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Evaluation of structures to improve Steelhead trout (Oncorhynchus mykiss) habitat

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EVALUATION OF STRUCTURES TO IMPROVE STEELHEAD TROUT (*Oncorhynchus mykiss*) HABITAT

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Neil S. Lassettre

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ABSTRACT

EVALUATION OF STRUCTURES TO IMPROVE STEELHEAD TROUT (*Oncorhynchus mykiss*) HABITAT

by Neil S. Lassettre

Freshwater habitat loss and degradation are factors responsible for the decline of Steelhead trout (*Oncorhynchus mykiss*) populations in California. Instream enhancement structures are used to restore naturally occurring steelhead habitat components. Projects that aim to restore habitat must be thoroughly evaluated to document any lessons that may be learned.

Moore's Gulch is a stream located in Santa Cruz County, California. Seven log weirs and twelve log deflectors were used to restore steelhead habitat. An evaluation compared Rosgen channel types, salmonid habitat types, and fish density between an experimental and a control section. The stability of structures was evaluated using a point system and by examining streamflow history. The results supported conclusions of increased steelhead production in experimental sections over control sections and that a lack of pool habitat may be a limiting factor to steelhead production. The results also demonstrate a high impairment and failure rate of instream structures.

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INTRODUCTION

Problem Statement

Importance. Freshwater habitat loss and degradation are the main factors responsible for the decline of steelhead trout populations (*Oncorhynchus mykiss*) in California and for the decline of salmonid (*Oncorhynchus* spp.) populations, in general, along the Pacific coast (Nehlsen 1994; Nehlsen, Williams, and Lichatowich 1991; McEwan and Jackson 1996; Moyle 1994). One management strategy to increase depressed populations is to restore degraded habitats (McEwan and Jackson 1996; Nehlsen, Williams, and Lichatowich 1991). Proper implementation of habitat restoration techniques can improve crucial steelhead spawning, rearing, and overwintering areas (Binns 1994; Burgess and Bider 1980; Crispin, House, and Roberts 1993; Gowan and Fausch 1996; House and Boehne 1985, 1986; Klassen and Northcote 1988; Moore and Gregory 1988; Nickelson et al. 1992; Shirvell 1990). To assure the quality and effectiveness of future steelhead and other salmonid restoration activities, current projects must be thoroughly evaluated (Frissell and Nawa 1992; Kondolf 1995; Kondolf and Micheli 1995; Kondolf, Vick, and Ramirez 1996; McEwan and Jackson 1996; Marcus, Noel, and Young 1990; National Research Council 1992).

Ranging in territory from Alaska to southern California, steelhead are the anadromous form of the rainbow trout (Emmet et al. 1991; McEwan and Jackson 1996). Spawning territory for steelhead in California covers coastal rivers and streams from Malibu Creek in Los Angeles County to the Smith River near the Oregon border (McEwan and Jackson 1996). The fish hatch in freshwater streams and remain for one to four years (usually two years) before migrating to the ocean (Emmet et al. 1991; McEwan and Jackson 1996). One to five years are spent in the ocean (usually one to two years) before steelhead return to their natal stream to spawn (Emmet et al. 1991). Spawning usually occurs between December and April, after a migration that may begin as early as the fall (Emmet et al. 1991; McEwan and Jackson 1996). Many fish migrate from January to April (Jerry Smith, personal communication, March 1997). Females deposit eggs in nests called redds, which are dug in areas containing medium and small gravel (>85 mm) to maximize intragravel flow that delivers dissolved oxygen to the developing eggs (Emmet et al. 1991; McEwan and Jackson 1996). An attendant male fertilizes the eggs as they are deposited in the redd (Emmet et al. 1991; McEwan and Jackson 1996). The eggs are then covered with gravel as the female constructs another redd just upstream (McEwan and Jackson 1996). Eggs hatch in 30 days on average (at 51° Fahrenheit stream water temperature), but hatch time can vary depending on water temperature and dissolved oxygen concentration (Emmet et al. 1991; McEwan and Jackson 1996). Hatchlings remain in the gravel for four to six weeks and then emerge as fry and move into defended feeding territories.

Steelhead require specific instream habitat components. Life history stage dictates the components that are essential for survival. Migrating adults, spawning adults, embryos, fry, and juveniles all occupy unique physical areas of a stream. Consequently, one factor important in determining the growth and survival of steelhead is the physical heterogeneity of the habitat (Schlosser 1991). Large pieces of organic debris that collect and form obstructions are a primary influence on channel conditions (Schlosser 1991). The obstructions govern stream heterogeneity by decreasing water velocity and promoting scouring processes that hasten channel development (Crispin, House, and Roberts 1993; Schlosser 1991).

Large woody debris (LWD) in the stream channel creates new plunge and scour pools, while maintaining the depth and hiding cover of existing pools (Gowan and Fausch 1996;

House and Boehne 1986). Large woody debris also forces the stream to meander, which dissipates water energy, trapping and recruiting gravel used for spawning (House and Boehne 1986). Additionally, meanders recruit LWD by undercutting banks and causing trees to tip over into the stream channel (House and Boehne 1986).

Land use activities such as grazing, agriculture, and forestry may degrade habitat by decreasing the amount of woody debris entering the stream and increasing the input of sediment (Schlosser 1991). Less debris and more sediment from erosion reduces stream complexity, resulting in a physically homogeneous habitat that negatively affects steelhead populations (Schlosser 1991).

Habitat restoration to increase stream channel complexity and fish production is an idea that has developed over time (Nickelson et al. 1992). The deliberate placement of LWD to form instream habitat enhancement structures is a salmonid restoration method found in scientific literature as far back as the 1930's (Ehlers 1956). Over the past three decades, the general use and acceptance of instream habitat enhancement techniques has grown, as is illustrated by the expanding amount of research dedicated to the effects of such techniques on fisheries habitat (Nickelson et al. 1992).

Despite an increased interest in salmonid habitat restoration, many such projects still receive little or no analysis of the final effects to the ecosystem (Frissell and Nawa 1992). Much of the available published research focuses on projects with positive effects on fishery habitat (Frissell and Nawa 1992). Frissell and Nawa (1992) found a majority of the projects reported were those considered “successful” in their results by the project principals. Studies show that adding LWD in the form of instream structures can increase the heterogeneity of stream channels and improve salmonid habitat (Binns 1994; Crispin, House, and Roberts 1993; Gowan and Fausch 1996; House and Boehne 1985, 1986;

Riley and Fausch 1995).

Ongoing evaluation of failures and successes is necessary to ensure programs are achieving economic and ecologic objectives (Frissell and Nawa 1992; Marcus, Noel, and Young 1990; McEwan and Jackson 1996). No general guidelines for evaluating stream restoration projects (or any restoration project, for that matter) are in use, despite a growing number of implementation activities (Kondolf and Micheli 1995). Generalized guidelines are needed to facilitate the systematic study of past, present, and future stream restoration projects (Kondolf and Micheli 1995). Since each stream restoration project addresses unique problems and strives for specific goals, a "detailed universally applicable procedure for post-project evaluation" is not practical (Kondolf and Micheli 1995). On the other hand, an effective field evaluation technique is necessary for identifying past restoration accomplishments and advancing the practice of stream restoration (Kondolf and Micheli 1995).

Restoration of degraded steelhead habitat may help to reverse past environmental damage. The family *Salmonidae*, which includes steelhead and salmon, is an important economic, cultural, and ecological resource (National Resource Council 1996). Improving watershed habitat for various salmonid species and life history stages may give populations a chance to increase. An evaluation process to distinguish both effective and ineffective restoration techniques will optimize future projects for success and help reverse anthropocentric impacts on the native landscape.

Generality. The recent legacy of humans in North America is mismanagement of native ecosystems that has caused the complete loss of many native biological resources (Bottom 1995). Pacific salmon represent an example of a group of species heavily impacted by humans. Atlantic salmon have been pushed to near extinction and populations of Pacific salmon are headed toward a similar fate (Bottom 1995). Nehlsen, Williams, and Lichatowich (1991) identified 214 native Pacific salmon stocks from California, Oregon, Washington, and Idaho that face a high to moderate risk of extinction. The decline of native stocks is a result of habitat loss and degradation, inadequate passage due to low water flows, overfishing and negative interactions with weaker hatchery stocks (National Research Council 1996; Nehlsen, Williams, and Lichatowich 1991). Prominent land use activities such as logging, agriculture, hydropower, road construction, grazing, and urbanization all contribute to these factors (Nehlsen, Williams, and Lichatowich 1991). Major changes are needed in the areas of land, water, and fisheries management if salmon resources are to persist (Nehlsen 1994; National Research Council 1996). In addition, a "new paradigm" that emphasizes habitat restoration and ecosystem function over hatchery production is necessary for Pacific salmon stocks to survive (Nehlsen, Williams, and Lichatowich 1991).

A significant amount of research has been conducted on restoring other animal and plant species' habitats (Berger 1990; Jordan, Gilpin, and Aber 1987; Kusler and Kentula 1990). The lessons learned from restoration projects of all kinds must be documented for habitat restoration to progress. A field tested evaluation process must be developed that can be applied to all restoration projects. Conclusions derived from such an evaluation program will provide restorationists with a guide for prioritizing future research.

Focus. The focus of this study is to evaluate instream habitat enhancement structures designed to improve steelhead habitat by: 1) determining the effects of restoration on steelhead pool and spawning habitat; 2) determining steelhead usage of enhanced and nearby unmodified habitat; 3) determining the current physical condition of the instream enhancement structures; 4) determining the streamflow events the instream structures have experienced.

Moore's Gulch is a small stream located in Santa Cruz County, California. A restoration project on Moore's Gulch employed instream enhancement structures to create steelhead spawning and rearing habitat. Santa Cruz County implemented a plan in the summer and fall of 1989 and installed nine instream log weirs in Moore's Gulch and a fish ladder at the confluence of Soquel Creek and Moore's Gulch (Hope 1989). A weir is a log dam designed to create pools for steelhead rearing habitat (Gore 1985). A local landowner then implemented a project in the fall and winter of 1993 that consisted of repairing the log weirs installed by the county of Santa Cruz and adding log deflectors to create steelhead spawning habitat (Gore 1985; Robert LaRosa, personal communication, November 1993).

This evaluation of both phases of the Moore's Gulch project was based upon a quantitative analysis of habitat in enhanced and natural unmodified areas, a quantitative analysis of the steelhead usage in modified and natural unmodified areas, a qualitative analysis of the current condition of the instream structures, and a quantitative analysis of the flow conditions the instream structures have experienced. Important physical characteristics and fisheries usage in restoration sites were compared to naturally occurring sites. Physical variables measured and compared were pool depth, instream cover, spawning area depth, and average channel substrate size.

This evaluation was limited by the lack of complete baseline data available for the restoration site. A 1981 study, conducted prior to any restoration activities, provided limiting factors to salmonid usage on 161 meters of Moore's Gulch starting at its confluence with Soquel Creek (Harvey and Stanley Associates 1982). No upstream habitat was examined. An unmodified reference site within Moore's Gulch was used as a control site. The control site allowed a comparison of salmonid use in altered and unaltered sites.

Related Research

An evaluation of instream structures designed to improve salmonid spawning and rearing habitat included field work and an examination of related research. The following discussion explores the important empirical research in this field, which focuses on salmonid habitat enhancement projects and methods used in evaluating these projects (Table 1).

Ehlers (1956) evaluated habitat enhancement structures placed in the East Fork of the Kaweah River, in the Sequoia National Forest, Tulare County, California at an elevation of approximately 2,400 meters. The physical condition of forty-one weirs and deflectors was examined eighteen years after their original installation. The study described the history of the devices and suggestions for "future work of this kind." The United States Forest Service implemented the project in 1935, but much of the baseline data collected in the first three years was no longer available. Evaluation of the project was therefore inferred from observed weaknesses in the remaining structures (Ehlers 1956). The original observations at the time of installation included pool depths above and below the structures, a discussion of maintenance needs, and general success of improvements. The original researchers opened the door for future evaluation when stating, "it may be some of the structures will do more harm than good, but only future surveys can recall how and why they are harmful." Ehlers (1956) found that only fifteen pools remained of sixty-seven that were expected to develop as a result of the installation of the structures. Ten of the forty-one structures still performed their original function of creating pool or gravel areas.

Gard (1961) evaluated a stream restoration project designed to create suitable juvenile brook trout (*Salvelinus fontinalis*) habitat in Upper Sagehen Creek, located in the northeastern Sierra Nevada Mountains at an elevation of approximately 7,400 feet. The section of Sagehen Creek modified in the project contained no trout prior to the project. Three types of weirs (log, rock, and stick/sod) were installed as part of the study. Conducted over a four year period, Gard examined sites for physical condition of the structures, critical dimensions of pool habitat created (depth, width, length and area) and trout size and usage. The study found that with maintenance, weirs provide greater amounts of aquatic habitat, hiding shelter, bottom organisms, and trout usage than would normally be found (Gard 1961). The author concluded that accompanied by the introduction of wild fish, small dams are a feasible means of establishing trout populations.

Hunt (1976) evaluated a project in Lawrence Creek, Wisconsin, intended to narrow and deepen the stream channel, improve channel sinuosity, and increase pool area and overhanging cover for brook trout. The improvements depended on deflectors and bank cover devices used to create escape cover for fish. The report expanded earlier findings of Hunt, who found that his previous evaluations of the same site may have ended prematurely. Hunt (1976) found a positive population response to habitat improvement measures, but the response varied depending on the amount of time between implementation and evaluation. The author concluded post-project evaluation of trout habitat enhancement structures should be delayed during a three to seven year transition period as a means of obtaining more valid results. The transition period allows for ecological adjustments to occur and stabilize in the modified habitat.

Maughan and Nelson (1980) examined log dams, rock-filled gabions, and boulder emplacements in four Virginia trout streams. The study compared physical stream characteristics, aquatic macro-invertebrate populations, and fish populations in enhanced and untreated sections. The researchers found the structures improved pool area and could be used where pool habitat is limited. However, they also found that many of the structures washed out in high flows.

House and Boehne (1985) evaluated rock and log weirs in East Fork Lobster Creek, Oregon, by analyzing the stability of structures, changes in stream width, depth, gravel condition, adult salmonid utilization, and juvenile density due to enhancement. After two years, the study found major changes in the physical condition of salmonid habitat associated with wire gabion weirs and boulder groupings. Steelhead, coho salmon (*Oncorhynchus kisutch*), and cutthroat trout (*Oncorhynchus clarki*) use of created rearing areas rose significantly over the two year period that followed. Steelhead, coho salmon, and cutthroat trout use of created spawning areas also rose over the two year period that followed, although House and Boehne (1985) did not prove this statistically. The study included management considerations gained from experience in this project. The guidelines cover pre-construction, site selection, logistics, and construction that the authors felt should be considered before beginning stream restoration activities. Post-project evaluation was not included in the guidelines.

House and Boehne (1986) studied a stream logged twenty years before enhancement with gabion weirs and compared physical and biological characteristics to an unlogged area. The logged site in Tobe Creek, Oregon was observed before and after the enhancement. The evaluation found that the most important factor controlling the physical parameters of the stream was LWD. Before the enhancement of the site, steelhead, coho salmon, and cutthroat trout biomass was greater in the unlogged section; after enhancement no significant difference was found between logged and unlogged areas.

Knudsen and Dilley (1987) examined salmonid populations in five pairs of stream sections shortly before and after flood and erosion control projects in western Washington state. The study used upstream areas away from the projects as control sections. The objective of the project was to determine if a stream's carrying capacity for juvenile salmonids was reduced after flood control activities. Steelhead and coho salmon young-of-the-year numbers were significantly reduced in the smaller streams, while yearling steelhead and cutthroat trout increased.

Klassen and Northcote (1988) evaluated the effects of gabion weirs in Sachs Creek, Queen Charlotte Islands, British Columbia on pink salmon (*Oncorhynchus gorbuscha*). Their objective was to examine egg survival in comparison to dissolved oxygen and permeability in stream gravel affected by the gabion weirs. The study found that gabion weirs can restore the intragravel environment of damaged streams within one year. No monitoring was conducted after the first year.

Frissell and Nawa (1992) examined the incidence and causes of physical failure of instream structures in selected streams in Washington and Oregon. The restoration structures in the selected projects experienced floods with a two to ten year recurrence interval within the first year after construction. Affirming the structures had been through such flows allowed an evaluation of how well the projects might be expected to survive over their life span. The survey found that the incidence of impairment and failure varied among streams, but was quite high in some cases. Despite high failure and damage rates and a lack of demonstrated biological success, Frissell and Nawa (1992) found that a "cookbook" approach dominated stream restoration planning and analysis. Such an approach assumes all degraded streams found in a particular region have the same ecological problems that can be solved using one standard method. They concluded that most ecological problems were not solved so easily. The problems are the result of complex physical and biological interactions that may be solved best through watershed-level contextual planning and analysis.

Nickelson et al. (1992) evaluated the effectiveness of pools created by log and rock weirs on juvenile coho salmon populations in coastal Oregon streams. Their objectives were to examine the types of habitat created by various habitat structures, determine the effectiveness of the created habitat to support summer and winter populations of coho salmon, and compare coho usage of natural and constructed areas. The authors note that most evaluations of habitat structures in the Pacific Northwest concentrate on summer habitat of salmonids; winter habitat is rarely considered. In the summer, newly created plunge pool habitats had juvenile density similar to natural pool habitats. However, the same pools in winter were poor habitat for juvenile coho. Dammed pools were found to support the highest density of juvenile coho in winter. Since many artificial dammed pools fill in naturally over time, the authors suggested that a design that will maintain depth be used to create winter habitat for juvenile coho. A final suggestion was that winter habitat was limiting and targeting that habitat was necessary to increase juvenile coho production.

Crispin et al. (1993) examined changes in instream pool habitat resulting from the placement of two hundred log weirs and deflectors in Elk Creek, a coastal Oregon stream. The instream structures were designed to enhance pool, off channel, and riffle habitat to increase winter rearing habitat for coho salmon. They examined physical characteristics of the stream channel before and after the restoration measures. The goal was to determine if stream conditions for coho salmon were improved after the physical changes. Winter rearing habitat improved after the restoration activities. Despite the creation of favorable habitat conditions, the authors suggested a better long-term method of habitat improvement is the creation and retention of riparian habitat to assure a constant source of LWD.

Binns (1994) and Binns and Remmick (1994) used the long-term response of brook trout and cutthroat trout to evaluate weirs installed in Beaver Creek and Huff Creek, two

Wyoming streams. The studies examined fish populations, habitat characteristics, and physical conditions of structures at the time of implementation and several years later. Long-term evaluations allowed the fish populations and habitat changes to stabilize over time. Both studies saw an overall increase in salmonid populations and habitat improvement.

Riley and Fausch (1995) and Gowan and Fausch (1996) evaluated the effects of log weirs on physical habitat and trout populations and biomass in high elevation streams in northern Colorado. Experiments measured changes in trout abundance and biomass in relation to habitat changes. The studies found that pool volume, amount of cover, depth, trout abundance, and trout biomass significantly increased in manipulated sections of stream.

Table 1.--Summary of studies of habitat improvement structures for increasing salmonid populations.

Author(s) and date	Location	Species	Structure type(s)	Evaluation methods	Result(s)
Ehlers 1956	Kaweah River, Tulare County, California	Oncorhynchus spp.	Weirs and deflectors	Examined physical condition of structures.	Ten of 41 structures still perform original function.
Gard 1961	Upper Sagehen Creek, northeastern Sierra Nevada Mountains	Brook trout	Log, rock and stick/sod weirs	Examined physical condition of structures, dimensions of created pool habitat and trout size and usage.	Weirs provide better habitat and greater trout usage than would normally be found.
Hunt 1976	Lawrence Creek, Wisconsin	Brook trout	Deflectors and bankcover devices	Examined population response to improvement measures.	Found positive population response to structures. Suggested evaluation be delayed to allow habitat to stablize.
Maughan and Nelson 1980	Four Virgina trout streams	Oncorhynchus spp.	Log dams, rock filled gabions and boulder emplacements	Compared physical stream characteristics, macroinvertebrate and fish populations in treated and untreated sections.	Structures improve pool areas.
House and Boehne 1985	East Fork Lobster Creek, Oregon	Steelhead trout, coho salmon and cutthroat trout	Wire gabions weirs and boulder groupings	Analyzed stability of structures, changes in stream dimension, changes in fish utilization and juvenile density.	Major changes in physical habitat, increase in usage of spawning and rearing areas.
House and Boehne 1986	Tobe Creek, Oregon	Steelhead trout, coho salmon and cutthroat trout	Wire gabion weirs	Compared physical and biological characteristics of unlogged to logged areas.	No significant difference between logged and unlogged areas.

Table 1 (continued).--Summary of studies of habitat improvement structures for increasing salmonid populations.

Author(s) and date	**Location**	**Species**	**Structure type(s)**	**Evaluation methods**	**Result(s)**
Frissell and Nawa 1992	Streams in Washington and Oregon	Chinook salmon, steelhead, cutthroat trout and brook trout	Various structures	Examined the incidence and causes of physical failure of instream structures.	Found incidence of impairment and failure could be quite high in some cases.
Nickelson et al. 1992	Coastal Oregon streams	Coho salmon	Various structures	Examined created habitat and compared coho usage in natural and contructed areas.	Plunge pools are good summer but poor winter habitat for juvenile coho. Dammed pools are preferred winter habitat.
Crispin et al. 1993	Elk Creek, Oregon	Coho salmon	Log weirs and deflectors	Examined physical characteritics before and after restoration.	Winter rearing habitat improved after restoration activities.
Binns 1994; Binns and Remmick 1994	Beaver Creek and Huff Creek, Wyoming	Brook trout and cutthroat trout	Log weirs	Examined fish populations, habitat characteristics and physical condition of structures.	Increase in salmonid populations and improved habitat.
Riley and Fausch 1995; Gowan and Fausch 1996	High elevation streams in northern Colorado	Brook trout, Brown trout, cutthroat trout and rainbow trout	Log weirs	Examined physical habitat and trout abundance and biomass.	Found trout abundance and trout biomass significantly increased in manipulated sections of stream.

The decline of Pacific salmon stocks in California, Oregon, Idaho, and Washington is a concern to fisheries biologists and the public. Nehlsen, Williams, and Lichatowich (1991) provided a list of 214 Pacific salmon, including steelhead and cutthroat trout, that "appear to be facing a high or moderate risk of extinction or are of special concern." At the time, only one of these fish, Sacramento River winter run Chinook salmon (*Oncorhynchus tsawytscha*), was protected under the Federal Endangered Species Act. Since then, Southern Coho salmon (south of Cape Mendocino, California) have been listed as threatened, and other California coho and steelhead populations have been proposed for listing (National Oceanic and Atmospheric Administration 1996). A follow-up article (Nehlsen 1994) confirmed earlier findings and identified 106 already extinct populations of Pacific salmonids.

Moyle (1994) explored the decline of anadromous fishes in California. He concluded "the fact that all of these populations are in decline indicates that large scale environmental changes are taking place, especially in river systems" (Moyle 1994). Habitat degradation is a major factor contributing to the decline of native salmonid stocks (Nehlsen 1994; Nehlsen, Williams, and Lichatowich 1991; Moyle 1994). One method suggested to slow the decline of native fish species was habitat restoration (Nehlsen, Williams, and Lichatowich 1991). Current management techniques, such as hatchery operations, have not been effective in controlling population loss (Nehlsen et al. 1994). Nehlsen, Williams, and Lichatowich (1994) believe a new paradigm that advances habitat restoration and ecosystem function rather than hatchery production is needed for many of these stocks to survive and prosper into the next century.

Restoration must address the specific habitat needs of the target species. Steelhead, which declined in numbers during the 1960's and 1970's, but have stabilized since, require a physically heterogeneous habitat to support various life history stages (Alley 1997; Fry 1979; Schlosser 1991). Varying levels of water depth and velocity, escape cover, and substrate types are required to maintain adult, juvenile, and hatchling fish (McGinnis 1984). Historically, the diverse habitat required for salmonids, including steelhead, was maintained through the input of LWD into the stream (Crispin, House, and Roberts 1993). The large pieces of debris influence water velocity to create ideal channel conditions. LWD forms obstructions that decrease overall water velocity, promoting the formation of pools, and trapping important gravel (Crispin, House, and Roberts 1993). Juvenile fish use pools as rearing habitat and adult fish use gravel for spawning and incubation of eggs and hatchlings (Crispin, House, and Roberts 1993). Modern land use activities disrupt the input of LWD into stream channels (Nehlsen, Williams, and Lichatowich 1991; Crispin, House, and Roberts 1993).

One method of restoring steelhead habitat is the deliberate placement of LWD. LWD is used to form instream enhancement structures. Weirs, dams placed in the stream to create pools for juvenile steelhead rearing habitat, and deflectors, devices that influence flow to recruit spawning gravel, are two common types of instream enhancement structures (Figures 2 through 6). The use of such enhancement devices has risen over the past 30 years (Nickelson et al. 1992). The scientific literature presents many accounts of successful implementation, but few instances of failure (Frissell and Nawa 1992). The lack of reporting on failed projects points to the need for an effective evaluation process that renders failures and successes equally important in advancing the practice of salmonid restoration.

Kondolf (1995) described five elements necessary for effective evaluation of stream restoration projects. The elements provide a framework for specific techniques outlined in

Kondolf and Micheli (1995). Effective evaluation of a stream restoration project should include clear objectives, baseline data, good study design, long term commitment and acknowledgement of failures (Kondolf 1995). Kondolf and Micheli (1995) believed evaluation must center on both physical and biological variables. Important physical variables to evaluate salmonid restoration projects are channel types, habitat types, channel depth, channel width, percent instream cover, channel substrate size, instream enhancement structure condition, and streamflow history. Important biological variables include salmonid growth, salmonid density, and salmonid age class distribution. Kondolf and Micheli (1995) also stressed the importance of identifying and addressing the factors limiting salmonid populations.

Study Site

Moore's Gulch (Figure 1) was a four kilometer long tributary to Soquel Creek, the main waterway of the 104 square kilometer Soquel Creek watershed that drained directly into the Monterey Bay (Singer and Swanson 1983). The 4.4 square kilometer Moore's Gulch watershed supported steelhead, but the population was believed to be impacted by high sediment loads in the stream (Hope 1989). The restoration project on Moore's Gulch was designed to enhance salmonid spawning and rearing areas by increasing woody debris to reduce the sediment deposition.

The restoration project on Moore's Gulch occurred in two phases. The Santa Cruz County Planning Office planned the first phase in the spring of 1989. The objective was to re-establish the historic runs of steelhead trout in Moore's Gulch (Hope 1989). Implemented in the summer and fall of 1989, the project consisted of nine instream log weirs, a fish ladder at the confluence of Soquel Creek and Moore's Gulch, the removal of a concrete dam, and the installation of baffles to decrease water velocity in several corrugated metal culverts (Hope 1989). The fish ladder, dam removal, and baffles improved fish passage in Moore's Gulch. The log weirs created and improved pool habitat for steelhead. Pool habitat was believed to be a limiting factor to steelhead survival on Moore's Gulch (Hope 1989).

A Moore's Gulch landowner planned the second phase of the project in the summer of 1993 (Robert LaRosa, personal communication, November 1993). Seven of the nine log weirs installed in Moore's Gulch by Santa Cruz County in 1989 bordered the landowner's property at 1000 Laurel Glen Road. The second phase consisted of repairing and modifying these seven existing log weirs and adding twelve log deflectors to enhance

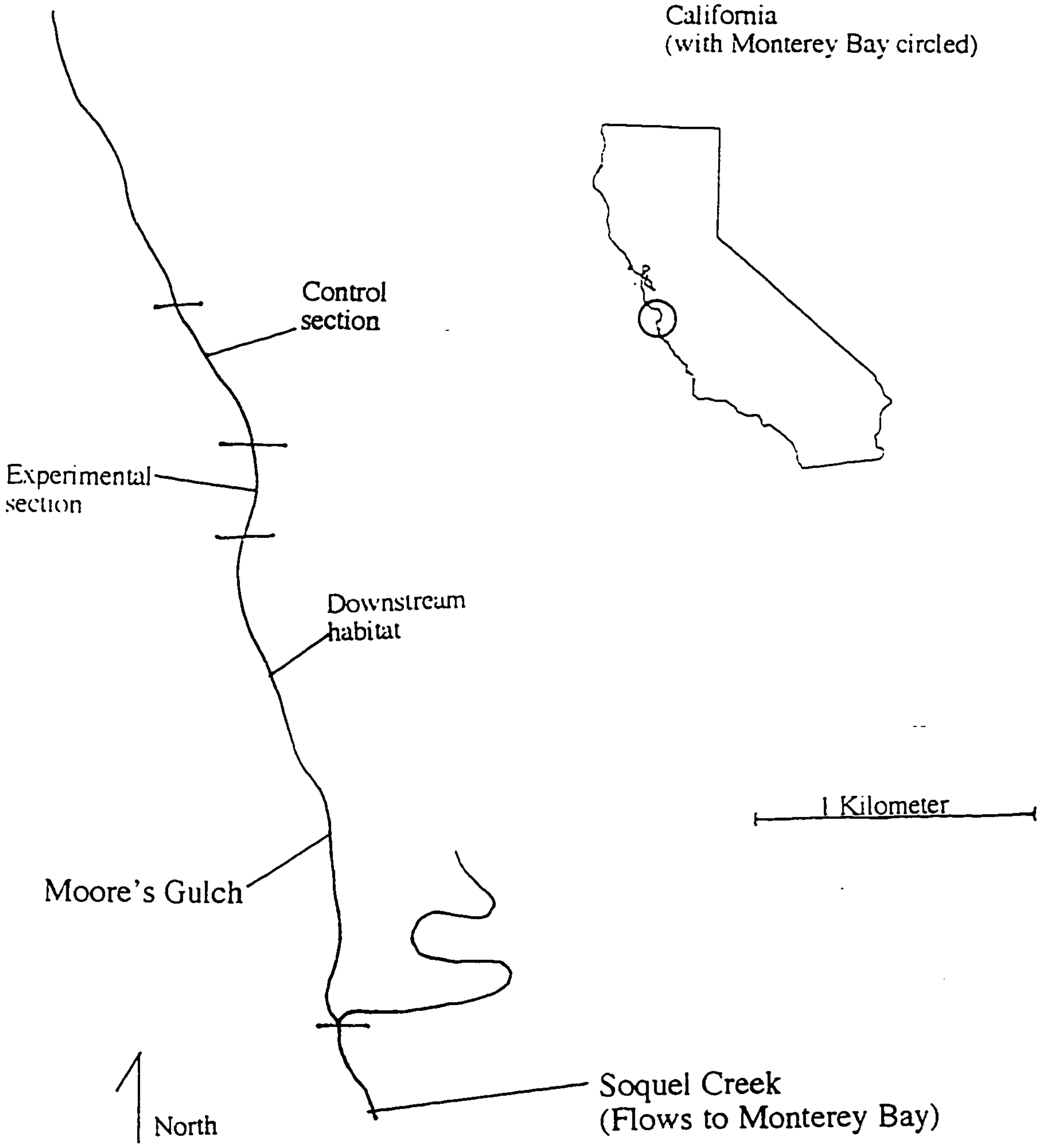


Figure 1.--Map of Moore's Gulch, Santa Cruz County, California.

spawning areas in the same section of stream. The repairs to the log weirs attempted to reverse existing damage. The weirs were modified to increase water flow over the structures. The second phase was implemented in the fall and winter of 1993. The success of this two phase restoration project had not been evaluated.

The evaluation undertaken on this thesis focused on the portion of stream that bordered 1000 Laurel Glen Road. This section, the most heavily modified by the project planners, was compared to a control section also located on Moore's Gulch. The seven log weirs in the section were made up of three straight log weirs (Figure 2), one diagonal log weir (Figure 3), two downstream-V log weirs (Figure 4), and one upstream-V log weir (Figure 5). The twelve log deflectors consisted of nine log wing deflector (Figure 6) and three double log chute deflectors.

The portion of stream surveyed in this evaluation extended upstream 3.4 kilometers from the confluence of Soquel Creek and Moore's Gulch (Figure 1). After the survey, the stream was divided into three units based on channel type and structure location. The first unit began at the confluence of Soquel Creek and ended 2,027 meters upstream at a culvert that runs under Laurel Glen Road, which crosses to the east side of Moore's Gulch at that point. This section was designated as downstream habitat. The second unit began at the culvert and ran 468 meters upstream to a bridge at 1440 Laurel Glen Road. This section was referred to as the experimental section, as it contained the instream habitat structures that are being evaluated for this study. The weirs and deflectors were numbered in an upstream direction. The third unit began at the bridge at 1440 Laurel Glen Road and extended upstream 856 meters to the intersection of Twin Lanes Road and Moore's Gulch. This unit served as the control section and contained similar channel types as the experimental unit.

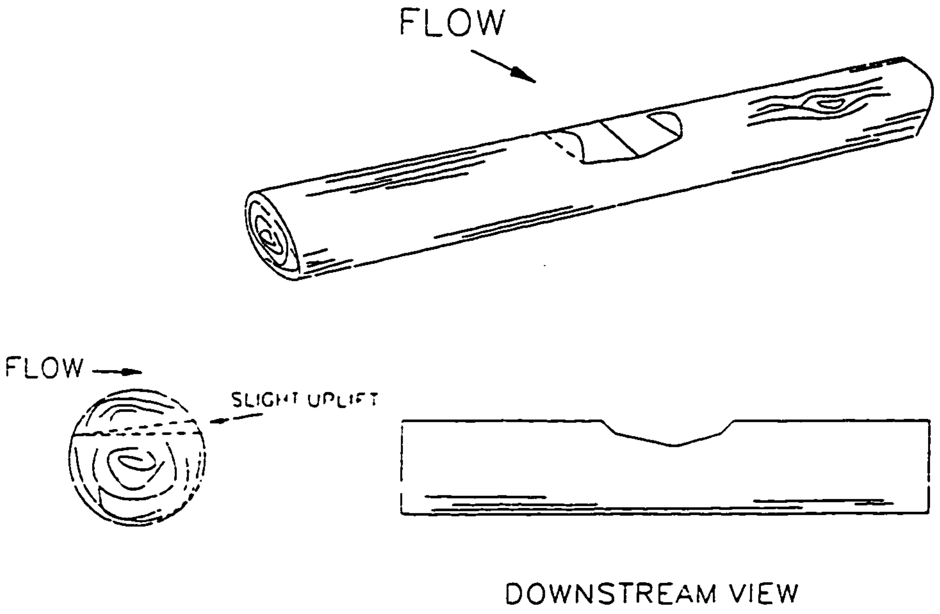


Figure 2.--Drawing of a straight log weir. Water flows over the log and creates a pool on the downstream side of the weir. Arrows indicate direction of flow over the log, which is held in place at each end by boulders (Taken from Flosi and Reynolds 1994).

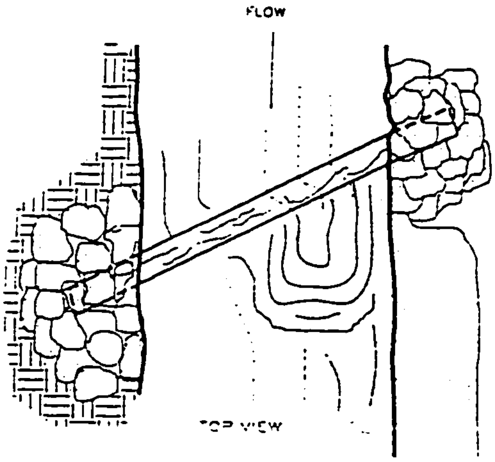


Figure 3.--Drawing of a diagonal log weir. Water flows over the log and creates a pool on the downstream side of the weir. Arrows indicate direction of flow over the log, which is held in place at each end by boulders (Taken from Flosi and Reynolds 1994).

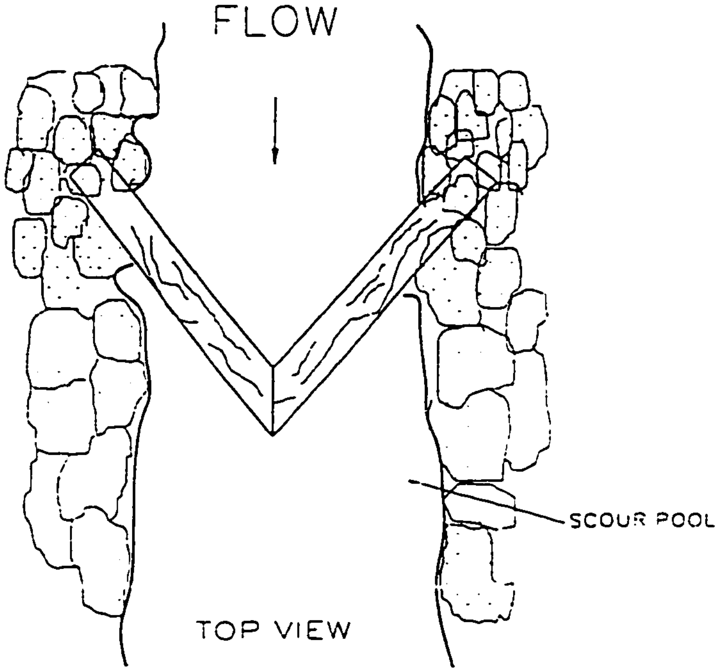


Figure 4.--Drawing of a downstream-V log weir. Water flows over the apex of the logs and creates a pool on the downstream side. Arrows indicate direction of flow over the log, which is held in place at each end by boulders (Taken from Flosi and Reynolds 1994).

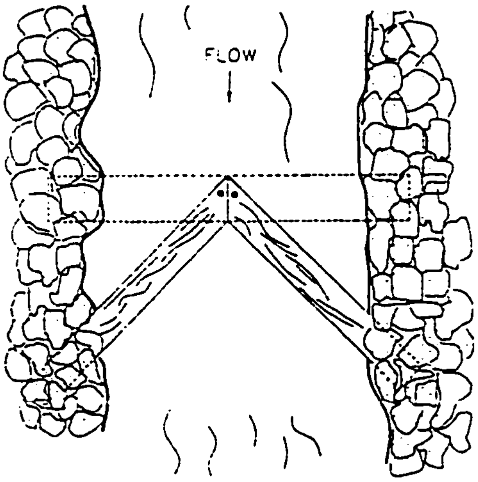


Figure 5.--Drawing of an upstream-V log weir. Water flows over the apex of the logs and creates a pool on the downstream side. Arrows indicate direction of flow over the log, which is held in place at each end by boulders (Taken from Flosi and Reynolds 1994).

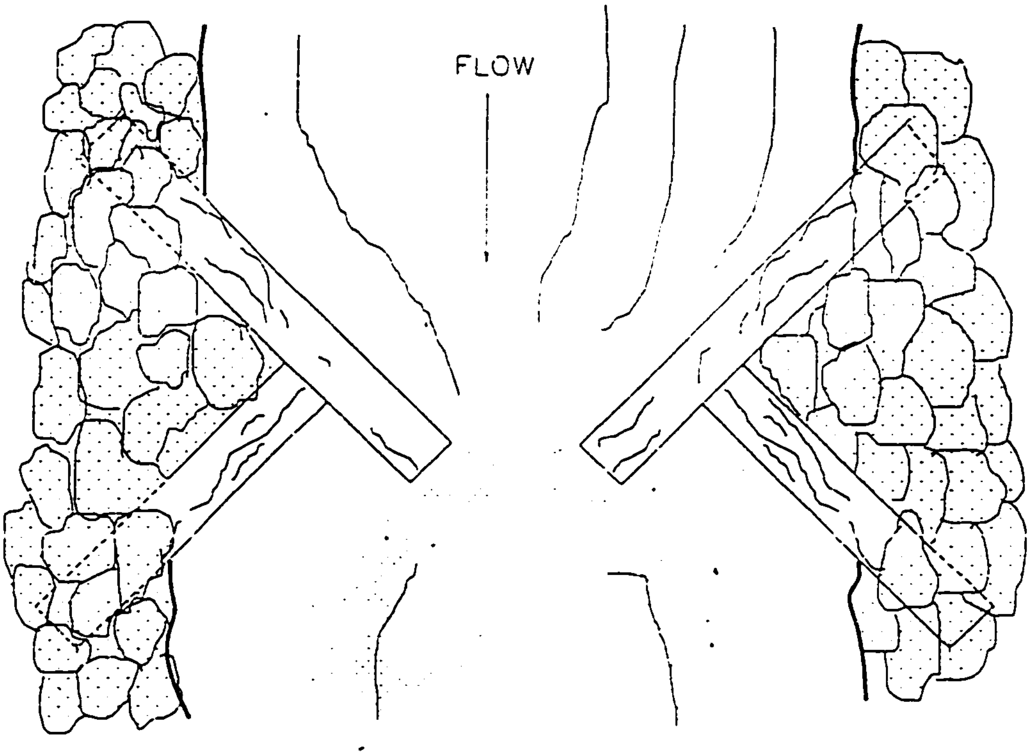


Figure 6.--Drawing of a log wing deflector filled with boulders. This double deflector has structures on both stream banks. Arrows indicate direction of flow (Taken from Flosi and Reynolds 1994).

Objectives

The data collection in this study determined the following:

- The channel types and percent composition of habitat types within Moore's Gulch.
- The number of steelhead using enhanced and naturally occurring habitat.
- The streamflow conditions the instream structures have experienced.
- The condition of instream structures used to enhance salmonid spawning and rearing habitat.

The data collection in this study supported or rejected the following null hypotheses:

- H_o: Average depth and percentage of instream cover does not differ significantly between control section pools and experimental section pools in Moore's Gulch.
- H_o: Average depth and average channel substrate size does not differ significantly between control section riffle/flatwater areas and experimental section riffle/flatwater areas in Moore's Gulch.
- H_o: Steelhead density does not differ significantly between control and experimental section pools, and control and experimental section riffle/flatwater areas in Moore's Gulch.

Methods

The habitat inventory was composed of stream channel classification and habitat typing. The stream channel classification used was developed by Rosgen (Flosi and Reynolds 1994; Figure 7). Five characteristics were measured to determine the stream type of Moore's Gulch according to the Rosgen method:

- 1) general description: general description of the channel geology, gradient,bank stability and pool or riffle occurrence;
- 2) entrenchment: the ratio between flood prone width and bankfull width. Flood prone width is the flat lowland that borders a stream and is covered by its waters at a flood stage with thalweg depth two times the bankfull depth. Bankfull width is the stream width at bankfull discharge (measured using a stadia rod and fiberglass tape);
- 3) dominant particle size of stream channel materials: the most common particle found on the bed of the stream;
- 4) width/depth ratio: the ratio of the bankfull width and the average depth at bankfull width; 5) water slope/gradient: the slope of the water surface at bankfull (using a clinometer);
- 6) sinuosity: the ratio of stream length to valley length (measured by consulting a topographic map).

Stream channels were classified from the mouth of Moore's Gulch and upstream 3.4 km to the intersection of Moore's Gulch and Twin Lanes Road. The Rosgen stream channel classification described the general physical characteristics of relatively long reaches within a stream, but lacked the resolution to describe small habitat units.

Habitat typing produced a more detailed description of the physical fish habitat (Flosi and Reynolds 1994; Figure 8). The habitat types are based on a hierarchical system

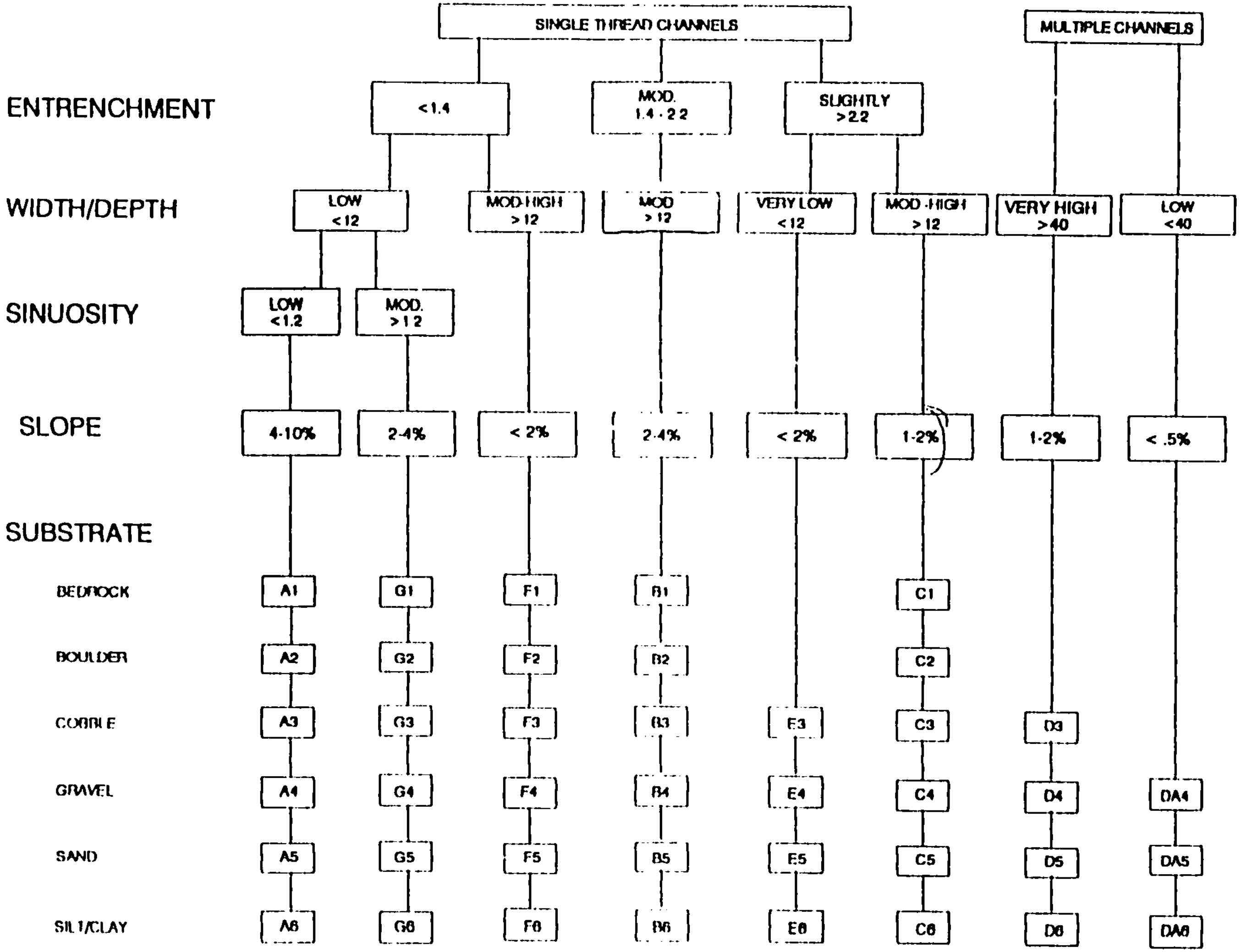
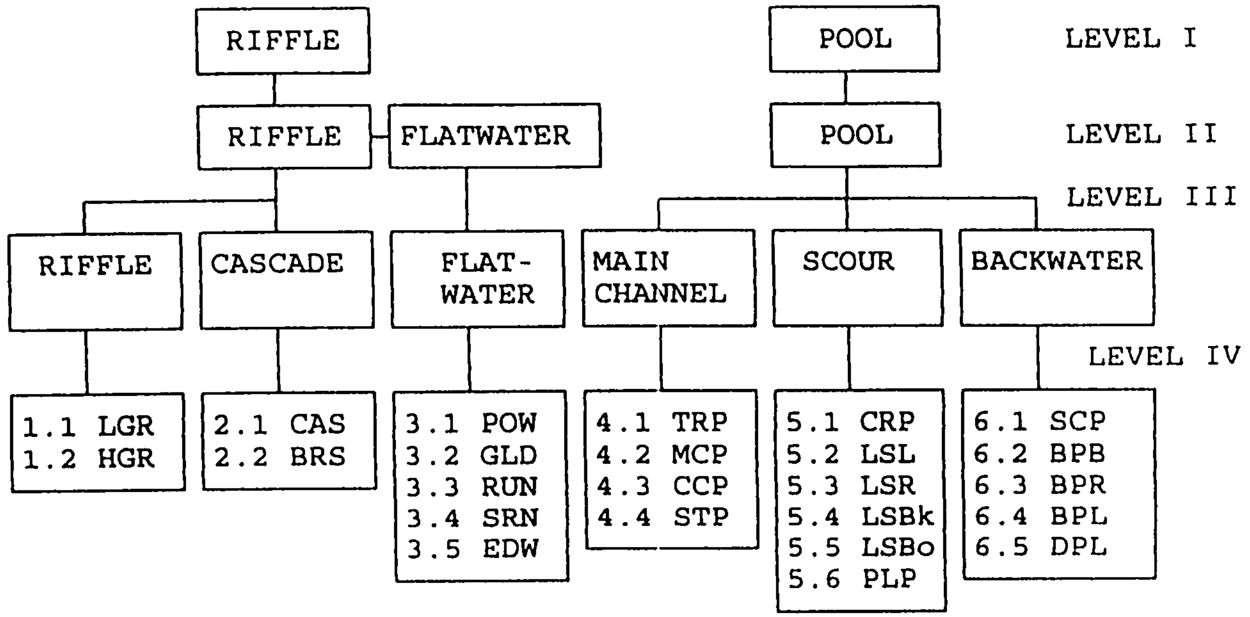


Figure 7.--Stream channel classifications developed by Rosgen (Taken from Flosi and Reynolds 1994).



RIFFLE
Low Gradient Riffle (LGR)
High Gradient Riffle (HGR)
CASCADE
Cascade (CAS)
Bedrock Sheet (BRS)
FLATWATER
Pocket Water (POW)
Glide (GLD)
Run (RUN)
Step Run (SRN)
Edgewater (EDW)

MAIN CHANNEL POOLS
Trench Pool (TRP)
Mid-Channel Pool (MCP)
Channel Confluence Pool (CCP)
Step Pool (STP)
SCOUR POOLS
Corner Pool (CRP)
Lateral Scour Pool -Log Enhanced (LSL)
Lateral Scour Pool -Root Wad Enhanced (LSR)
Lateral Scour Pool -Bedrock Form (LSBK)
Lateral Scour Pool-Boulder Formed (LSBO)
Plunge Pool (PLP)

BACKWATER POOLS
Secondary Channel Pool (SCP)
Backwater Pool - Boulder Formed (BPB)
Backwater Pool - Root Wad Form (BPR)
Backwater Pool - Log Formed (BPL)
Dammed Pool (DPL)

Figure 8.--Habitat types hierarchy (Taken from Flosi and Reynolds 1994).

separating pools and riffle areas according to location, orientation, and waterflow (Flosi and Reynolds 1994).

Habitats were also classified from the mouth of Moore's Gulch upstream to the intersection of Moore's Gulch and Twin Lanes Road. Four levels of classification were used to describe salmonid habitat in Moore's Gulch. Each level provided a more detailed description of the same habitat unit. The hierarchy starts at level one by dividing areas into riffles or pools and progresses to level four, which identifies twenty four distinct habitat types (Figure 8). The length of each habitat unit and upstream sequence of habitat types were recorded. The habitat inventory identified dominant habitat types within stream reaches and detected the presence or absence of habitat types that may limit salmonid populations.

A transect was used to measure the physical characteristics of pools and riffle areas. Pool depth and percent instream cover, and riffle area depth, and channel substrate were measured. At each enhanced and natural pool and riffle, widths were measured to the nearest centimeter with a fiberglass open reel tape. At one meter intervals along the tape, depths to the nearest centimeter were measured. All measurements were repeated at two mean stream width intervals, working upstream until the entire habitat was measured (Simonson, Lyons, and Kanehl 1994). At each pool, the area of a pool occupied by instream cover was estimated from visual observation. At each riffle area, randomly chosen instream particles were categorized as boulder, cobble (small and large), gravel, sand or silt/clay according to diameter at one meter intervals along the tape (Flosi and Reynolds 1994). A student's t-test was used to detect significant differences in depth and percent instream cover in pools, and average depth and substrate size in riffle/flatwater areas.

Data from United States Geological Survey stream gauge #11160000 on Soquel Creek was used to estimate flow conditions on Moore's Gulch from 1993 to present (United States Geological Survey 1996). The magnitudes of flows on Soquel Creek were plotted against the frequency of occurrence of those flows to produce a flood-frequency curve. The values were plotted on Pearson Type III distribution paper to obtain a straight line (Leopold 1994). Recurrence intervals can be estimated from this plot. The recurrence interval is the average interval of time in which a flood of given magnitude will be equaled or exceeded once (Leopold 1994).

The instantaneous flow values for the winters of 1994-1995, 1995-1996, and 1996-1997 were then plotted for Soquel Creek. The streamflow history of Soquel Creek was then compared to the flows at known recurrence intervals. The streamflow history of Moore's Gulch was then estimated. Flows on Moore's Gulch were not assumed equal to Soquel Creek, but if a large event occurred on Soquel Creek, it was assumed Moore's Gulch experienced an event of similar recurrence.

The stability of the instream structures was evaluated using a combination of two methods. This study used the Binns (1994) method to assign points and the terminology from Frissell and Nawa (1992) to classify structures. Binns (1994) used a point system to evaluate the condition of weirs and deflectors. The condition of each was evaluated in five categories, each being worth three points. Points were assigned after careful examination of each structure. The categories to rate weir condition were: 1) ends covered with rocks; 2) weir sealed, not undercut; 3) all parts intact; 4) structure in proper position; 5) anchor rocks in original position. Categories to rate deflector condition were: 1) ends of logs buried; 2) rock fill intact; 3) structure functional; 4) structure deposits over; 5) structure intact. The Binns (1994) method rated weirs as in "good condition" (12 out of 15 points) or “bad condition,” according to points earned. A score of 7 or below was considered a “failure”; a score of 8 to 11 was considered “impaired”; a score of 12 or greater was considered “successful.” A damage rate (the proportion of failed and impaired structures) and a failure rate (the proportion of failed structures) was computed for the surveyed structures (Frissell and Nawa 1992).

Steelhead density in control and experimental sections was determined with a backpack electroshocker. Each habitat to be electrofished was blocked with mesh seines weighted at the bottom to ensure population closure (Riley and Fausch 1992). Each section was shocked in an upstream direction, with one person carrying the electroshocker, while another netted fish. Fish captured during each pass were retained in separate live baskets in the stream. Fish were counted and measured to total length to determine population estimates for separate year classes (Flosi and Reynolds 1994). Year classes were separated by length-frequency. Multiple passes were made at each site to allow for population estimates by regression (Ney 1993). Control and experimental sections also were sampled for steelhead density after storm events to determine if habitat preferences changed. A student’s t-test was used to detect significant differences in salmonid density in control and experimental pools and for salmonid density in control and experimental section riffle/flatwater areas.

RESULTS

Habitat Survey

Moore's Gulch channel types and habitat types were determined from August 6, 1996 to October 16, 1996 on the lower 3.4 kilometers of Moore's Gulch. The downstream habitat was made up of three A1 channels, one A2 channel, two A3 channels, one B1 channel, and one B3 channel (Table 2). The experimental section was made up of one B1 channel and two B5 channels (Table 2). The control section was comprised of three B1, two B3, and four B5 channels (Table 2).

Habitat types were tallied separately for all three sections. The downstream habitat consisted primarily of glide (39.8% of downstream habitat types; 44.7% of total downstream habitat length), step-run (22.4% of downstream habitat types; 28.3% of total downstream habitat length) and run (8.7% of downstream habitat types; 4.3% of total downstream habitat length), bedrock sheet (6.8% of downstream habitat types; 8.6% of total downstream habitat length) and plunge pool (5.0% of downstream habitat types; 1.8% of total downstream habitat length) (Table 3).

The experimental section consisted primarily of glide (35.7% of experimental section habitat types; 48.9% of total experimental section length), run (30.4% of experimental section habitat types; 27.7% of total experimental section length) and plunge pool (12.5% of experimental section habitat types; 7.0% of total experimental section length) (Table 4).

The control section consisted primarily of glide (33.3% of control section habitat types; 32.6% of total control section length), low gradient riffle (15.1% of control section habitat types; 6.3% of total control section length), lateral scour bedrock formed pools (12.7% of control section habitat types; 15.5% of total control section length), run (11.1% of control section habitat types; 15.1% of total control section length), and bedrock sheet (9.5% of control section habitat types; 8.3% of total control section length) (Table 5).

Table 2.--The channel types and lengths of channel types found in the Downstream, Experimental and Control sections (See Figure 7 for explanations of Rosgen channel types).

Habitat section	Rosgen channel type	Rosgen channel length (m)	Habitat section length (m)	Moore's Gulch cumulative length (m)
Downstream	A3	262.5	262.5	262.5
	A1	264.7	527.2	527.2
	B3	89.2	616.4	616.4
	A3	25.9	642.3	642.3
	A1	306.9	949.2	949.2
	A2	41.1	990.3	990.3
	A1	449.4	1,439.7	1,439.7
	B1	588.3	2,028.0	2,028.0
Experimental	B5	272.9	272.9	2,300.9
	B1	19.9	292.8	2,320.7
	B5	175.6	468.4	2,496.3
Control	B3	75.5	75.5	2,571.8
	B1	17.4	92.9	2,589.2
	B5	114.6	207.5	2,703.7
	B3	32.8	240.3	2,736.5
	B5	145.3	385.6	4,063.9
	B1	82.7	468.3	2,964.5
	B5	275.8	744.1	3,240.3
	B1	54.4	798.5	3,294.7
	B5	57.7	856.2	3,352.4

Table 3.--The percentage of each type of habitat unit and the percent of total length each habitat type occupied in the Downstream habitat.

Habitat unit type	**N**	**% of total**	**% of total length**
Riffle			
Bedrock sheet	11	6.8	8.6
Cascade	1	0.6	0.1
Low gradient riffle	9	5.6	2.2
Flatwater			
Glide	64	39.8	44.7
Run	14	8.7	4.3
Step run	36	22.7	28.3
Pool			
Lateral scour bedrock formed pool	6	3.8	2.3
Lateral scour boulder formed pool	1	0.6	0.4
Lateral scour log formed pool	1	0.6	0.2
Lateral scour rootwad formed pool	2	1.2	0.9
Mid-channel pool	3	1.9	1.2
Plunge pool	8	5.0	1.8
Step pool	5	3.1	5.0

Table 4.--The percentage of each type of habitat unit and the percent of total length each habitat type occupied in the Experimental section.

Habitat unit type	**N**	**% of total**	**% of total length**
Riffle			
Bedrock sheet	1	1.8	0.8
Flatwater			
Run	17	30.4	27.7
Step run	3	5.4	5.1
Glide	20	35.7	48.9
Pool			
Corner pool	1	1.8	0.8
Lateral scour bedrock formed pool	1	1.8	3.7
Lateral scour boulder formed pool	1	1.8	0.3
Lateral scour log formed pool	2	3.6	1.6
Lateral scour rootwad formed pool	2	3.6	2.3
Mid-channel pool	1	1.8	1.9
Plunge pool	7	12.5	7.0

Table 5.--The percentage of each type of habitat unit and the percent of total length each habitat type occupied in the Control section.

Habitat unit type	**N**	**% of total**	**% of total length**
Riffle			
Bedrock sheet	12	9.5	8.3
Low gradient riffle	19	15.1	6.3
Flatwater			
Edgewater	1	0.8	1.0
Glide	42	33.3	32.6
Run	14	11.1	15.1
Step run	6	4.8	9.5
Pool			
Backwater pool boulder formed	2	1.6	0.9
Backwater pool log formed	2	1.6	4.9
Backwater pool rootwad formed	1	0.8	0.2
Lateral scour bedrock formed pool	16	12.7	15.5
Lateral scour boulder formed pool	1	0.8	0.2
Lateral scour log formed pool	1	0.8	0.6
Lateral scour rootwad formed pool	5	4.0	1.6
Mid-channel pool	4	3.1	3.2

Pool Characteristics

Pool types in the experimental section were corner pool, lateral scour bedrock formed pool, lateral scour boulder formed pool, lateral scour log formed pool, lateral scour rootwad formed pool, mid-channel pool, and plunge pool (Table 4). While control section pools were a mixture of backwater, corner, lateral scour, and mid-channel, but included no plunge pools (Table 5). No significant differences in mean depth or percent instream cover were found between control section and experimental section pools for any pool type or for all pools combined (Tables 6 and 7).

Table 6.--Pools compared for mean depth (cm) in Control and Experimental sections.

Pool types	Control section	Experimental section
Backwater pool boulder formed	32.0± 3.4	---
Backwater pool log formed	24.1± 6.2	---
Backwater pool rootwad formed	21.0± 0.0	---
Corner pool	---	19.5± 0.0
Lateral scour bedrock formed pool	27.8±11.7	23.7± 0.0
Lateral scour boulder formed pool	14.9± 0.0	13.7± 0.0
Lateral scour log formed pool	26.7± 0.0	22.5± 4.5
Lateral scour rootwad formed pool	28.9± 9.8	26.3± 5.6
Mid-channel pool	30.7±11.0	27.9± 0.0
Plunge pool	---	39.6±17.0
Total	27.1±10.6	30.6±14.6

--- Habitat type not found in this section.

Table 7.--Pools compared for percent instream cover in Control and Experimental sections.

Pool types	Control section	Experimental section
Backwater pool boulder formed	50.0±14.1	---
Backwater pool log formed	50.0±28.3	---
Backwater pool rootwad formed	60.0± 0.0	---
Corner pool	---	
Lateral scour bedrock formed pool	36.3±17.0	70.0± 0.0
Lateral scour boulder formed pool	25.0± 0.0	20.0± 0.0
Lateral scour log formed pool	80.0± 0.0	70.0±42.4
Lateral scour rootwad formed pool	34.0±16.4	55.0±35.4
Mid-channel pool	55.0±37.0	10.0± 0.0
Plunge pool	---	52.9±13.8
Total	40.6±22.1	52.0±24.0

--- Habitat type not found in this section.

Riffle/flatwater Characteristics

In control sections, riffle/flatwater areas consisted primarily of bedrock sheet, glide, low gradient riffle, run, and step run. Experimental section riffle/flatwater areas were primarily glide, run, and step run (Tables 4 and 5). No low gradient riffles were present in the experimental section. Overall, experimental riffle/flatwater habitats were significantly deeper than control riffle/flatwater habitats ($P = 0.0345$), because experimental section run habitats were significantly deeper ($P = 0.0038$; Table 8). Experimental habitats also had significantly smaller substrate size than control habitats ($P = 0.0415$; Table 9).

Table 8.--Riffle/flatwater habitats compared for mean depth (cm) in Control and Experimental sections.

Riffle/flatwater types	**Control section**	**Experimental section**
Bedrock sheet	6.7±2.9	7.1±0.0
Edgewater	6.4±0.0	---
Glide	12.5±4.9	12.6±5.7
Low gradient riffle	3.2±1.2	---
Run	5.3±1.7	* 8.8±3.9
Step run	5.4±0.7	5.8±1.3
Total	8.3±5.3	* 10.4±5.2

* Significant difference from control section riffle/flatwater areas (P <0.05).

--- Habitat type not found in this section.

Table 9.--Riffle/flatwater habitats compared for mean substrate size (cm) in Control and Experimental sections.

Riffle/flatwater types	**Control section**	**Experimental section**
Bedrock sheet	100.0± 0.0	100.0± 0.0
Edgewater	7.5± 0.0	---
Glide	2.6±15.4	0.3± 0.9
Low gradient riffle	2.9± 1.7	---
Run	8.2±26.5	3.2± 3.0
Step run	1.1± 1.4	1.3± 0.0
Total	15.9±35.4	* 4.0±15.6

* Significant difference from control section riffle/flatwater areas (P <0.05).

--- Habitat type not found in this section.

Steelhead Density

There was no significant difference in steelhead density between control and experimental section pools for any pool type or age group, except total steelhead density in lateral scour rootwad formed pools was significantly higher in the experimental section (P = 0.0367; Table 10). In the experimental section, the density of age 1+/2+steelhead in all pools was twice as great, and total steelhead was noticeably greater than the control section. However, due to a high variation in the density among habitats, the difference was not statistically significant.

No significant difference was found in steelhead density between control and experimental section riffle/flatwater areas for any riffle/flatwater type or age group (Table 11). In glides, runs, and for all riffle/flatwater areas, age 1+/2+ steelhead densities were eight times as great in the experimental section as in the control section. Overall steelhead density was two times as great. Although, as with pool densities, the differences were not statistically significant due to large variation in density of individual habitats.

In the control section, density of age 0+ steelhead was more than twice as great in pools as in riffle/ flatwater areas, and density of age 1+/2+steelhead was eighteen times as great in pools as in riffle/flatwater areas (Table 12). In the experimental section, density of age 0+ steelhead was twice as great in pools as in riffle/flatwater areas, and the density of age 1+/2+ steelhead was five times as great in pools as in riffle/flatwater areas. Significant differences in steelhead density were found in age 1+/2+ (P = 0.001) and total steelhead (P = 0.0339) between control section pools and riffle/flatwater areas and age 1+/2+ (P = 0.0023) and total steelhead (P = 0.0057) between experimental section pools and riffle/flatwater areas (Table 12).

Coho salmon were captured in four of the log weir created pools in the experimental section on Moore's Gulch. With coho density added, salmonid density in experimental section pools was almost twice as great as control section pools, but with a large variation, and almost four times greater than experimental section riffle/flatwater areas (Tables 13 and 14). Despite large habitat density variation, salmonid density was significantly greater in experimental section pools than in experimental section riffle/flatwater areas ($P = 0.0037$; Table 14).

After major storms, densities of both experimental and control section pools had declined, but those in the control section had declined more (Tables 10 and 15). No significant difference in steelhead density was found between control and experimental section pools for any pool type or age group, although experimental section pools had noticeably larger densities of age 0+, age 1+/2+, and total steelhead for all pools (Table 15). No significant difference in steelhead density was found between control and experimental section riffle/flatwater areas for any riffle/flatwater type or age group (Table 16). In experimental section pools, age 1+/2+ steelhead densities were eight times as great as experimental section riffle/flatwater areas (Table 17). A significant difference in steelhead density was found between experimental pools and riffle/flatwater areas in age 1+/2+ ($P = 0.0005$) and total steelhead density ($P = 0.0008$; Table 17). Experimental section pools had more than three times the salmonid density of control section pools. Due to high variation in habitat density, no significant difference in salmonid density was found between control and experimental pools (Table 18). Salmonid density in experimental section pools was five times as great as riffle/flatwater areas ($P = 0.0005$; Table 19).

Table 10.--Pools sampled and compared for steelhead density (N/100 ft) in Control and Experimental sections.

Pool types	Control section	Experimental section
Backwater pool log formed		
Age 0+	3.2± 0.0	---
Age 1+/2+	3.2± 0.0	---
Total	6.3± 0.0	---
Corner Pool		
Age 0+	---	16.9± 0.0
Age 1+/2+	---	8.5± 0.0
Total	---	25.4± 0.0
Lateral scour bedrock formed		
Age 0+	13.8±21.0	11.1± 0.0
Age 1+/2+	13.2± 9.5	11.1± 0.0
Total	27.1±28.8	22.2± 0.0
Lateral scour log formed		
Age 0+	---	8.5± 0.0
Age 1+/2+	---	16.9± 0.0
Total	---	25.4± 0.0
Lateral scour rootwad formed		
Age 0+	5.1± 0.0	8.7± 1.6
Age 1+/2+	10.2± 0.0	21.3± 2.3
Total	15.2± 0.0	* 30.0± 0.7
Mid-channel pool		
Age 0+	---	10.9± 0.0
Age 1+/2+	---	7.3± 0.0
Total	---	18.1± 0.0
Plunge pool		
Age 0+	---	11.0±17.9
Age 1+/2+	---	34.0±25.1
Total	---	45.0±38.7
All pools		
Age 0+	11.1±17.8	10.9±12.8
Age 1+/2+	11.3± 8.7	24.9±20.9
Total	22.4±24.9	35.9±29.4

* Significant difference from control section pools (P <0.05).

--- Habitat type not sampled in this section.

Table 11.--Riffle/flatwater areas sampled and compared for steelhead density (N/100 ft) in Control and Experimental sections.

Riffle/flatwater types	**Control section**	**Experimental section**
Glide		
Age 0+	4.3±4.0	4.8± 4.2
Age 1+/2+	1.3±2.8	7.4± 9.1
Total	5.6±5.5	12.2±11.6
Low gradient riffle		
Age 0+	0.0±0.0	---
Age 1+/2+	0.0±0.0	---
Total	0.0±0.0	---
Run		
Age 0+	5.2±7.7	7.3± 8.6
Age 1+/2+	0.0±0.0	3.2± 4.9
Total	5.2±7.7	10.6±13.3
Step run		
Age 0+	---	3.3± 4.6
Age 1+/2+	---	0.0± 0.0
Total	---	3.3± 4.6
All riffle/flatwater areas		
Age 0+	3.9±5.3	1.5± 2.3
Age 1+/2+	0.6±1.9	4.8± 7.3
Total	4.4±5.9	10.3±11.3

--- Habitat type not sampled in this section.

Table 12.--Steelhead density (N/100 ft) compared between pool and riffle/flatwater habitats in Control and Experimental sections.

Section	**Pool**	**Riffle/flatwater**
Control		
Age 0+	11.1±17.8	3.9± 5.3
Age 1+/2+	11.3± 8.7	* 0.6± 1.9
Total	22.4±24.9	* 4.5± 5.9
Experimental		
Age 0+	10.9±12.8	5.5± 5.9
Age 1+/2+	24.9±20.9	* 4.8± 7.3
Total	35.9±29.3	* 10.3±11.3

* Significant difference from control section ($P < 0.05$).

Table 13.--Salmonid density (N/100 ft) compared between all pools in the Control and Experimental sections.

Habitat type	**Control section**	**Experimental section**
Pools	22.4±25.0	41.4±34.5

Table 14.--Salmonid density (N/100 ft) compared between pool and riffle/flatwater habitats in Experimental section.

Section	**Pool**	**Riffle/flatwater**
Experimental	41.43±34.5	* 10.3±11.2

* Significant difference from pools (P <0.01).

Table 15.--Pools sampled and compared for steelhead density (N/100 ft) in Control and Experimental sections after storms.

Pool types	**Control section**	**Experimental section**
Lateral scour bedrock formed		
Age 0+	1.7±2.4	---
Age 1+/2+	8.4±7.0	---
Total	10.1±4.5	---
Lateral scour rootwad formed		
Age 0+	0.0±0.0	---
Age 1+/2+	19.8±0.0	---
Total	19.8±0.0	---
Plunge pool		
Age 0+	---	8.4±10.6
Age 1+/2+	---	27.5±16.5
Total	---	34.9±18.5
All pools		
Age 0+	1.2±2.0	8.4±10.6
Age 1+/2+	12.2±8.3	27.5±16.5
Total	13.4±6.5	34.9±18.5

--- Habitat type not sampled in this section.

Table 16.--Riffle/flatwater habitats sampled and compared for steelhead density (N/100 ft) in Control and Experimental sections after storms.

Riffle/flatwater types	**Control section**	**Experimental section**
Glide		
Age 0+	0.0± 0.0	5.9±3.9
Age 1+/2+	19.5±27.6	4.2±4.0
Total	19.5±27.6	10.1±6.5
Run		
Age 0+	2.6± 2.3	3.4±3.6
Age 1+/2+	0.0± 0.0	2.4±4.1
Total	2.5± 2.3	5.7±7.5
Step run		
Age 0+	0.0± 0.0	---
Age 1+/2+	0.0± 0.0	---
Total	0.0± 0.0	---
All riffle/flatwater areas		
Age 0+	1.5± 2.1	4.5±3.9
Age 1+/2+	7.8±17.5	3.2±3.8
Total	9.3±16.7	7.8±6.9

--- Habitat type not sampled in this section.

Table 17.--Steelhead density (N/100 ft) compared between pool and riffle/flatwater habitats in Control and Experimental sections after storms.

Section	**Pool**	**Riffle/flatwater**
Control		
Age 0+	1.2± 2.0	1.5± 2.1
Age 1+/2+	12.2± 8.3	7.8±17.5
Total	13.4± 6.5	9.3±16.7
Experimental		
Age 0+	8.4±10.6	4.5± 3.9
Age 1+/2+	27.5±16.5	* 3.2± 3.8
Total	34.9±18.5	* 7.8± 6.9

* Significant difference from pools ($P < 0.001$).

Table 18.--Salmonid density (N/100 ft) compared between all pools in the Control and Experimental sections after storms.

Habitat type	Control section	Experimental section
Pools	13.4±6.5	42.0±22.7

Table 19.--Salmonid density (N/100 ft) compared between pool and riffle/flatwater habitats in Experimental section.

Section	Pool	Riffle/flatwater
Experimental	42.0±22.7	* 7.8±6.9

* Significant difference from pools (P <0.001).

Streamflow History

Soquel Creek recurrence intervals were determined for various magnitudes of flows using United States Geological Survey Water Resources Data for Soquel Creek stream gauge #11160000 (Figure 9). A flood with a chance of occurring once every two years (a two year flood) has a magnitude of 1,790 cubic feet per second (cfs), a flood with a chance of occurring once every ten years (a ten year flood) has a magnitude of 4,320 cfs, and a flood with a chance of occurring once every fifty years (a fifty year flood) has a magnitude of 8,370 cfs (Figure 9).

The flow record for Soquel Creek from December 1, 1994 to April 5, 1995 shows one event that was a thirty-five year flood, one additional event that was a ten year flood, and one additional event that was at least two year flood (Figure 10).

The flow record for December 1, 1995 to April 6, 1996 shows one event that was a five year flood (Figure 11).

The record for November 21, 1996 to February 15, 1997 was preliminary data from the United States Geological Survey, the final values may be adjusted. The preliminary data shows no events greater than a two year flood, although final values may be larger (Figure 12).

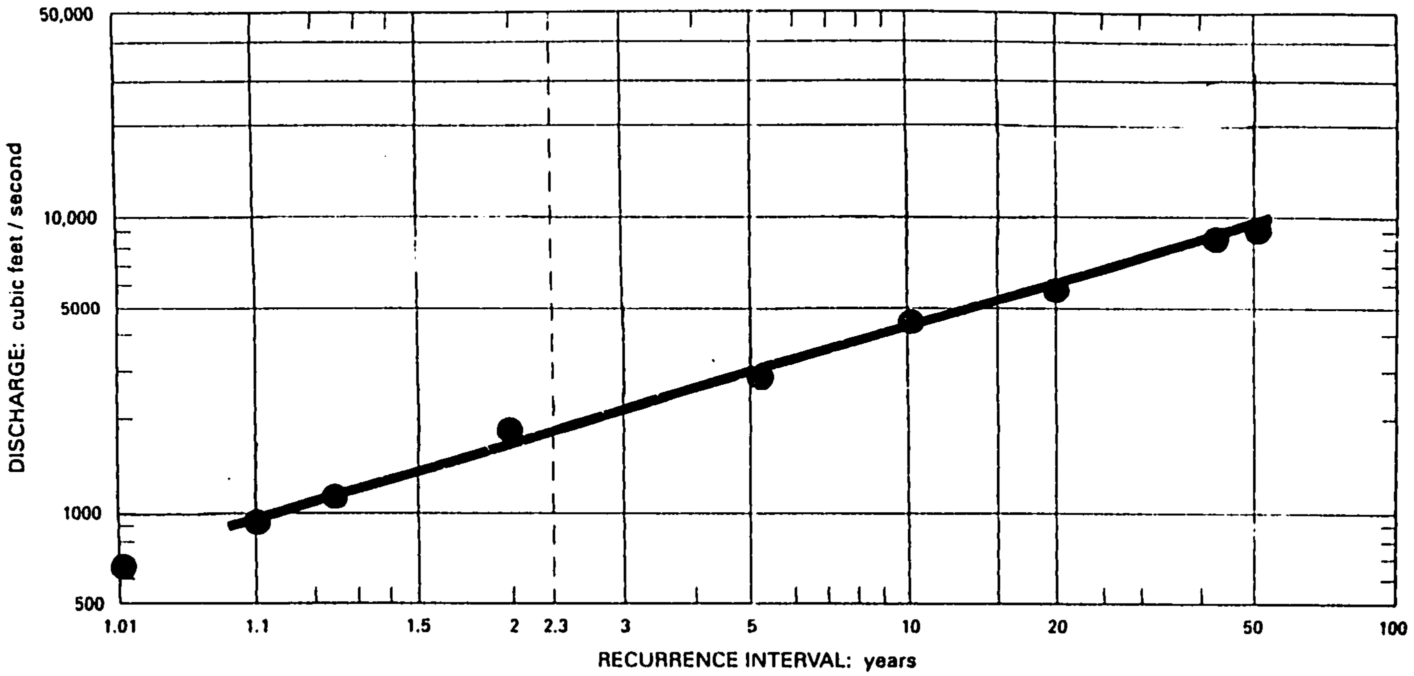


Figure 9.--Flood-frequency plot of Soquel Creek. Dashed line indicates bankfull occurrence.

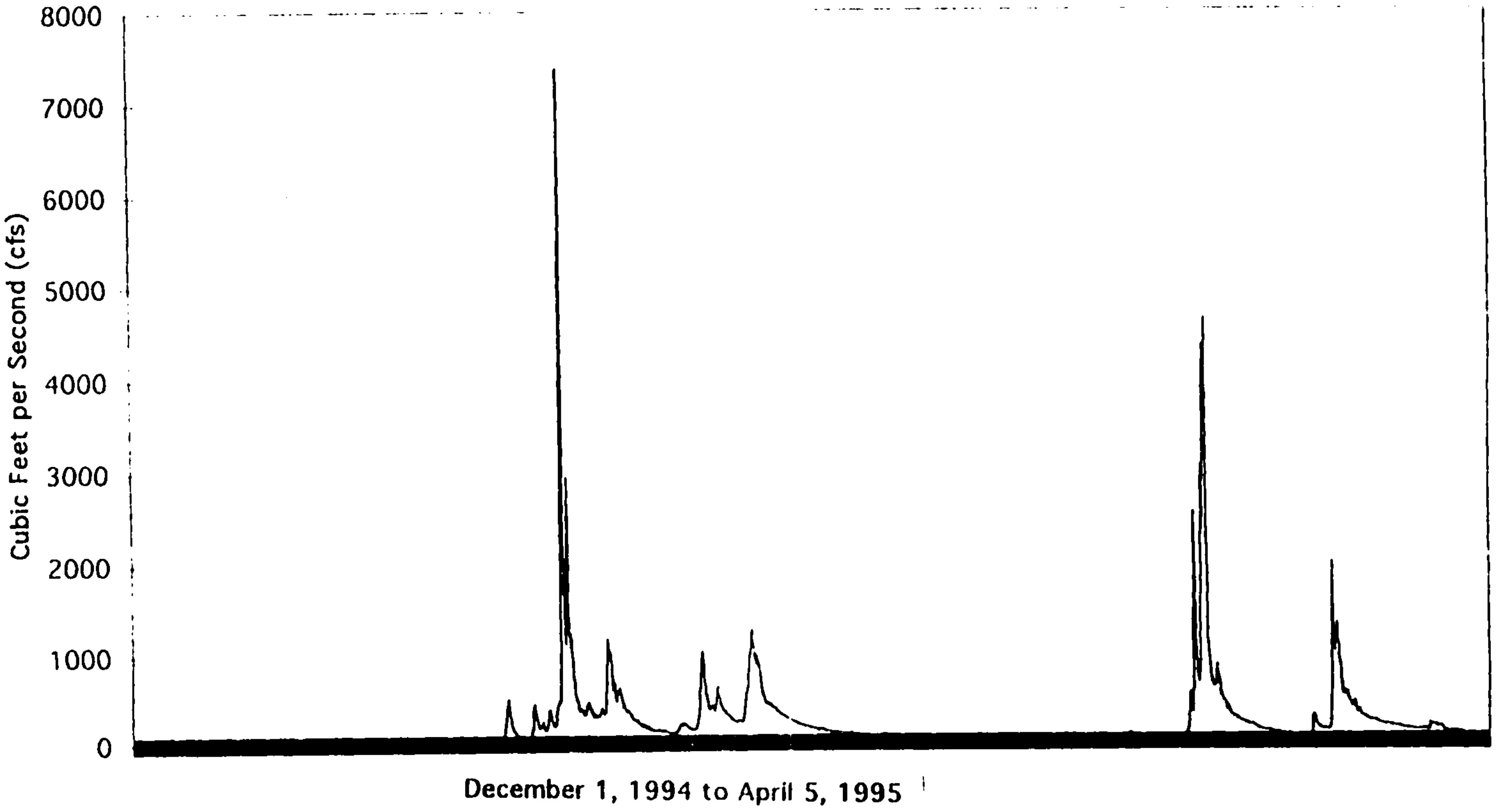


Figure 10.--Streamflow history of Soquel Creek from December 1, 1994 to April 5, 1995.

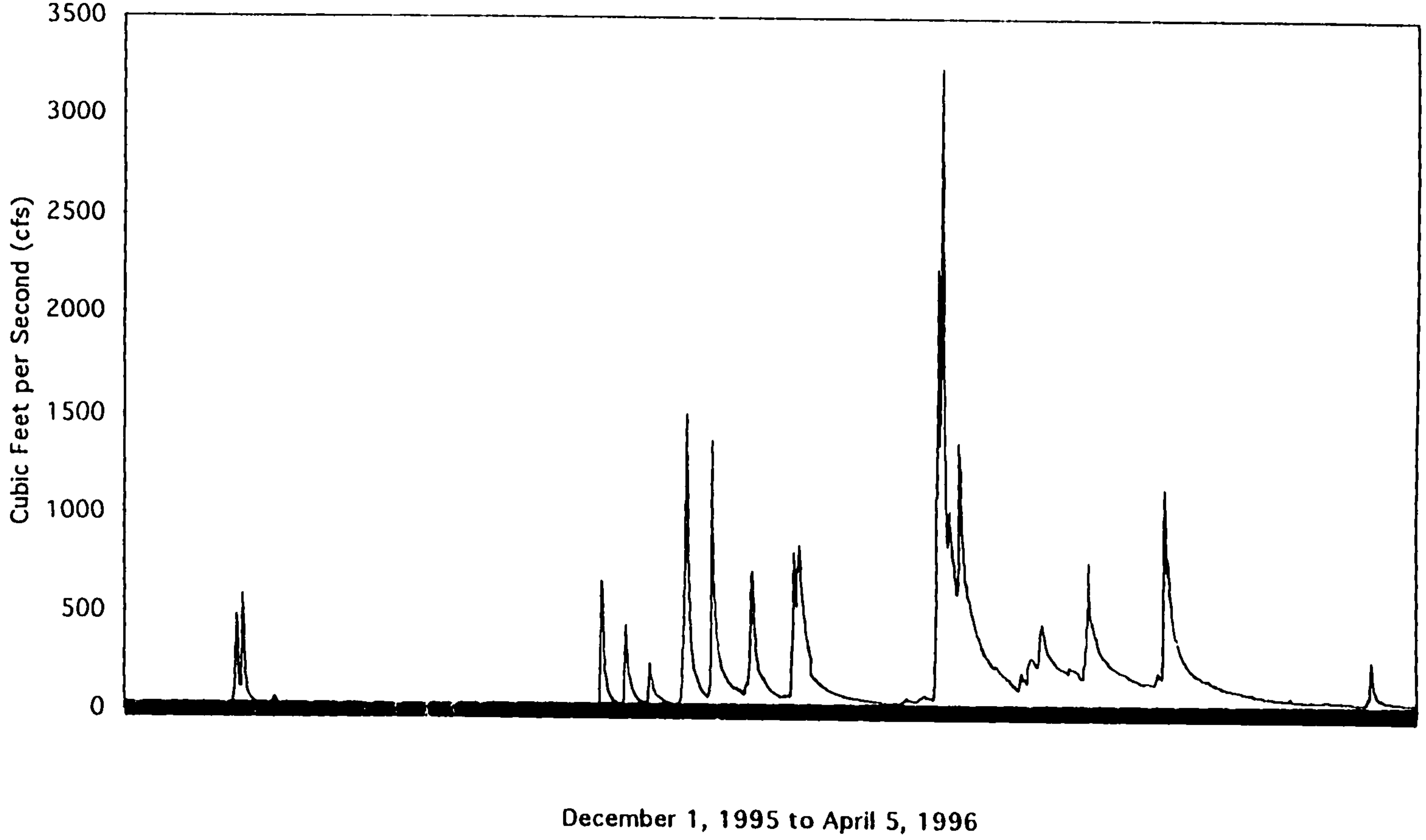


Figure 11.--Streamflow history of Soquel Creek from December 1, 1995 to April 5, 1996.

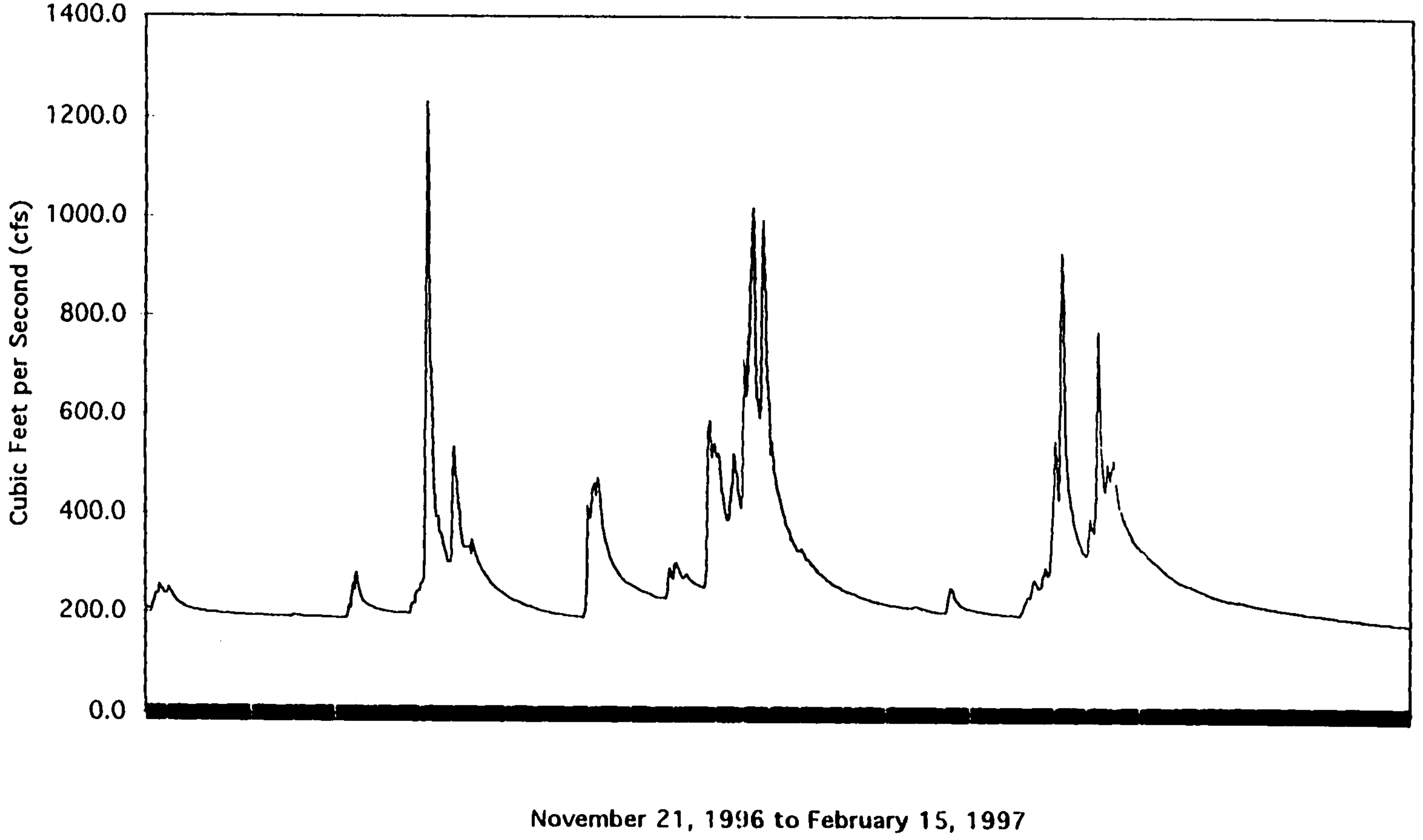


Figure 12.--Streamflow history of Soquel Creek from November 21, 1996 to February 15, 1997.

Stability of Instream Structures

The condition of the log weirs and deflectors was assessed on August 6, 1996 and again on February 7, 1997. The structures were designated as failure (≤7), impaired (8-11), or successful (≥12) according to points earned. Between the time of completion of the second phase of the restoration project on Moore's Gulch in winter 1993 and the August 6, 1996 survey, the structures had experienced one thirty-five year flood, one ten year flood, one five year flood, and at least one two year flood. On August 6, 1996, all seven log weirs scored eight to eleven points and were judged impaired, but none had failed (Table 20). When resurveyed on February 9, 1997 after an estimated three two year floods had occurred on Soquel Creek, six of the structures had lower scores. Four log weirs were judged impaired, while three had failed (Table 21).

On August 6, 1996, nine of the twelve log deflectors surveyed were judged impaired, while two had failed, and one was operating successfully (See Table 22). When reexamined on February 7, 1997, all had lower scores. Three of the deflectors were judged impaired and the remaining nine were judged failures (See Table 23).

The damage rate for weirs was 100% on August 6, 1996, and February 7, 1997 (Table 24). The damage rate for deflectors increased from 91.7% on August 6, 1996 to 100% on February 7, 1997. The weir failure rate increased from 0% on August 6, 1996 to 42.9% on February 7, 1997 and the deflector failure rate increased from 16.7% to 83.3%. The total damage rate for all structures was 94.7% on August 6, 1996 and 100% on February 7, 1997. The overall failure rate for all structures rose from 10.5% to 68.4% over the two dates.

Table 20.--Ratings of condition of components (1-3) for log weirs on Moore's Gulch on August 6, 1996.

Date	**Struc-ture**	**Ends covered with rocks**	**Weir sealed**	**All parts intact**	**Structure in proper position**	**Anchor rocks in original position**	**Total points**
Aug. 6, 1996	Weir #1	3	2	1	2	3	**11** **Impaired**
Aug. 6, 1996	Weir #2	2	2	2	2	2	**10** **Impaired**
Aug. 6, 1996	Weir #3	3	2	2	2	2	**11** **Impaired**
Aug. 6, 1996	Weir #4	1	1	2	2	2	**8** **Impaired**
Aug. 6, 1996	Weir #5	1	2	2	2	2	**9** **Impaired**
Aug. 6, 1996	Weir #6	1	2	2	2	2	**9** **Impaired**
Aug. 6, 1996	Weir #7	2	2	1	2	2	**9** **Impaired**

Table 21.--Ratings of condition of components for log weirs on Moore's Gulch on February 7, 1997.

Date	**Structure**	**Ends covered with rocks**	**Weir sealed**	**All parts intact**	**Structure in proper position**	**Anchor rocks in original position**	**Total points**
Feb. 7, 1997	Weir #1	3	1	1	2	3	**10** **Impaired**
Feb. 7, 1997	Weir #2	1	2	2	2	2	**9** **Impaired**
Feb. 7, 1997	Weir #3	2	2	1	2	2	**9** **Impaired**
Feb. 7, 1997	Weir #4	1	1	1	1	1	**5** **Failure**
Feb. 7, 1997	Weir #5	1	1	1	1	1	**5** **Failure**
Feb. 7, 1997	Weir #6	1	1	2	1	1	**6** **Failure**
Feb. 7, 1997	Weir #7	2	2	1	2	2	**10** **Impaired**

Table 22.--Ratings of condition of components for current deflectors on Moore's Gulch on August 6, 1996.

Date	**Structure**	**Ends of logs buried**	**Rock fill intact**	**Structure functional**	**Structure deposits over**	**Structure intact**	**Total points**
Aug. 6, 1996	Deflector #1	1	2	3	1	3	**10 Impaired**
Aug. 6, 1996	Deflector #2	1	2	2	1	2	**8 Impaired**
Aug. 6, 1996	Deflector #3	1	2	2	2	2	**9 Impaired**
Aug. 6, 1996	Deflector #4	1	2	3	3	3	**12 Successful**
Aug. 6, 1996	Deflector #5	0	1	1	2	3	**7 Failure**
Aug. 6, 1996	Deflector #6	2	3	1	1	3	**10 Impaired**
Aug. 6, 1996	Deflector #7	1	2	1	1	2	**7 Failure**
Aug. 6, 1996	Deflector #8	1	2	2	1	2	**8 Impaired**
Aug. 6, 1996	Deflector #9	1	2	1	2	3	**9 Impaired**
Aug. 6, 1996	Deflector #10	1	1	1	3	2	**8 Impaired**
Aug. 6, 1996	Deflector #11	1	2	2	2	2	**9 Impaired**
Aug. 6, 1996	Deflector #12	1	2	2	2	3	**10 Impaired**

Table 23.--Ratings of condition of components for current deflectors on Moore's Gulch on February 7, 1997.

Date	**Structure**	**Ends of logs buried**	**Rock fill intact**	**Structure functional**	**Structure deposits over**	**Structure intact**	**Total points**
Feb. 7, 1997	Deflector #1	0	1	3	1	3	**8 Impaired**
Feb. 7, 1997	Deflector #2	0	1	2	1	1	**5 Failure**
Feb. 7, 1997	Deflector #3	0	1	1	2	1	**5 Impaired**
Feb. 7, 1997	Deflector #4	1	2	3	3	2	**11 Impaired**
Feb. 7, 1997	Deflector #5	0	1	0	1	3	**5 Failure**
Feb. 7, 1997	Deflector #6	2	2	1	0	2	**7 Failure**
Feb. 7, 1997	Deflector #7	1	1	1	2	1	**6 Failure**
Feb. 7, 1997	Deflector #8	0	1	1	1	2	**5 Failure**
Feb. 7, 1997	Deflector #9	0	1	1	3	2	**7 Failure**
Feb. 7, 1997	Deflector #10	1	1	1	2	1	**6 Failure**
Feb. 7, 1997	Deflector #11	1	0	3	0	0	**4 Failure**
Feb. 7, 1997	Deflector #12	1	2	1	1	3	**8 Impaired**

Table 24.--The failure and damage rates for structures in Moore's Gulch on August 6, 1996 and February 7, 1997.

Date	**Weir damage rate**	**Weir failure rate**	**Deflector damage rate**	**Deflector failure rate**	**Total damage rate**	**Total failure rate**
Aug. 6, 1996	100% (7/7)	0% (0/0)	91.7% (11/12)	16.7% (2/12)	94.7% (18/19)	10.5% (2/19)
Feb. 7, 1997	100% (7/7)	42.9% (3/7)	100% (12/12)	83.3% (10/12)	100% (19/19)	68.4% (13/19)

DISCUSSION

Hunt (1976) suggested that post-project evaluation of stream restoration projects be delayed from three to seven years to allow for ecological adjustments to occur and to stabilize the modified habitat. Since the first phase of this project was implemented in 1989 and the second phase in 1993, the three to seven year time interval had elapsed prior to this first evaluation.

No baseline data for Moore's Gulch were collected prior to project implementation, preventing before and after comparisons. The Santa Cruz County Planning Office did not conduct any pre-project studies, but felt from visual observation of the area that restoration was needed to create suitable spawning and rearing habitat for steelhead in a section that had little or no habitat (Dave Hope, personal communication, December 1996). An examination of the present state of the habitat is useful and important. Evaluation also determines if the structures have caused damaged ecological conditions for salmonids. The presence of somewhat similar habitat upstream of the treatment reach served as a control area to judge effectiveness of the structures in improving habitat for salmonids.

The control section contained some habitat types not found in the experimental section. The most obvious was the absence of low gradient riffles from the experimental section. These habitat units can be used as spawning areas for steelhead, as can run and step run, which were present in the experimental section. The absence of low gradient riffles suggested that the deflectors, which were intended to encourage gravel deposition, were impaired. However, the percentage (35.8%) and length (32.8%) of run and step run in the experimental section was nearly the same as the percentage (31.0%) and length (30.9%) of low gradient riffle, run, and step run in the control section. The low gradient riffle in the experimental section may have been replaced by run and step run due to structure installation.

Riffle/flatwater areas in the experimental section also were significantly deeper than control section riffle/flatwater areas (Table 8). The greater depth of these areas may have been caused by the log deflectors, which cause channel scouring (Flosi and Reynolds 1994). The channel scouring may have significantly deepened experimental runs over control runs (Table 8). Low gradient riffles which were submerged by the added depth may have become runs, which are described by Flosi and Reynolds (1994) as "flooded riffles."

Riffle/flatwater areas in the experimental section also had significantly smaller substrate than control section riffle/flatwater areas (Table 9). The experimental section was made up of two B5 channels and one B1 channel (Table 2). B5 channels are predominantly sand and were 95.8% of the total length of the experimental section (Figure 7; Table 2). The control section was made up of B3 channels, which are predominantly cobble (Figure 7; Table 2). Adult steelhead spawn in gravel ranging from 0.5 cm to 10 cm (McEwan and Jackson 1996). The experimental section appeared sandy, but with patches of gravel suitable for spawning.

Another difference between the control and experimental sections was in the types of pools that were found. The control section contained primarily lateral scour and backwater pools, while the experimental section contained plunge pools, resulting from the installation of the log weirs. The seven plunge pools accounted for almost half (seven out of fifteen) of the pools in the experimental section (Table 4). Plunge pools and lateral scour pools may have existed historically in Moore's Gulch, but might have been eliminated if woody debris was removed for flood control purposes.

Pools were believed to be a limiting factor to steelhead production in Moore's Gulch (Hope 1989). The experimental section was a highly degraded area that was treated with log weirs to facilitate pool development and increase steelhead production (Hope 1989; personal communication). Log weirs may have facilitated pool development in the experimental section by enhancing depth and instream cover (Tables 6 and 7). Since no pre-project survey was attempted, the overall effect of the log weirs on pool development is unknown.

Although no significant difference in steelhead density between most control and experimental section pools for any age group or pool type was found, the log weirs did appear to have had an effect on trout production in Moore's Gulch compared to typical trout habitat. Experimental pools supported age 1+/2+ steelhead densities that were twice as large as control section pools, but with a high variation that made it difficult to detect differences (Table 10). Age 0+ fish densities were similar for control and experimental section pools. The log weir created plunge pools supported higher densities of age 1+/2+ and total steelhead than any other experimental or control pool type. The steelhead densities found in the log weir created plunge pools were one-third greater than the mean in all pools combined in the experimental section. The log weirs appeared to have a positive effect on age 1+/2+ steelhead production.

Riffle/flatwater areas are also important for trout production. These shallow habitats may be used as refuge by age 0+ steelhead after emergence from the gravel. Log deflectors did not significantly increase the density of any steelhead age group in experimental riffle/flatwater areas over control areas (Table 11). But, total steelhead densities in experimental section riffle/flatwater areas were, on average, twice those found in the control section, and age 1+/2+ were eight times as abundant. This suggested that the habitat created by the deflectors for steelhead shelter was important to age 1+/2+ steelhead as usable habitat.

Steelhead may station themselves in pools or riffle/flatwater areas. Small fish tend to be found in shallow habitats and larger fish may be found in deeper habitats (McEwan and Jackson 1996). Habitat availability may become a limiting factor to steelhead production if a shortage of pools or riffle/flatwater areas exists. The density of steelhead in pools and riffle/flatwater areas was compared to determine if a preference between the two existed. Age 0+ and age 1+/2+ steelhead showed a preference for pools over riffle/flatwater areas in the control and experimental sections (Table 12). While only age 1+/2+ and total steelhead preferences were statistically significant, age 0+ were twice as likely to be found in pools as well. Steelhead preferred to station themselves in pools rather than riffle/flatwater areas in the control and experimental sections.

After major storms, habitat preferences may change. Steelhead may shift into deeper habitats that provide the greatest cover and depth (Jerry Smith, personal communication, March 1997). If fish prefer a certain habitat during storm conditions, and that habitat is in short supply, steelhead production may be limited. Steelhead density was determined after a storm that produced at least a bankfull event (United States Geological Survey 1997). Once again, steelhead showed no significant preference for any specific pool or riffle/flatwater type in the control or experimental section (Tables 15 and 16). However, the same situation of greater age 1+/2+ and total steelhead densities in experimental section pools was continued, and age 0+ fish also occurred at greater densities in experimental section pools (Table 15). After storms, riffle/flatwater area steelhead densities were low in both the control and experimental sections (Table 16). Pools also were preferred over riffle/flatwater areas by age 0+, age 1+/2+ and total steelhead in the experimental section after storms (Table 17). In the control section, no significant difference was found for any age group between pools and riffle/flatwater areas after storms (Table 17). This appears to be due to the low quality of the bedrock pools as high flow refuge in the control section.

An unexpected result of the steelhead population survey was the capture of coho salmon and their presence only in log weir created pools. Coho salmon had not been recorded in Moore's Gulch prior to this survey. The coho did not increase the overall density of salmonids in experimental section pools to significant levels over control section pools before and after storms, although densities in the experimental section pools were almost twice as large before storms and almost three times as large after storms (Tables 13 and 18). Salmonids also preferred pool habitats before and after storms in the experimental section (Tables 14 and 19). It was not known if coho populations have increased or decreased due to habitat modifications.

The instream structures experienced several high flow events prior to being surveyed on August 6, 1996 and February 7, 1997. Between the end of the second phase of the restoration project on Moore's Gulch in winter 1993 and the August 6, 1996 survey, one thirty-five year flood, one ten year flood, one five year flood, and at least one two year flood occurred on Soquel Creek. It is assumed that Moore's Gulch experienced flows either slightly more or slightly less in magnitude and duration. At the time of the first survey, the log weirs were all damaged, but none had failed, while most log deflectors were damaged and two had failed (Tables 20, 22, and 24). Between the first survey and the second survey on February 7, 1997, Soquel Creek experienced three two year floods based on preliminary United States Geological Survey data. The damage and failure rates increased dramatically from the first survey to the second, suggesting that the structures needed maintenance before the winter of 1996-1997 to restore functionality.

The high failure rate, but increased fish densities, indicated that these instream structures were one solution for habitat creation in Moore's Gulch. However, due to lack of pre-restoration surveys there are no data on how the structures specifically may have improved the pre-existing experimental section instream habitat. Other studies have noted improvements in habitat and increased production of steelhead and coho (House and Boehne 1985, 1986; Crispin, House, and Roberts 1993; Riley and Fausch 1995; Gowan and Fausch 1996). The results supported a conclusion of increased steelhead production, especially age 1+/2+ steelhead, in experimental sections over control sections and that the lack of pools in the control section may be a limiting factor to steelhead production. The results also demonstrate a very high failure rate of instream enhancement structures, similar to the conclusions of Frissell and Nawa (1992). Any gains in habitat from instream structures must be maintained through diligent repair of the structures or, ideally, through modified land use practices, such as improved erosion control and riparian corridor management. Modified land use practices may reduce the long-term pressure placed on the structures to maintain habitat gains over time.

RECOMMENDATIONS

A primary recommendation for future stream restoration projects is the inclusion of a detailed pre-project survey. Baseline data will provide a reference for environmental change that may result from a project. Post-project conditions should be compared to previously existing habitat or to a specific control site. The project on Moore's Gulch had no baseline data, so any changes in habitat could not be quantified or graded.

A restoration plan should define the criteria used to evaluate the project. Objectives should specify the degree of desired habitat change, such as an increase in pool depth and instream cover. Depth may increase significantly according to a t-test, but the criteria may call for a 50% increase in pool depth, which could have a greater impact on steelhead production. The spacing of transects, the definition of cover, and even the system used to identify pools and riffle/flatwater areas must be duplicated in baseline and post-project data collection. Variations in the data collection from baseline collection to the evaluation will produce invalid comparisons and both data sets will be limited in their usefulness.

Failure and damage should have been factored into the budget for this project. This evaluation noted high damage and failure rates three to four years after installation. The damage and failure rates may have been lower for the second survey if repairs had been made. Damaged structures may cancel out habitat gains and may even cause habitat losses. Damage and failure rates should be noted in project planning so budgets can be structured accordingly. Kondolf and Micheli (1995) recommend allocation of funds for at least a ten year evaluation program. Small projects should be designed to withstand at least a ten year flood, while larger scale expensive projects should be designed to withstand larger flood events.

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