2.8030	0.385
		Flow (cfs)	0.0033	0.0009	0.001
		Photoperiod (hours)	0.5875	0.1996	0.009

Rearing Distribution

We did not sample adequately to compare distributions before and after closure of the dam. Population density of juvenile steelhead measured in each of the three river sections on each date of each year is given in Appendix Table A-10.

We detected no significant differences, even at $P \leq 0.1$, in population density of yearling steelhead among the upper, middle, and lower sections of the Applegate River in the postimpoundment years of 1983-85. Population density of yearling steelhead for all sections sampled in late August averaged 0.56, 0.40, and 0.50 fish/m in 1983, 1984, and 1985, respectively. This gives an average of 17 yearling steelhead in each pool, given the average pool length of 34.1 m for all years and all river sections sampled.

The population density of subyearling steelhead on riffles was significantly higher in the upper river than in either the middle or lower river in 1983 and 1984, but was not significantly higher in 1985 (Table 10). We detected no significant difference between the middle and lower river in density of subyearling steelhead populations.

We also measured the mean length of 30 subyearling steelhead captured with electrofishing gear during each survey (Appendix Table A-10). We detected no significant differences in mean length among years within river sections. However, we detected significant differences among the river sections within each year (Table 11). Newman-Keuls test indicated mean length was significantly different at $P \leq 0.05$ among all river sections, the fish being largest in the lower river and smallest in the upper river. The data indicate emergence is earlier, growth is faster, or both in downstream areas.

Table 10. Comparison of population density of subyearling steelhead (fish/m^2) among the upper (km 66-67), middle (km 39-41), and lower (km 3-13) sections of the Applegate River each year in late August.

Year	Section Upper	 Middle	 Lower	Probability of difference among sections *P*
1983	0.59	0.09	0.06	0.003
1984	0.71	0.09	0.14	0.001
1985	0.57	0.15	0.16	0.105

Table 11. Comparison of mean length (cm) of subyearling steelhead among the upper (km 66-67), middle (km 39-41), and lower (km 3-13) sections of the Applegate River each year in late August.

Year	Section Upper	 Middle	 Lower	Probability of difference among sections *P*
1983	4.2	6.4	8.5	<0.001
1984	5.4	6.6	8.0	<0.001
1985	4.7	6.4	7.7	<0.001

Based on the limited results from all of our analyses on juvenile steelhead biology, we recommend that during 1 June through 15 September outflow temperature at the dam should be 12.8°C, and during 1 July through 30 September storage in excess of the needs of chinook salmon should be used to maintain constant flow in order to reduce rearing density, increase growth, and increase survival of juvenile steelhead throughout the river. Time periods differ between these temperature and flow recommendations because of an authorized minimum flow for chinook salmon in June, and because of temperature recommendations for chinook salmon that start 15 September.

Effects of Applegate Dam on Adult Steelhead

Abundance

We were unable to determine the effects of Applegate Dam or other environmental factors on the abundance of adult steelhead migrating up the river because of the short data sets, small sample sizes each year, and lack of needed corrections for the effects of flow and turbidity on electrofishing efficiency. Although the electrofishing catch appears to be low in the postimpoundment years of 1981-84 (Table 12), we believe that the high flow caused by precipitation during these years reduced the catch. We have not been able to develop a sampling technique that will yield a satisfactory index of the abundance of steelhead migrating up the Applegate River. ODFW management biologists maintain indexes of spawner escapement to some tributaries of the Applegate River, but this does not provide an index of abundance at river entry prior to in-river harvest and mortality.

Table 12. Indexes of winter steelhead abundance (number) in the Applegate River.

Year	Electrofishing catch	Collection facility count		
		Hatchery	Wild	Total
1979	435	--	--	--
1980	130	--	--	--
1981	33	43	162	205
1982	(a)	10	153	163
1983	53	288	127	415
1984	128	596	521	1,117

[a] *No electrofishing in 1982.*

Life History Composition and Fish Size

Because of small sample sizes (35-267 fish per year), we are unable to compare life history composition between broods reared before and after Applegate Dam was closed. Adult life history composition of steelhead in the Applegate River from 1979-85 has varied, with compositions in 1979 and 1980 being the most different from each other and from compositions in the other years sampled (Table 13). We saw a slight trend toward a lower percentage of first spawning migrants through time, but no trends were evident for changes in other life history types. The percentage of first-spawning migrants for all years combined (34.1%) was similar to that for two-salt spawners (33.0%). These were the two most common adult life histories. Because of the high percentage of first-spawning migrants, mortality and harvest of half-pounder steelhead that enter the Rogue River in summer may affect abundance of adult winter steelhead in the Applegate River.

Average length of adult steelhead that returned to the Applegate River after Applegate Dam was completed showed a tendency to increase, with first-spawning migrants increasing by about 7 cm from approximately 55 to 62 cm (Table 14). However, sample sizes were insufficient to test for a change in fish length between broods reared before and after completion of Applegate Dam. Because they did not make a previous migration (as half-pounders), two-salt migrants were consistently larger than first-spawning migrants (Table 14). We also saw a tendency for adults that smolted at older ages to be larger within each adult life history type (Table 14).

Table 13. Life history composition (%) of adult steelhead captured in the Applegate River by electrofishing.[a]

Life history type	1979	1980	1981[b]	1984	1985
First-spawning migrants	53.5	45.0	17.8	27.1	22.9
Second-spawning migrants	7.2	18.5	12.5	11.8	11.4
Two-salt spawners	31.3	7.5	37.1	23.5	34.3
Other[c]	8.0	29.0	32.6	37.6	31.3

[a] *No electrofishing in 1982. Sample size in 1983 was too small to determine life history composition.*

[b] *Sample size from electrofishing was insufficient; data are from a trap in the ladder at Murphy Dam (km 21).*

[c] *Highly variable mixture of one-salt spawners, three-salt spawners, repeat spawners from one-, two-, or three-salt spawners, and a few rare types.*

Table 14. Average length ± 95% confidence interval (cm) of adult steelhead captured in the Applegate River by electrofishing.[a]

Life history type, smolt age	1979	1980	1981[b]	1984	1985
First-spawning migrant:					
1	53.7 ± 1.5	51.0 ± 7.6	49.1 ± 5.4	53.6 ± 8.6	55.2 ± 11.8
2	55.5 ± 1.3	53.8 ± 6.1	55.4 ± 2.9	62.4 ± 2.8	61.7 ± 5.8
3	52.1 ± 8.7	58.2 ± 13.4	60.0 --	61.7 ± 13.0	--
Second-spawning migrant:					
1	60.5 ± 7.3	57.8 ± 12.6	57.6 ± 4.1	64.5 ± 4.7	62.1 ± 11.7
2	62.4 ± 4.0	63.2 ± 1.7	60.7 ± 5.8	64.8 ± 1.5	--
Two-salt spawner:					
1	62.0 ± 3.3	--	62.2 ± 4.3	66.0 --	71.5 --
2	65.1 ± 0.9	--	63.9 ± 1.0	66.9 ± 3.8	70.2 ± 3.0
3	63.8 ± 2.8	--	65.5 ± 2.7	68.8 ± 3.3	--

[a] *No electrofishing in 1982. Sample size in 1983 was too small to determine life history composition.*

[b] *Sample size from electrofishing was insufficient; data are from a trap in the ladder at Murphy Dam (km 21).*

Smolt age composition indicated a time trend towards more age 2 and 3 smolts and fewer age 1 smolts for all life history types of adults combined (Table 15). The trend was not as apparent within any individual adult life history type. If this trend toward older smolt age continues, we may see a shift towards larger adults and a higher percentage of two-salt spawners produced by the Applegate River population. This is largely because two-salt spawners have older smolt ages than spawning migrants (Table 15). Cramer et al. (1985) found that winter steelhead in the Rogue River tended to smolt at an older age than in the Applegate River (Table 16), and salt migrants were more common than spawning migrants in the Rogue River. Applegate Dam may be improving survival to older smolt ages by reducing summer temperature and cropping peaks in winter flow, as expected from predictions by Everest (1973), and this may lead to a higher percentage of two-salt spawners in the Applegate River population.

Table 15. Smolt age composition (%) for each major life history type of adult steelhead captured in the Applegate River by electrofishing.[a]

Life history type, smolt age	1979	1980	1981[b]	1984	1985
First-spawning migrant:					
1	51.2	55.0	23.8	29.2	37.5
2	45.4	32.3	71.8	58.3	62.5
3	3.4	12.7	4.5	12.5	0
Second-spawning migrant:					
1	36.5	31.5	56.8	60.0	100
2	63.5	68.5	43.2	40.0	0
Two-salt spawner:					
1	5.1	0	6.9	4.5	8.3
2	81.8	100	82.6	68.2	91.7
3	12.3[c]	0	10.5	27.3	0
Combined:[d]					
1	33.1	38.8	25.8	27.1	17.5
2	59.8	55.5	68.8	60.0	71.9
3	6.3[c]	5.7	5.4	12.9	10.5

[a] *No electrofishing in 1982. Sample size in 1983 was too small to determine life history composition.*

[b] *Sample size from electrofishing was insufficient; data are from a trap in the ladder at Murphy Dam (km 21).*

[c] *Age 4 smolts (<1%) were also found, but not included here.*

[d] *All adult life history types, including uncommon types that are not listed in this table.*

Table 16. Smolt age composition (%) for each major life history type of adult winter steelhead captured in the lower Rogue River by electrofishing km 14-29.

Life history type, smolt age	1979	1980	1981
First-spawning migrant:			
1	28.4	24.7	--
2	65.2	72.7	--
3	6.4	2.6	--
Two-salt spawner:			
1	3.5	2.5	3.5
2	80.3	70.9	63.2
3	16.2	26.6	33.3
Combined:[a]			
1	13.7	21.2	6.5
2	71.6	62.3	69.2
3	14.7	14.1[b]	23.3[c]

[a] *All adult life history types, including uncommon types that are not listed in this table.*
[b] *Age 4 and age 0 smolts (<3%) were also found, but are not included here.*
[c] *Age 4 smolts (<1%) were also found, but are not included here.*

Effects of Applegate Dam on the Sport Fishery

Annual sport catch of adult steelhead in the Applegate River (estimated from salmon-steelhead catch cards returned by anglers) decreased after completion of Applegate Dam ($P = 0.053$; Table 17). Annual catch estimates cover the entire Applegate River steelhead season from January through March (Appendix Table A-11). Because of an analysis of the effects of flow on catch explained below, we were concerned that catch may have dropped when flow was reduced to fill the dam from February through April. However, we detected no significant change in the average flow during January through March after completion of Applegate Dam (Table 17). Also, in order to determine the effects of Applegate Dam on the catch of adult steelhead, we need a reliable measure of the abundance of adults in the river during the angling season.

We examined the 1967-85 catch estimates from salmon-steelhead catch cards to determine if relationships existed between sport catch and the environmental factors that could be altered by the dam (temperature, flow, and turbidity). Catch during January through March was highest when flow during the same time period averaged 800-1,200 cfs, and generally decreased when flow averaged above or below this range (Table 18; Figure 7). Although the catch

Table 17. Comparison of steelhead sport catch estimated from angler returns of salmon-steelhead catch cards and comparison of flow near Applegate during January through March before and after closure of Applegate Dam. MDD = minimum detectable difference.

Variable	1967-80	1981-85	Difference	*P*	MDD (%)
Catch	1,274	660	-614	0.053	--
Flow (cfs)	1,212	892	-207	0.561	94.3

Table 18. Multiple regression analysis of the relationship between steelhead sport catch estimated from angler returns of salmon-steelhead catch cards and flow in the Applegate River near Applegate, 1967-85. Data from 1974 were excluded (*see* pages 33-34).

Dependent variable	*N*	R^2	Independent variables	*P*	Regression coefficient	Standard error of regression coefficient
Catch	18	0.36	Constant	0.692	315.2091	780.8179
			Flow	0.015	2.5514	0.9310
			$Flow^2$	0.012	-0.0013	0.0005

of 251 fish and a flow of 2,600 cfs in 1974 was consistent with the tendency for low catch at high flow, we excluded the 1974 data. Inclusion of the 1974 data indicated the need for an asymptotic tail on the relationship for flow levels above 2,000 cfs, and we did not have enough data at these rare flow levels to define the asymptotic tail. Like most rivers, the Applegate River undoubtedly has an optimum flow level for a given type of angling, and it appears to be about 800-1,200 cfs for winter steelhead angling in the Applegate River.

Some precision in the relationship of sport catch to flow is lacking because we could not account for the effect of steelhead abundance on catch. Winter steelhead counts at Gold Ray Dam on the Rogue River were the only measure of steelhead abundance in the vicinity during these years. We thought they might also reflect between-year differences in relative abundance in the Applegate River. These counts, however, did not account for any of the variation in the Applegate River catch estimates.

Flow reductions from Applegate Dam may create slightly more favorable conditions for anglers at times of high natural runoff, and less favorable conditions for anglers at times of low natural runoff. However, the period of record for January through March flow near Applegate indicates that 62% of the

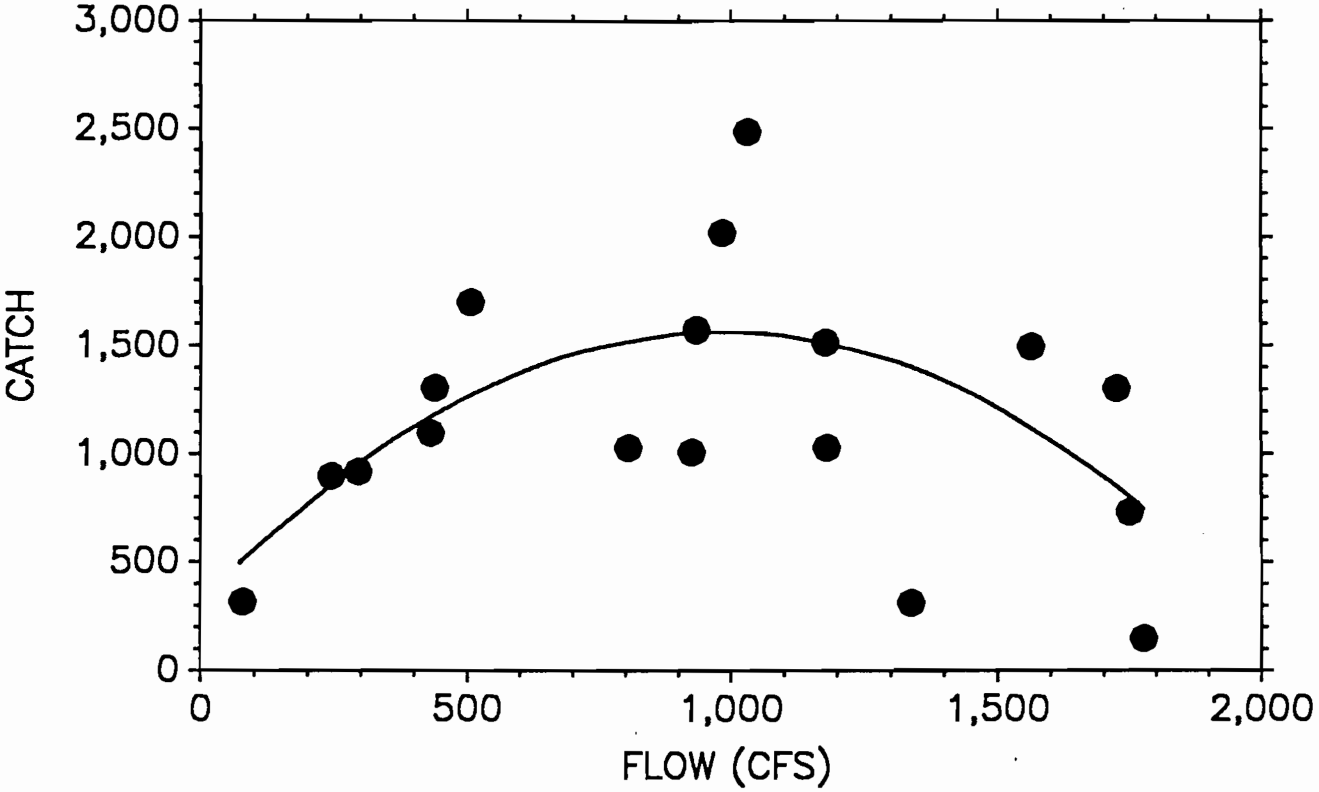

Figure 7. Relationship between annual sport catch of winter steelhead in the Applegate River and average flow near Applegate during January-March, 1967-85. Data from 1974 were excluded (*see* pages 33-34).

years preceding dam closure (1939-80) had an average flow that was less than 1,000 cfs. Therefore, we anticipate that the dam will have a negative effect on water conditions for fishing, because it will further reduce January through March flow in order to fill the reservoir.

The net effect of the dam on water conditions for winter steelhead angling may be negative unless alternative schedules for refilling the reservoir, such as faster refilling before 15 February can be adopted for years with relatively low runoff. Sport catch estimated from salmon-steelhead catch cards and adult abundance indexed from electrofishing historically increased after 15 February.

RECOMMENDATIONS FOR OPERATION OF APPLEGATE DAM

Flow

1. Use an alternative filling schedule that will allow up to 1,200 cfs in the middle river from 15 February through 31 March to provide optimum flow for steelhead angling (*see* pages 34-35). The dam will have a negative effect

on water conditions for winter steelhead angling unless alternatives, such as faster filling before 15 February, can be adopted for years with relatively low runoff.

2. Use storage in excess of the spring and fall needs of chinook salmon to maintain a constant flow as high as possible during 1 July through 30 September for juvenile steelhead growth and survival (*see* page 29). This recommendation is expected to result in a release flow of 100-300 cfs, depending on reservoir storage and inflow each year.

3. Limit peak flow to the greatest extent possible (unless such action threatens flood control capability) during 31 March through 30 June to increase survival of eggs and fry of steelhead that spawned in the main river below Applegate Dam (*see* page 21; based on other studies and professional judgment).

4. Limit the rate of decrease in outflow to an average of 50 cfs per hour with individual adjustments limited to 150 cfs (e.g., 150 cfs decreases every 3 hours) to minimize stranding of juvenile salmonids, unless such action threatens flood control capability (based on page 20 of Satterthwaite [1987]).

Temperature

1. Gradually increase the temperature of release water from 3.0°C to 12.8°C from 1 March to 1 June, closely following the historic rate of temperature increase at the damsite before the dam was built. This rate of increase would mimic the historic rate of increase encountered by incubating steelhead eggs in the main river, and allow emergence from the gravel on historic dates. *See* pages 18 and 21 (based partly on other studies and professional judgment).

2. Maintain temperature of the release water at 12.8°C from 1 June to 15 September to provide the best rearing temperature for steelhead in the middle and lower sections of the river without causing suboptimal temperature for the growth of juvenile steelhead that are concentrated in the upper sections of the river (*see* page 29; based partly on other studies and professional judgment). If this action is expected to deplete cold water storage to the extent that the temperature requirements for chinook salmon spawners and eggs cannot be met during October-February, allow warmer water to be released in July (15.0°C limit), August (17.2°C limit), and early September (15.0°C limit).

RECOMMENDATIONS FOR FUTURE RESEARCH RELATED TO THE OPERATION OF APPLEGATE DAM

1. Determine whether reduced catch of adult steelhead after completion of Applegate Dam persists. If it does, determine if it is caused by a decline in angling conditions, fewer fish in the population, or other causes.

2. Determine the beneficial contribution of Applegate River steelhead to the sport catch in the Rogue River.

3. Determine upper limit of flow during the winter steelhead spawning period (March through May) and lower limit of flow during April-June that will prevent dewatering of eggs and alevins remaining in the gravel.

RECOMMENDATIONS FOR FUTURE RESEARCH RELATED TO FISH MANAGEMENT

1. Develop accurate, precise, and efficient methods of determining the abundance of steelhead spawners (a) entering and (b) escaping to spawn in the Applegate River basin.

2. Develop accurate, precise, and efficient methods of determining abundance of (a) emergent fry and (b) juvenile outmigrants of steelhead in the Applegate River.

3. Using data from 1b, 2a, and 2b above, determine optimum spawning escapement for production of outmigrants, and determine if juvenile production is being limited anywhere in the egg-to-outmigrant life stage.

4. Determine the mortality and harvest of juvenile steelhead in the Applegate River attributable to trout anglers.

5. Develop and evaluate methods of maintaining the genetic integrity and diversity of wild steelhead in the Applegate River basin, and methods of maintaining genetic diversity within the hatchery program for steelhead released in the Applegate River basin. The maintenance of wild populations and the maintenance of genetic diversity within wild and hatchery populations is considered to be important in providing sustainable production in a changing environment (Bottom et al. 1986; Dentler and Buchanan 1986; Norton 1987).

6. Monitor the abundance and distribution of the recently introduced smallmouth bass *Micropterus dolomieui* and northern squawfish *Ptychocheilus oregonensis* and determine their effects on steelhead.

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APPENDIX A

Tables of Information Related to Analyses of River Temperature, Steelhead Biology, and Angler Catch of Steelhead in the Applegate River.

Appendix Table A-1. Classification of spawning areas of the Applegate River basin based on estimated size of spawning populations of winter and summer run steelhead.[a]

Area	Applegate River kilometer	Classification[b] Winter run	Summer run
Lower main river	0-32	1	(c)
Upper main river	32-75	1	3
Basin above damsite	76-88	1[d]	3[d]
Slate Creek:			
Main stem	5	3	(c)
Round Prairie Creek	--	(c)	3
Elliott Creek	--	(c)	3
Waters Creek	--	(c)	3
Cheney Creek	6	(c)	2
Jackson Creek	13	(c)	3
Murphy Creek	21	(c)	3
Grays Creek	22	(c)	3
Caris Creek:			
Main stem	30	(c)	3
Slagle Creek	--	(c)	3
Williams Creek:			
Main stem	32	3	(c)
Powell Creek	--	(c)	3
Mungers Creek	--	3	3
Bear Wallow Creek	--	(c)	3

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[a] *Winter steelhead data are from a meeting on 7 September 1988 with Michael D. Jennings, ODFW, District Biologist, Central Point, Oregon, and summer steelhead data are from Everest (1973) with minor modifications based on the meeting with M. D. Jennings.*

[b] *Class 1 streams support estimated spawning populations of more than 1,000 fish, class 2 support between 500 and 1,000 fish, and class 3 support up to 500 fish.*

[c] *Not used by spawners.*

[d] *Classification prior to complete blockage of migration by Applegate Dam (main river and tributaries are included).*

Appendix Table A-1. Continued.

Area	Applegate River kilometer	Classification[b] Winter run	Summer run
Thompson Creek:			
Main stem	41	3	2
Nine Mile Creek	--	(c)	3
Forest Creek	52	(c)	3
Little Applegate River:			
Main stem	54	3	(c)
Yale Creek	--	(c)	3
Glade Creek	--	3	(c)
Star Gulch	61	(c)	3
Beaver Creek	66	(c)	3
Palmer Creek	67	3	3

Appendix Table A-2. Independent variables tested in multiple regressions to determine changes in water temperature at the USGS gauge near Applegate caused by Applegate Dam.

Time period	Independent variable
01/01-05/15	1. Daily maximum temperature at Big Butte Creek (°C). 2. Daily maximum air temperature at Grants Pass (°C). 3. Daily maximum air temperature at Ashland (°C). 4. Daily mean flow near Applegate (cfs). 5. Daily photoperiod at Medford airport (hours and minutes).
05/16-09/15	Same variables as above, except number 3 not tested.
09/16-12/31	Same variables as above, except numbers 1 and 3 not tested.

Appendix Table A-3. Minimum and maximum values of independent variables from 1974-80 used to construct models for predicting the natural water temperature of the Applegate River near Applegate that would have occurred in each postimpoundment year if the dam was not present, and the minimum and maximum values of these variables in each postimpoundment year, 1981-84. Min = minimum, Max = maximum.

Period, year(s)	Photoperiod (hours)		Big Butte Creek temperature (°C)		Flow near Applegate (cfs)		Grants Pass air temperature (°C)	
	Min	Max	Min	Max	Min	Max	Min	Max
01/01-05/15:								
1974-80	9.1	14.4	2.2	16.8	--	--	--	--
1981	9.1	14.4	5.1	19.8[a]	--	--	--	--
1982	9.1	14.4	2.8	15.1	--	--	--	--
1983	9.1	14.4	3.3	14.1	--	--	--	--
1984	9.1	14.4	3.0	13.5	--	--	--	--
05/16-09/15:								
1974-80	--	--	10.4	23.7	10	2,250	12.2	41.1
1981	--	--	12.1	23.8[a]	10	223	15.6	43.3
1982	--	--	11.7	22.2	15	1,582	15.6	37.2
1983	--	--	12.7	22.0	45	3,292[a]	16.7	36.7
1984	--	--	10.7	21.0	11	1,021	15.0	40.6
09/16-12/31:								
1974-80	9.0	12.3	--	--	--	--	1.7	35.6
1981	9.0	12.3	--	--	--	--	2.8	38.3[a]
1982	9.0	12.3	--	--	--	--	2.2	27.8
1983	9.0	12.3	--	--	--	--	1.1[a]	28.9
1984	9.0	12.3	--	--	--	--	2.8	36.1[a]

[a] *Value outside the range of values used to construct model.*

Appendix Table A-4. Regression models of daily maximum river temperature (°C) of the Applegate River near Applegate developed from 1974-80 data and used to predict natural river temperature that would have occurred during 1981-84 if the dam was not present.

Time period	N	R^2	Coefficient	Independent variable	Partial t[a]
01/01-05/15	207	0.86	-2.71850	Constant	-3.66
			0.38370	Photoperiod (hours and minutes)	4.16
			0.75358	Maximum temperature of Big Butte Creek in (°C)	14.99
05/16-09/15	150	0.90	5.83478	Constant	7.78
			-0.00553	Mean flow near Applegate (cfs)	-16.22
			0.13850	Maximum air temperature at Grants Pass (°C)	4.63
			0.63587	Maximum temperature of Big Butte Creek (°C)	11.14
09/16-12/31	150	0.94	-22.87540	Constant	-13.33
			2.90110	Photoperiod (hours and minutes)	14.41
			0.25033	Maximum air temperature at Grants Pass (°C)	9.98

[a] *All values significant at* $P \leq 0.01$.

Appendix Table A-5. Daily maximum water temperature (°C) near Applegate averaged by 2-week intervals, 1974-80. CI = confidence interval.

Time Period	Actual	Predicted natural	Difference[a] ± 95% CI
01-15 January	4.9	4.8	0.0 ± 0.44
16-31 January	4.9	5.0	0.1 ± 0.30
01-15 February	5.6	5.7	0.1 ± 0.42
16-28 February	7.1	6.5	-0.5 ± 0.20[b]
01-15 March	7.8	7.2	-0.7 ± 0.28[b]
16-31 March	8.9	8.7	-0.4 ± 0.44
01-15 April	9.2	9.5	-0.1 ± 0.44
16-30 April	10.8	10.8	0.0 ± 0.48
01-15 May	12.3	12.9	0.6 ± 0.66
16-31 May	14.2	14.0	0.5 ± 0.54
01-15 June	17.5	17.5	0.2 ± 0.64
16-30 June	20.7	20.2	-0.1 ± 0.36
01-15 July	22.2	21.8	-0.5 ± 0.48[b]
16-31 July	24.3	23.9	-0.5 ± 0.48
01-15 August	23.5	23.1	-0.6 ± 0.46[b]
16-31 August	21.8	21.5	-0.2 ± 0.40
01-15 September	20.0	20.6	0.5 ± 0.66
16-30 September	18.4	18.4	0.0 ± 0.38
01-15 October	15.8	15.9	0.2 ± 0.44
16-31 October	12.6	12.0	-0.3 ± 0.54
01-15 November	9.5	9.1	-0.4 ± 0.72
16-30 November	6.9	6.9	0.0 ± 0.56
01-15 December	5.8	5.8	0.1 ± 0.66
16-31 December	4.4	4.9	0.8 ± 0.66[b]

[a] *Biweekly average of daily difference between actual and predicted natural temperature.*

[b] $P \leq 0.05$.

Appendix Table A-6. Comparison of monthly flow[a] (cfs) before (1979-80) and after (1981-84) closure of Applegate Dam (* = $P \le 0.05$; ** = $P \le 0.01$). CI = confidence interval.

Location, month	Before closure	After closure	Difference[b] ± 95% CI
Copper:			
January	873	646	-226 ± 589
February	564	889	355 ± 746
March	627	639	12 ± 365
April	596	545	-51 ± 364
May	603	872	269 ± 393
June	212	521	309 ± 257*
July	91	272	181 ± 50**
August	58	237	179 ± 17**
September	47	329	282 ± 82**
October	103	381	278 ± 122**
November	218	802	584 ± 352**
December	333	1,431	1,098 ± 744**
Applegate:			
January	1,112	890	-225 ± 764
February	677	1,309	631 ± 1,056
March	753	947	194 ± 496
April	715	831	116 ± 487
May	732	1,041	309 ± 471
June	257	601	343 ± 322*
July	74	266	192 ± 74**
August	25	211	186 ± 21**
September	27	314	283 ± 87**
October	116	390	274 ± 134**
November	258	890	632 ± 393**
December	430	1,901	1,471 ± 954**

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[a] *Monthly mean of of daily mean flow.*

[b] *Monthly mean of daily difference between 1979-80 mean and 1981-84 mean.*

Appendix Table A-6. Continued.

Location, month	Before closure	After closure	Difference[b] ± 95% CI
Wilderville:			
January	1,680	1,391	-289 ± 1,211
February	1,006	2,150	1,144 ± 1,580
March	1,142	1,563	421 ± 827
April	981	1,345	362 ± 759
May	928	1,164	235 ± 489
June	278	653	375 ± 355
July	65	274	210 ± 88**
August	9	212	203 ± 32**
September	26	332	306 ± 105**
October	156	448	292 ± 158**
November	416	1,356	940 ± 640**
December	771	2,895	2,124 ± 1,368**

Appendix Table A-7. Comparison of monthly temperature[a] (°C) before (1979-80) and after (1981-84) closure of Applegate Dam (* = $P \leq 0.05$; ** = $P \leq 0.01$). CI = confidence interval.

Location, month	Before closure	After closure	Difference[b] ± 95% CI
Copper:			
January	4.6	4.8	0.2 ± 0.9
February	5.1	5.4	0.3 ± 1.0
March	7.3	6.2	-1.1 ± 0.5**
April	9.2	7.1	-2.2 ± 0.8**
May	12.6	10.0	-2.6 ± 1.5**
June	17.5	10.9	-6.6 ± 1.4**
July	22.1	11.7	-10.3 ± 1.6**
August	21.6	12.1	-9.4 ± 1.2**
September	18.6	13.9	-4.8 ± 1.3**
October	13.8	13.4	-0.4 ± 2.0
November	8.0	9.1	1.2 ± 1.6
December	5.8	5.7	-0.1 ± 0.7
Applegate:			
January	4.5	5.6	1.1 ± 0.9*
February	5.7	6.5	0.8 ± 1.0
March	8.3	8.6	0.3 ± 0.8
April	10.4	10.8	0.4 ± 1.5
May	13.9	13.7	-0.3 ± 1.7
June	19.5	16.6	-2.9 ± 2.0**
July	23.5	19.3	-4.2 ± 1.5**
August	23.3	19.2	-4.0 ± 1.3**
September	19.9	16.9	-3.0 ± 1.2**
October	14.8	14.1	-0.7 ± 1.9
November	9.1	9.5	0.4 ± 1.9
December	6.1	6.2	0.1 ± 0.9

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[a] *Monthly mean of daily maximum temperature.*

[b] *Monthly mean of daily difference between 1979-80 mean and 1981-84 mean.*

Appendix Table A-7. Continued.

Location, month	Before closure	After closure	Difference[b] ± 95% CI
Wilderville:			
January	5.8	6.4	0.6 ± 1.0
February	6.7	7.2	0.5 ± 1.1
March	9.8	9.5	-0.4 ± 0.8
April	12.2	11.9	-0.3 ± 1.8
May	15.8	15.2	-0.6 ± 1.9
June	20.5	18.6	-1.8 ± 2.2
July	24.6	22.1	-2.5 ± 1.7**
August	24.2	22.4	-1.8 ± 1.3**
September	20.6	18.6	-2.0 ± 1.6*
October	16.4	14.4	-2.1 ± 1.9*
November	9.8	9.3	-0.5 ± 1.6
December	7.4	6.3	-1.1 ± 1.3

Appendix Table A-8. Annual mean of growth measurements from subyearling steelhead captured each September at McKee ditch trap on the Applegate River.

Year	Outer band width (mm at 88X)		Average circuli spacing (mm at 88X)	Fish length (cm)
	I	I + II		
1979	3.01	5.60	1.65	7.7
1980	2.86	5.53	1.78	6.7
1981	3.62	7.30	2.24	7.3
1982	3.52	7.38	2.43	6.5
1983	3.46	7.62	2.46	6.0
1984	3.63	7.30	2.41	6.3
1985	2.80	5.89	1.74	7.0

Appendix Table A-9. Annual mean of growth measurements from subyearling steelhead captured at Murphy ditch trap on the Applegate River.

Year	Width of outer band I (mm at 88X)			Average circuli spacing[a] (mm at 88X)	Fish length[a] (cm)
	July	August	September		
1979	3.19	3.19	2.89	1.91	7.4
1980	3.47	2.93	2.70	1.89	7.5
1981	3.44	3.25	3.33	2.03	8.9
1982	3.70	3.12	(b)	(b)	(b)
1983	3.91	3.71	3.30	2.18	9.4
1984	3.79	3.32	2.64	1.95	7.7
1985	3.44	2.90	3.03	1.76	7.8

[a] *September.*
[b] *Catch was inadequate for representative sample.*

Appendix Table A-10. Population density and size of juvenile steelhead in the Applegate River.

Location, date sampled	Subyearling Density (fish/m^2) Mean[a] ± SD	Subyearling Fork length (cm) Mean[b] ± SD	Yearling density (fish/m) Mean[c] ± SD
Upper river (km 67-66):			
08/22/83	0.59 ± 0.19	4.2 ± 0.71	0.62 ± 0.27
08/02/84	0.64 ± 0.26	3.6 ± 0.68	0.70 ± 0.44
08/31/84	0.71 ± 0.13	5.4 ± 1.07	0.43 ± 0.06
09/27/84	0.34 ± 0.01	6.1 ± 0.82	0.25 --
08/15/85	0.57 ± 0.39	4.7 ± 1.01[d]	0.67 ± 0.43
Middle river (km 41-39):			
08/30/83	0.09 ± 0.05	6.4 ± 0.69	0.32 ± 0.07[e]
08/03/84	0.23 ± 0.06	6.0 ± 0.89	1.03 ± 0.66
08/31/84	0.09 ± 0.05	6.6 ± 0.70	0.50 ± 0.43
09/27/84	0.30 ± 0.10	7.5 ± 0.85	0.37 ± 0.38
08/16/85	0.15 ± 0.02	6.4 ± 0.89	0.32 ± 0.37
Lower river (km 13-3):			
08/18/83	0.06 ± 0.07	8.5 ± 1.43	0.73 ± 0.57
08/01/84	0.14 ± 0.12	7.5 ± 1.58	0.37 ± 0.15
08/29/84	0.14 ± 0.14	8.0 ± 1.32	0.33 ± 0.06
09/28/84	0.41 ± 0.31	8.4 ± 1.19	--
08/16/85	0.16 ± 0.02	7.7 ± 1.30	--

[a] *Mean of 3 riffles in each river section on each date.*
[b] *Mean of at least 30 fish in each river section on each date.*
[c] *Mean of 3 pools in each river section on each date.*
[d] *Only 18 fish captured.*
[e] *Yearling steelhead sampled on 8 September because water on 30 August was too turbid to count fish.*

Appendix Table A-11. Estimated sport catch of adult steelhead in the Applegate River based on angler returns of salmon-steelhead catch cards.

Year	January	February	March	Total
1967	151	1,063	808	2,022
1968	392	597	585	1,574
1969	135	435	439	1,009
1970	263	700	340	1,303
1971	334	596	565	1,495
1972	89	521	120	730
1973	169	406	522	1,097
1974	105	97	49	251
1975	771	863	850	2,484
1976	360	215	733	1,308
1977	3	81	230	314
1978	498	559	460	1,517
1979	42	573	1,085	1,700
1980	257	234	540	1,031
1981	120	321	455	896
1982	95	57	159	311
1983	41	30	78	149
1984	187	326	513	1,026
1985	55	253	608	916