Exxon Valdez Oil Spill
Restoration Project Final Report

Montague Island Riparian Rehabilitation

Restoration Project 97139C1
Final Report

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Study History: This project was initiated under Restoration Project 94139C1. An annual report was issued in 1994 by Schmid, D. et al., under the title *Montague Island Chum Salmon Restoration*. The project was continued in 1995 and 1996 with additional riparian rehabilitation work. The final monitoring of the project occurred in 1997. Annual reports were issued in 1995 and 1996 by Ken Hodges under the title *Montague Island Riparian Rehabilitation*.

Abstract: From 1994 to 1996, riparian restoration work was undertaken in four watersheds on Montague Island where logging had occurred in the 1960's and 1970's. Although this work would not deal directly with the habitat oiled by the *Exxon Valdez* oil spill, it was felt that the restoration of these watersheds would improve conditions throughout the stream systems and contribute to the overall restoration of chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*) in Prince William Sound. The work involved two major parts: building instream structures to reduce erosion, moderate flows, and improve fish habitat; and thinning crowded riparian vegetation to stimulate the growth of Sitka spruce, which was the dominant species before the logging. A small crew working without heavy equipment built 32 instream structures and thinned 17 acres. Most of the structures designed to create habitat were successful, but those built to reduce velocities in the main channel of Hanning Creek either washed out or had limited effects. While the habitat structures provide rearing area for Dolly Varden (*Salvelinus malma*), the main channel structures have had no apparent benefit for the targeted salmon species. Mainstem and whorl growth of trees in thinned areas was significantly greater than growth in untreated areas. Thinning should accelerate the production of large diameter trees which will become the source of large woody material for the streams in the future. Current timber harvest regulations should reduce the need for similar projects in the future.

Key Words: *Exxon Valdez*, instream structures, thinning, woody debris, Montague Island.

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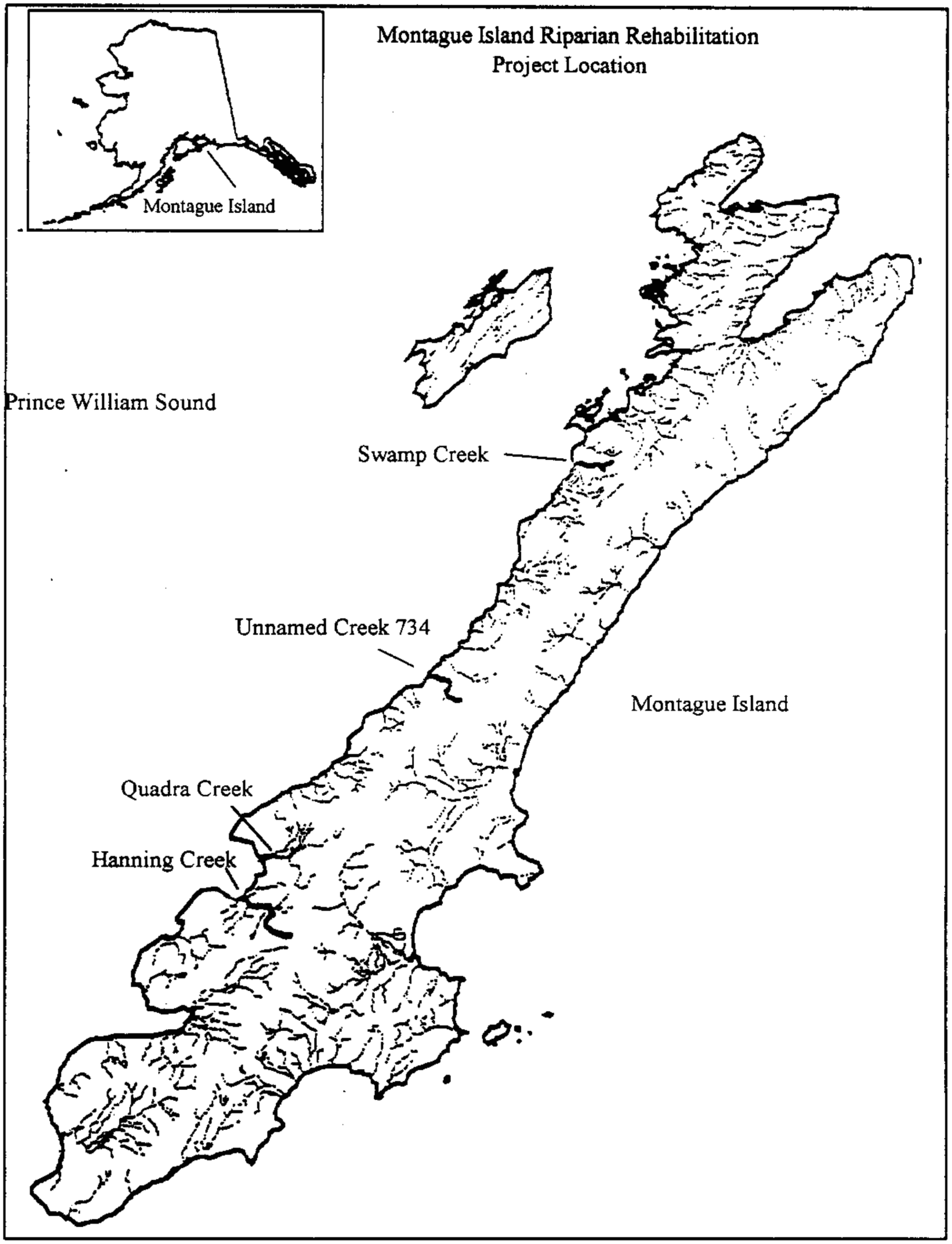
Montague Island Riparian Rehabilitation
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Executive Summary

After the *Exxon Valdez* oil spill it became apparent that not all of the direct effects of the oil spill or the injuries to various species could be undone. There was an opportunity, however, to help restore a number of watersheds on the western side Montague Island where logging had occurred in the 1960's and 1970's. Although this work would not deal directly with the habitat oiled by the spill, we felt that the restoration of these watersheds would improve conditions throughout the stream systems and contribute to the overall restoration of chum salmon *Oncorhynchus keta* and pink salmon *O. gorbuscha* in Prince William Sound.

These watersheds receive high amounts of precipitation, ranging from 305 cm at the lower elevations to 890 cm on the peaks. Thus, the streams are subject to naturally high flows, especially during fall storms and snowmelt periods in the spring. Most of the logged areas are on alluvial floodplains or fans where the generally coarser substrate provides better drainage and growing conditions for Sitka spruce (*Picea sitchensis*), but the soils are poorly consolidated. These areas are also depositional zones and are susceptible to channel shifting and other natural disturbances.

Although these areas are naturally prone to disturbances, aerial photographs taken before the areas were logged suggest that the stream channels may have been more stable previously. Comparisons of the older and later photographs show that the channels have widened and more extensive wide, bare gravel bars have formed. At Swamp, Quadra, and the unnamed creeks, the 1964 earthquake or inherent channel instability may have contributed to these conditions. However, the problems we observed in these streams are consistent with the effects that might be expected from logging the riparian areas. We suspect that removal of the trees from the riparian areas and the subsequent death of the roots may have made the banks more vulnerable to erosion, facilitating channel shifts or stream widening.

At Hanning Creek, the effects of the logging operations are much more clear. Aerial photographs taken in 1975, about three years after the harvest, show roads and skid trails crossing the creek. Aerial photographs taken in 1993 show the stream shifted at two of these sites, eroding new channels along these roads. One channel is now 10 m wide, 2 m deep at its upstream end, and 0.8 km long. Downstream there are relatively few pools, and there are wide gravel bars which are not apparent on the earlier photographs. It is assumed that the eroded material from the channel filled downstream pools and has caused the stream to widen. This new channel is still downcutting, contributing additional bedload material.

One problem that is directly attributable to logging is the eventual loss of large woody debris from the streams. All of the sites were logged without leaving buffer strips along the streams. Although there may be some trees in upstream areas, most of the trees that would have been the sources of woody debris in the future were harvested. In addition, some woody material may have been removed from the streams in the post-logging cleanup. A 1972 photograph taken at Russell Creek, which is 1 km from Swamp Creek and was harvested as part of the same sale, shows a section of stream where all of the woody material was removed. It is not known if wood was removed from the other streams, but it is a possibility. Since large woody debris helps to reduce water velocities, stores sediment, creates pools, and provides habitat for fish, these benefits are lost when wood is removed or is not available for input.

The main effects on chum and pink salmon are that their redds in downstream spawning areas may be subjected to displacement, burial, or sedimentation due to the channel shifts and increased bedload deposition from the bank erosion. Habitat for other fish species is also degraded with the loss of pools and woody debris.

Although the stream channels have been degraded, the surrounding areas do not seem to be a continuing problem. The logged areas are on flat alluvial zones, so there are no upslope problems such as landslides, road deterioration, or debris torrents. The disturbed areas have also revegetated with shrubs and small trees over the past 20 to 35 years since the timber harvest, so surface erosion is not a problem. We felt that the main problems derived from the continuing bank erosion and high bedload movement.

We developed a two-part project intended to address these problems. The first part consisted of building instream structures to reduce stream velocities, prevent erosion of banks where young trees were growing, reduce bedload movement, and provide fish habitat. These artificial structures would perform the same roles that fallen trees from the old-growth forest would have played if the logging and removal of woody material from the streams had not occurred. By reducing erosion, the downstream spawning areas should be less prone to disturbances and sedimentation. For this part of the project, we concentrated our efforts in the Hanning Creek watershed to maximize the effect and to determine how much of an impact a small crew working without heavy equipment could have.

A 73-m downstream study site was established to indirectly monitor the cumulative effects of the structures. We hypothesized that a reduction in velocities might result in a decrease in substrate size, revegetation of the gravel bars, and narrowing of the bankfull width in this monitoring site. The site was mapped, noting the bankfull widths, depths, gravel bars, and other features. Four cross-channel transects were made to document the channel geometry. We performed Wolman pebble counts to assess the substrate. The same procedures were repeated in 1997 for comparison.

The second part of the project was the rehabilitation of the riparian vegetation. After the clearcutting, crowded stands of Sitka spruce emerged. These stands were thinned to reduce competition among the trees and produce larger trees in a shorter amount of time. These trees will then be the source of large woody material for the streams in the future. The intensity of the thinning varied. Generally, the spacing between trees varied according to their size. The tree diameter at breast height (in inches) plus three equaled the number of feet of between trees. Thus, a 4-inch tree would have a 7-ft. cleared area around it (4+3). At a few sites at Hanning Creek where the spruce were small, only the competing Sitka alder *Alnus sinuata* and willow *Salix spp.* were removed. At Quadra Creek, long-term monitoring sites were established with "diameter plus five" spacing at one site and consistent 4.3- meter spacing at the other.

In 1994, we built 32 instream structures. Although all of the structures survived two bankfull high water events during the summer and fall of 1994, only half of the structures were functional by 1997. Of the 14 structures intended to moderate flows, nine failed, including six in the main channel of Hanning Creek. Of the five erosion control structures, one was successful, protecting 35 m of bank where young spruce are growing. The structures intended to provide habitat were more successful, with 10 of 13 structures functioning as planned and creating 163.4 sq m of pool habitat and 21.4 sq m of spawning area.

We were unable to determine whether any changes in the downstream monitoring site were due to the effects of the structures. Unfortunately, a channel shift just above the downstream study area radically changed the site. A large section of the main gravel bar eroded, a pool filled, and a wide shallow riffle was created. The substrate size decreased significantly in the area, but this and the other changes were most likely due to the channel shift rather than any effect caused by the remaining structures. There was no evidence of revegetation or narrowing of the channel.

We thinned 17 acres in 1994 and 1995. Sitka spruce showed significantly greater mainstem and whorl growth in areas where all species were thinned, compared to untreated areas. At a site where only willow and alder were removed, the spruce showed greater growth for one year, but then appeared to compete with each other. There was no apparent blowdown, sunburn, or other negative effect in the younger stands at Hanning and Swamp Creeks. At Quadra Creek, where the trees were larger, there were several trees which blew down in thinned areas.

Generally speaking, the project has had some small successes, but the larger goals have not been achieved. The failure of most of the main channel structures is disappointing, since these were intended to address the most significant problems of the watershed: the erosion and excessive bedload movement. The remaining structures are functioning, but the effects are too limited to benefit the pink and chum salmon. Further main channel work is not recommended due to the difficulty of working in this remote area without heavy equipment. On the positive side, the habitat structures are providing refuge areas and spawning sites on tributaries off of the main channel for other species. The one remaining erosion protection structure is allowing a stand of Sitka spruce to become established.

While mainstem and whorl growth have been significantly greater in the thinned areas, recently acquired data from southeast Alaska suggest that differences in height narrow over time. The main benefit from thinning is a more substantial increase in mean diameter rather than average height. Growth is dependent on the intensity of the thinning and specific site conditions, but the southeast Alaska data indicate thinning can produce trees with an effective diameter size (30 cm) 30 to 60 years sooner than unthinned stands. Sitka spruce growth in the Prince William Sound area is probably slower than in areas farther south, but thinning should still produce greater mean diameters more quickly than in unthinned areas.

Current federal and Alaskan timber harvest regulations should preclude the need for similar projects in the future. Buffer strips along fish-bearing streams and increased regulation of stream crossing sites should reduce riparian disturbances, unnatural erosion, and channel degradation. Buffer strips should eliminate the need for thinning in riparian areas.

Introduction

Following the *Exxon Valdez* oil spill it became apparent that not all of the direct effects of the oil spill or the injuries to various species could be undone. We felt it was possible, however, to help injured species such as chum salmon *Oncorhynchus keta* and pink salmon *O. gorbuscha* by improving habitat conditions in other areas of Prince William Sound. Of particular concern were several watersheds on Montague Island which had been logged in the 1960's and 1970's. These included Hanning and Quadra creeks which flow into Hanning Bay on the southwest end of the island, an unnamed creek to the north of Hanning Bay, and Swamp Creek near Port Chalmers on the northwest side of the island (see location map). If these stream systems could be rehabilitated, the overall conditions for the salmon and other fish could be improved.

All of these streams have highly eroded banks, wide gravel bars, and, from both quantitative and qualitative observations, relatively low amounts of pool habitat and large woody debris. Comparisons of aerial photographs taken before (1959) and after the logging (1975, 1993) show channel shifts, more extensive gravel bar formation, and stream widening in the later years. (Quadra Creek was logged in 1958, but except for a channel shift, none of the changes that appear in later photographs had yet taken place.) The lack of vegetation on these bars also suggests that the substrate is being mobilized during high flows (Lisle 1989). The earliest aerial photographs do show some sections of the streams where wide gravel bars were present naturally, but the later photographs also show these conditions in entirely new areas and to a greater extent.

The apparent instability of these channels creates a number of problems for fish. The bedload movement can affect chum salmon, pink salmon, and other fish by displacing, burying, or crushing eggs in spawning areas (McNeil 1964). The erosion of the banks adds additional bedload material and can increase sedimentation of the spawning areas as the fine material from eroded areas settles out when flows subside (Chapman 1988). The bedload movement and low amounts of woody debris and pool habitat also adversely affect juvenile coho salmon *O. kisutch* and other species which spend the winter in the streams. Winter survival is highly dependent on stable substrate, woody debris, and lower velocity areas in pools (Sedell et al. 1984, Heifetz et al. 1986).

It is not certain if all of the current problems in these watersheds are directly attributable to the logging, since these areas are naturally prone to high flows, bank erosion, and bedload transport and deposition. These watersheds receive high amounts of precipitation, ranging from 305 cm at the lower elevations to 890 cm on the peaks (Chugach National Forest Environmental Atlas, unpublished). Thus, considerable flows can be expected during fall storms and during the spring snowmelt. Most of the logged areas are on alluvial floodplains or fans where the coarser substrate provides better drainage and growing conditions for Sitka spruce *Picea sitchensis*. However, the soils in these areas are poorly consolidated and are more easily eroded. The alluvial areas are also natural bedload transport and deposition zones, so bedload movement and the formation of gravel bars are expected to a certain degree. Lastly, the 1964 earthquake uplifted the area near Swamp Creek 3.7 m and the area near Hanning Bay 6.5 m. There has been natural downcutting at the mouths and lower sections of the streams, but it is not known whether the uplift may have affected the upland areas.

The effects of logging have also been lessened by the topography of the harvested areas. As mentioned, the clearcuts were on alluvial fans and floodplains, which are relatively flat. Except for one small downstream area at Hanning Creek, none of the hillsides or other upper slope areas had been logged or disturbed. Thus, there are no landslides or upland roads introducing material into the streams. The harvested sites and roads in these areas have also revegetated with small trees and shrubs over the past 20 to 35 years, so there is little or no surface erosion from the disturbed areas.

The main effects of the logging appear to be related to the loss of trees in the riparian areas, logging-related channel shifts, and continuing channel instability. These problems are most apparent in the upper Hanning Creek watershed. This harvest unit, as all of them, was logged before buffer strips were required along the streams. Thus, there were soil disturbances and the loss of trees and other vegetation along most of the stream banks. Aerial photographs taken in 1975, about three years after the harvest, also show roads and skid trails crossing the creek. Photographs taken in 1993 show the stream shifted at two of these sites, eroding new channels down these roads. Richard Groff, former USDA Forest Service Area Manager, witnessed the beginnings of these changes (personal communication). He said the creek overflowed its banks during exceptionally heavy rains, and "all of the roads became rivers." Evidently, at some sites, there was enough downcutting along the roads to shift the course of the creek.

One former road is now a channel 10 m wide, 2 m deep at its upstream end, and 0.8 km long. It appears that the eroded material from the channel has helped to fill downstream pools and cause the stream to straighten and widen. This new channel has not yet stabilized and is still widening and downcutting at its head, contributing additional bedload material. As we will discuss in a later section, one of our primary mistakes in this project was not recognizing that this stream section is probably still adjusting to the multi-year flood events and the natural bedload material being deposited from upstream areas.

The aerial photographs at the other three streams also show channel shifts and stream widening, but the connection to logging is not as clear. The 1959 photograph of Quadra Creek shows a suspiciously straight channel breaking off from the main stream, but we have no earlier photographs showing that the channel was a former logging road as we did at Hanning Creek. Channel shifts at the unnamed creek occurred between 1959 and 1975, but we cannot tell whether these changes were due to logging or the 1964 earthquake. In the case of upper Swamp Creek, there may have been a natural channel shift due to substrate deposition in an alluvial fan formation.

Stream widening and more extensive gravel bar formation have also taken place at these streams during the same time period. We suspect that removal of the trees from the riparian areas may have made the banks more vulnerable to erosion, facilitating stream widening (or channel shifts). If the trees are cut, the roots (which hold the banks together) decay within three to eight years, and the impacts may last for several decades or longer (Hartman et al. 1996). Stands of young Sitka spruce have been recolonizing the banks, but their root systems have not developed enough to stabilize the banks. In many areas the young trees are being washed away as the banks erode, so the streams continue to widen.

Another problem is that the harvest of trees in the riparian areas also removed the source of large woody debris for the streams. Large wood serves a number of beneficial functions in streams. It creates pools and other important habitat for salmonids (Bryant 1983, Heifetz et al. 1986), reduces stream velocities and erosive power (Heede 1972, Crispin et al. 1993), and helps store excess sediment and reduce bedload movement (Sedell et al. 1984, Smith et al. 1993). Although we did not count the pieces of wood in the streams, the low amounts of pool habitat in Quadra and Hanning creeks appeared to be due, in part, to the lack of large woody material. This was particularly the case in the section of Hanning Creek where the stream is flowing down the former logging road.

In addition, large woody debris that was already in the streams may have been removed during post-logging cleanup efforts, when slash and other logging debris were taken out. Photographs of Russell Creek before and after cleanup, show that all woody material was removed. Russell Creek is 1 km from Swamp Creek and was part of the same harvest unit. It is not known whether Swamp Creek or the other creeks were similarly cleaned, but it is possible that this practice was applied to all.

Our project tried to address these problems in two ways. To hasten the availability of large Sitka spruce for recruitment into the streams in the future, crowded stands of spruce saplings were thinned to accelerate the growth of the remaining trees. Sitka alder *Alnus sinuata* and willow *Salix spp.* shading the spruce were thinned as well. Although there is little information for Prince William Sound, thinning crowded stands and removing competing vegetation have been shown to increase the growth of Sitka spruce in other areas and are standard silvicultural practices (Smith 1962, Fowells 1965). Thinning was conducted in all of the watersheds. The benefits from this work will not be realized until the trees mature, but the intent is to accelerate the natural process and return the areas to the condition which existed before the logging. Monitoring of the sites has shown significantly increased growth in the thinned areas compared to unthinned areas.

In the short term, however, log and boulder instream structures were built to play the role that fallen trees and other woody material would perform in a natural system. Artificial structures have been successfully used to improve salmonid habitat (House and Boehne 1986, Fuller 1990, Nickelson et al. 1992) or perform other hydrologic functions which would benefit fish (Payne and Copes 1986, Reeves et al. 1991). On Montague Island, some structures were designed to improve fish habitat by creating pools and increasing the habitat complexity of the channels. Other structures were intended to reduce velocities, trap gravel, and lower bedload movement. Erosion would be reduced with the lower velocities and with structures specifically designed to protect eroding banks.

Almost all of the instream structures were built in Hanning Creek (31 of 32 structures) to maximize the effect in one watershed, and admittedly, as a test to see how much of an impact a small crew working without heavy equipment could have. The results have been mixed. Although all of the structures held up to bankfull flows initially, most of the structures meant to reduce velocities in the main channel have failed over the last several years. While the remaining structures have localized effects, there is no evidence of changes in the overall stream dynamics. Thus, there appears to have been no benefit for the main species of concern, pink and chum salmon. Structures designed to create habitat in the smaller tributaries have been more successful and provide some habitat for Dolly Varden and juvenile coho salmon.

Objectives

1. Accelerate the growth of Sitka spruce in the riparian areas by thinning crowded stands of young spruce and removing competing species. This should hasten the restoration of the Sitka spruce forest that existed before the logging.

2. Build instream log and boulder structures to replace large woody material that may have been removed or is not naturally available due to the lack of buffer strips in the riparian areas. The structures should reduce stream velocities, reduce erosion, and provide fish habitat.

3. Determine the effectiveness of small crews working without heavy equipment in medium-sized Alaskan streams.

Methods

Before this project was funded by the *Exxon Valdez* Oil Spill Trustee Council, the USDA Forest Service had conducted a series of surveys to assess the conditions in streams that had historically produced chum salmon on Montague Island. In 1991, habitat inventories were conducted in Hanning (Alaska Department of Fish and Game #17100) and Quadra (#17110) creeks using the habitat classifications described by Bisson (1982). Habitat features were measured in six sections approximately 50 meters long within various channel types (Rosgen 1985). It was at this time that the problems in the clearcut areas were identified, particularly the lack of pool habitat and eroding banks. In 1992, crews qualitatively assessed clearcut riparian areas to determine whether tree planting or thinning were needed. As a result of these surveys, we identified four streams where thinning or structure work would be most effective: Hanning Creek, Quadra Creek, Swamp Creek (#17390), and an unnamed creek (#17340). The crews noted the kinds of restoration work that were needed and developed the preliminary work plans. Funding for the proposed work was received for Fiscal Year 1994.

We also used aerial photographs to get a better idea of what these watersheds looked like before the logging. One cannot see pools or eroding banks, but channel shifts, relative channel widths, gravel bars, shallow braided stream sections, and riparian vegetation are discernible. We have photographs from 1959, 1975, and 1993. The 1959 photographs show all of the sites in their prelogging state, except for Quadra Creek which was logged in 1958. We had to assume that the main channel conditions had not changed dramatically at that point, although it appears that part of the flow has been diverted down a logging road. The 1975 photographs were taken one to five years after the other areas were logged. The 1993 photographs were not available until 1995 after the instream structure work and most of the thinning was completed.

Instream Structures

In 1994, the crew built 32 structures (31 in the Hanning Creek watershed and one at the unnamed creek) using six basic structure designs. Full-span diagonal log weirs, and V-shaped weirs were used to reduce velocities, store sediment, and reduce erosion. Wing deflectors were built to divert flows and reduce bank erosion. Log barbs, tree tops, and log jams were built to provide backwater pools and cover for fish habitat. The structures were modeled after designs in Seehorn (1985), and Payne and Copes (1986).

A crew of four or five people built the structures using hand tools and small power tools, such as chain saws, gas powered drills, and a gas-powered winch. No vehicles or heavy equipment were used. These structures were made of logs left on site from the logging period and other local material. The logs were generally 6-10 m long and 30-60 cm in diameter. The structures were held in place by cabling the logs to stumps at the site, pinning the logs to the streambed with 1.3-m lengths of reinforcement rod (rebar), placing the log in trenches dug into the bank, or some combination of these methods. The ends of the structure and the banks were lined with large rocks to prevent erosion. Four structures which had been damaged were rebuilt in 1996 with soil anchors driven into the substrate.

Riparian vegetation thinning

Crowded stands of Sitka spruce saplings were thinned within a zone 30 m wide on both sides of the streams, except for a 3-m buffer of uncut trees along the stream side to prevent bank erosion. Willow and Sitka alder were removed to give the spruce more room and light, since Sitka spruce are not highly shade tolerant (Fowells 1965). In some areas in the Hanning Creek watershed where the spruce were small (less than 3 m), the crew removed only the alder and willow. In most areas, however, all species were cut.

The spacing between the spruce at most sites was determined using a simple formula, where the diameter at breast height, DBH, (in inches) plus three equals the number of feet to be cleared between trees. Thus, a 4-inch tree would have a 7-ft. cleared area around it (4+3). At Quadra Creek where the trees were taller, one plot was thinned with "diameter plus five" spacing and another with 14- ft. (4.3-m) spacing. The differences in spacing will be used to test the differences in long-term growth and also the effects on the growth of understory vegetation.

Monitoring Methods

Instream Structures

Diagrams were drawn of the structures and the surrounding area to document the changes caused by the structures over time. Depths, bankfull channel widths, pools, fish habitat, and other features were measured. Substrate composition was estimated visually. This was repeated for the structures that remained in 1997.

Downstream from all of the structures, a 73-m section of Hanning Creek was chosen as a study site to assess the cumulative effects of the structures. It was hypothesized that if the structures helped to reduce the energy in the system or reduce bedload movement, the combined effects may be manifested downstream by changes in the substrate size (MacDonald et al 1991, Harrelson et al. 1994), channel geometry, or riparian vegetation (Lisle 1989). The site consisted of a pool, two riffles, and a gravel bar running the length of the site. The site was divided into three sections containing one of the habitat units and the adjacent area of the gravel bar. A diagram of the entire area was drawn which included bankfull widths, active widths and depths, and habitat features. The channel geometry was recorded along four transect lines, one near the downstream end of the site and the other three through the centers of the habitat units. Iron stakes were driven into the banks to mark the transect locations and each end of the site. The site was remapped at similar low-flow conditions in July 1997.

To analyze the substrate, Wolman pebble counts were conducted in each of these sections, including the unwetted area within the bankfull width, as described by Harrelson et al. (1994). Two 50-pebble counts were conducted in each of the three sections. By 1997, the boundaries of the gravel bar, pool, and riffles had changed considerably, so direct comparisons within the habitat units were no longer meaningful. We resampled the areas as they existed in 1994, but for the analysis we pooled all of the data to create 300-pebble samples of the entire site for each year. Bevenger and King (1995) used Wolman pebble counts and the chi-square statistic with a 2x2 contingency table to test whether the substrate above or below a certain size class has changed significantly. Using the Statgraphics statistical software package, we tested whether the substrate smaller than 64 mm (the upper end of the gravel size used for spawning) had changed. Using the formulas presented in Bevenger and King (1995), we concluded that the sample size was adequate for detecting a 15% change with a .05 probability of committing either a Type I or II error.

Riparian vegetation thinning

We monitored the general health of the trees in thinned areas by looking for any signs of sunburn, discoloring of the needles, or lack of new growth. The stands were also checked to make sure that no trees had blown down, which can happen to trees that had formerly been sheltered from the wind by other trees. However, this is generally not a problem when thinning young stands (Susan Kesti, USDA Forest Service silviculturist, personal communication).

To determine the effect on growth, we measured the mainstem and top whorl growth in thinned and unthinned areas along Hanning and Swamp creeks. Mainstem growth was measured between the uppermost whorl and the first whorl below, which would represent the previous year's growth. Whorl growth was calculated by measuring the previous year's growth of two whorl stems on opposite sides of the tree and averaging the two measurements. The methods for physically measuring the growth changed each year because of the difficulty of measuring the taller trees. In 1995, we measured the growth in an area at Hanning Creek where only alder and willow were removed and at an untreated site (n=15 at each site). Measurements were made to the nearest 12.7 mm (0.5 inch) using a tape measure extended on a pole. In 1996, we remeasured growth at the Hanning Creek site and also at Swamp Creek where all species were thinned (n=20). Measurements were made with a telescoping rod to the nearest 6.1 mm (0.02 ft). A ladder was used to improve access to the tops of the trees. Although the trees were relatively small, 1.5 to 3 m at Hanning Creek and 3 to 6 m at Swamp Creek, these measuring techniques were not entirely satisfactory. In 1997 we employed "destructive sampling" (Deal and Farr 1994) and were able to accurately measure growth to the nearest 1.0 cm. We only sampled the Swamp Creek sites (n=25) because there were not enough trees to cut down at Hanning Creek.

The data were analyzed using the single classification ANOVA or Kruskal-Wallis tests in the Statgraphics computer software package. The Kruskall-Wallis tests were performed only when the distributions were still non-normal after log transformation of the data. Comparisons were made between thinned and unthinned areas at Hanning Creek in 1995 and 1996, between thinned and unthinned areas at Swamp Creek in 1996 and 1997, and between thinned areas at both sites in 1996.

At Quadra Creek, three 0.4 hectare (1.0 acre) treatment plots were established to monitor the long-term effects of thinning. One plot is a control area where no thinning was done. The other two plots were thinned using the "diameter plus five" and 4.3 m spacing. A 0.04 hectare (0.1 acre) monitoring site was established at the center of each treatment area as described in a previous annual report (Hodges 1995). Within these plots, trees were marked with individual identification tags, measured, and aged. We will then be able to identify and remeasure these trees to determine DBH growth rates. Growth data are not scheduled to be collected until five years after the thinning, since the change in DBH will be slower and significant differences may not be detectable until then. The sites have also been examined to determine the response of understory vegetation and the rate of decay of the slash piles.

Results

The 1991 habitat surveys showed that there were relatively low amounts of pool habitat in both Hanning and Quadra creeks. Pool area in the four channel types in Hanning Creek ranged from 0.0% to 24.8%, with an overall average of 8.6%. In the two channel types in Quadra Creek, pool area was 10.3% and 19.2%, and 15.1% overall. At this time, the crews qualitatively noted that there were long stretches of eroding banks and areas where young spruce trees were being washed into the creeks.

In 1992, crews identified areas at all four creeks where there were crowded stands of young Sitka spruce which could be thinned. Regeneration of spruce was not a problem in most areas, except where dense salmonberry (*Rubus spectabilis*) growth occurred. The crews identified sites where regeneration had failed, but no trees were planted due to the uncertainty of our ability to keep the salmonberry from growing back and outcompeting the spruce.

Instream structures

Although all of the structures in the Hanning Creek watershed survived two bankfull floods during the summer and fall of 1994, almost half of the structures failed by 1997 (Table 1). Most of the structures that failed were designed to reduce velocities or protect banks from erosion in the main channel where flows are highest. Only five of the 14 structures intended to reduce velocities are still functioning as intended. One additional structure may function only at higher flows. Of the five structures built to protect banks from erosion, one remains. It is functioning well, however, protecting about 35 m of bank and allowing young alder and Sitka spruce to become established along the shoreline. Ten of 13 habitat structures in the smaller tributaries are functioning as intended, creating 163.4 sq m of pool habitat and 21.4 sq m of spawning area. Juvenile Dolly Varden (*Salvelinus malma*) and one adult have been observed using the habitat created by the structures, but no other species have been seen so far. Diagrams of the remaining structures, the habitat created, and other changes in the channels are presented in Appendix 2.

Table 1. Types of instream structures built, purpose, effect in 1995 and 1997. SA = spawning area. DV = Dolly Varden present.

Number	Type	Purpose	Effect 1995	Effect 1997
1	Tree top	Provide rearing area, cover	Washed out	Rebuilt, washed out
2	Tree top	Provide rearing area, cover	7.0 sq m cover	7.0 sq m cover
3	Log barb	Create backwater pool, rearing	1.1 sq m pool	1.9 sq m pool
4	Deflector	Create backwater pool, rearing	1.9 sq m pool	6.0 sq m pool
5	Tree top	Provide rearing area, cover	4.6 sq m cover	1.1 sq m cover, stream shift
6	Tree top	Provide rearing area, cover	11.6 sq m cover	5.9 sq m cover
7	Log jam	Provide rearing area, cover	45.5 sq m cover	13.0 sq m cover
8	Deflector	Create pool, protect bank	13.4 sq m pool	5.0 sq m pool
9	Log barb	Create backwater pool, rearing	3.7 sq m pool	6.7 sq m pool
10	Log V	Create pool, provide habitat	32.7 pool, 7.4 SA	23.2 pool, 15.8 SA, DV
11	Log barb	Create backwater pool, rearing	9.3 sq m pool	7.9 sq m pool
12	Log weir	Create pool, reduce velocity	42.9 sq m pool	40.0 pool, 5.6 SA
13	Log weir	Create pool, reduce velocity	2.2 sq m pool	structure buried
14	Deflector	Protect stream bank	Protects 35 m bank	Same, revegetating
15	Log barb	Create backwater pool, rearing	Washed out	Washed out
16	Log V	Create pool, reduce velocity	50.6 sq m pool, DV	20.2 sq m pool, DV
17	Log barb	Create backwater pool, rearing	3.7 sq m pool	2.7 sq m pool
18	Log weir	Create pool, reduce velocity	5.8 sq m pool	1.9 sq m pool
19	Log weir	Create pool, reduce velocity	Washed out	Washed out
20	Deflector	Protect stream bank	Washed out	Washed out
21	Bank cover	Reduce bank erosion	Partial protection	Washed out
22	Log barb	Deflect flow from bank	Deflected flow	Buried
23	Bank cover	Reduce bank erosion	Bank protected	One anchor pulled, minimal effect
24	Log weir	Create pool, reduce velocity	Washed out	Washed out
25	Log weir	Create pool, reduce velocity	7.4 sq m pool	7.2 sq m pool
26	Log weir	Create pool, reduce velocity	Washed out	Rebuilt, 16.4 sq m pool
27	Log weir	Create pool, reduce velocity	Washed out	Rebuilt, washed out
28	Log weir	Create pool, reduce velocity	Log broke	Washed out
29	Log weir	Create pool, reduce velocity	Washed out	Washed out
30	Log weir	Create pool, reduce velocity	5.8 sq m pool	Works at high flows only
31	Log weir	Create pool, reduce velocity	Washed out	Washed out
32	Log weir	Create pool, reduce velocity	not monitored	Washed out

The downstream study site has undergone considerable changes since 1994 (Figure 1a, 1b), but as will be discussed, the changes are probably not due to the instream structures. The site begins where two channels of Hanning Creek join. A channel shift upstream, however, has diverted most of the flow into what was a small, secondary channel in 1994. The main flow now hits the right bank at an approximately 60-degree angle instead of running parallel to the bank.

It appears that much of the stream's energy is expended as it hits the bank. The active stream channel, as it crosses from the right bank to the left, is no longer a relatively narrow, deep glide. Instead, it is a wide, shallow riffle. The pool which was in the center of the site has filled, but deeper areas have formed around a debris jam at the downstream end of the site. The channel geometry at the four transect sites has changed accordingly. Comparisons are shown in Figure 2. Bankfull widths have not changed, and there is no evidence that alder, willow, or other pioneer species are recolonizing the gravel bars. The analysis of the Wolman pebble counts shows that there has been a significant increase in the substrate material smaller than 64 mm (chi-square = 17.29 with Yates' correction, df=1, $p < .001$).

Figure 1 a. Downstream control site in 1994.

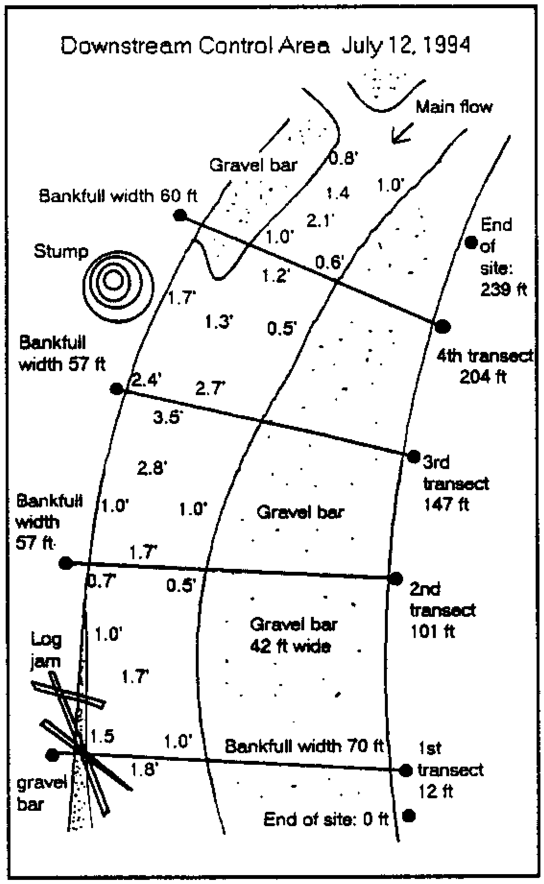


Figure 1 b. Downstream control site in 1997.

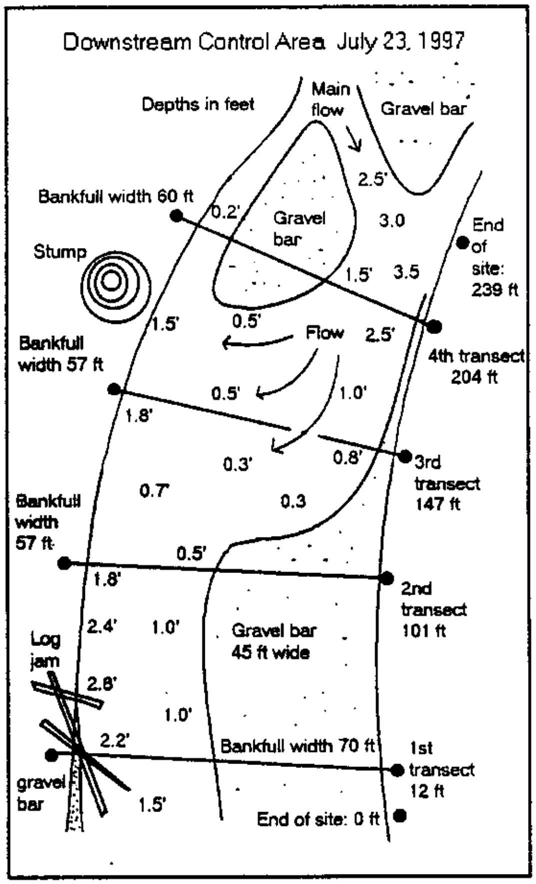
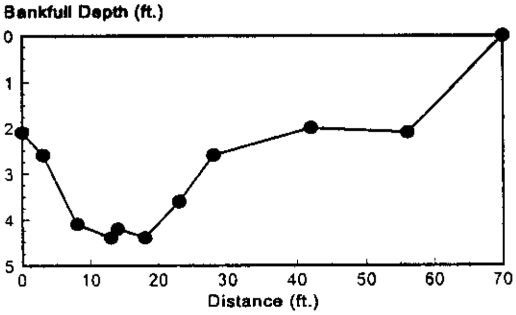
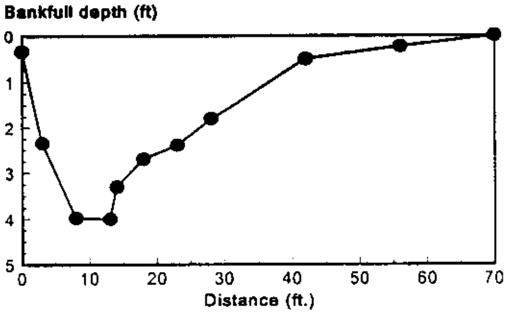
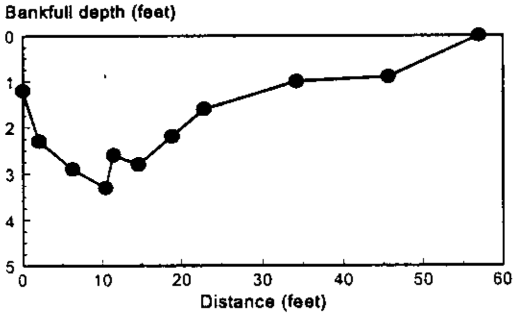
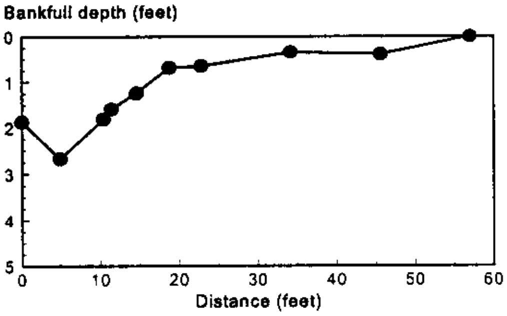


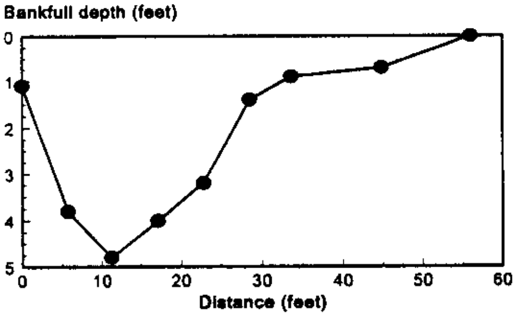
Figure 2. Changes in channel geometry from 1994 to 1997 at the downstream monitoring site at Hanning Creek.

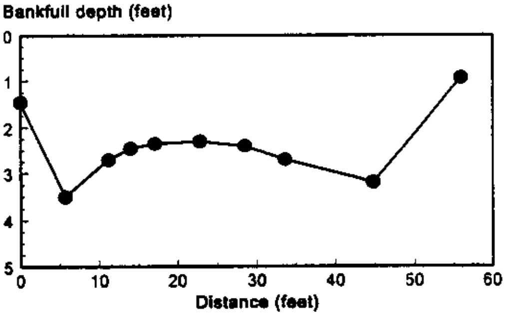

1994 Channel Cross Section at 12 ft Transect

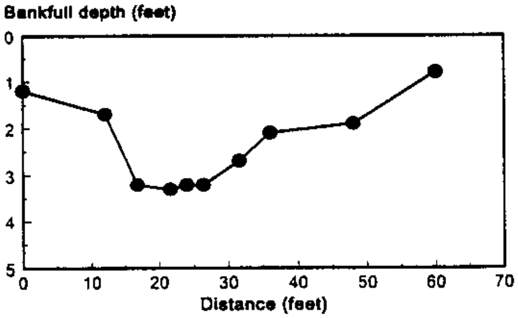

1997 Channel Cross Section at 12' Transect

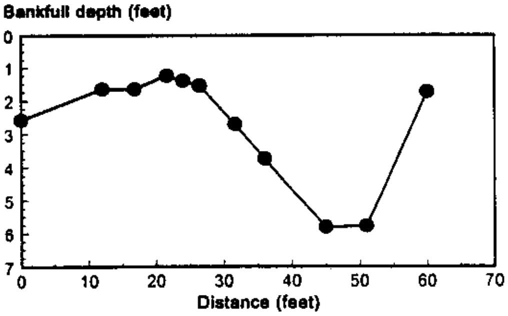

1994 Channel Cross Section at 101 ft. Transect


1997 Channel Cross Section at 101 ft. Transect


1994 Channel Cross Section at 147 ft. Transect


1997 Channel Cross Section at 147 ft. Transect


1994 Channel Cross Section at 204 ft. Transect


1997 Channel Cross Section at 204 ft. Transect

Monitoring of Sitka spruce growth in thinned and unthinned areas showed different results depending on the type of thinning that was done. The Hanning Creek sample site, where just the competing alder and willow were removed, was monitored in 1995 and 1996. The first year there was significantly greater mainstem and whorl growth in the thinned sample site than in an unthinned area, but there were no differences the following year (Table 2).

Table 2. Differences in mainstem and whorl growth between thinned and unthinned areas, and between thinned sites at Swamp Creek (all species thinned) and Hanning Creek (where only competing willow and alder were removed). The Kruskall-Wallis tests were performed when the data were still non-normal after a log transformation. An asterisk denotes a significant difference.

Site, year, measurement	N (both sites)	Mean Growth (cm)		F stat.	K-W stat	p-value
		Thinned	Unthinned			
1995 Hanning Creek						
Mainstem growth	15	18.5	12.7		9.27	0.002*
Whorl growth	15	14.0	11.2		8.86	0.003*
1996 Hanning Creek						
Mainstem growth	20	21.3	17.4		0.594	0.441
Whorl growth	20	11.6	11.9	0.030		0.857
1996 Swamp Creek						
Mainstem growth	20	38.4	29.6	6.820		0.013*
Whorl growth (log transformation)	20	19.8	14.3	10.86		0.002*
1996 Swamp vs Hanning (both thinned)						
Mainstem growth	20	38.4	21.3	16.21		< 0.001*
Whorl growth	20	19.8	11.6	26.27		< 0.001*
1997 Swamp Creek						
Mainstem growth	25	42.8	25.8	16.21		< 0.001*
Whorl growth	25	20.9	12.7		19.87	< 0.001*

At the Swamp Creek sites, where all species were thinned, there was significantly greater growth in the thinned areas than in the untreated areas for both 1996 and 1997. (The site was not monitored in 1995.) The spaces between the trees were starting to fill, but the stand was not yet crowded. Both mainstem and whorl growth in thinned areas were significantly greater at Swamp Creek than at Hanning Creek in 1996. No blowdown, sunburn, or other negative effects were noted at these sites.

The site at Quadra Creek was examined qualitatively. The canopy is still open in both treated areas, so the trees should be benefitting from the reduced competition. Although there is additional light reaching the forest floor, understory plants such as blueberry *Vaccinium spp* or bunchberry *Cornus canadensis* have not become established yet. The slash, which was cut up and piled, has not fully decayed yet. Unlike the other areas, there has been limited blowdown at the treated areas at Quadra Creek. One tree blew down in the "diameter plus five" treatment area, and three others at the 4.3 m treatment site. No blowdown occurred at the control area. As mentioned earlier, the growth of the trees at Quadra Creek will not be measured for several years.

Discussion

One of the questions that has been posed is whether the stream conditions that we have observed - the highly eroded banks, wide channels and gravel bars, and limited pool habitat - are due to logging or are actually a result of naturally unstable conditions in these streams. The implication is that if the streams are naturally unstable, then there is little that can be done with instream structures or other means to alleviate these problems. This does not appear to be the case with the streams we worked at. In the pre-logging aerial photographs from 1959, the wide channels and extensive bare gravel bars are either not apparent or present to a much lesser degree. Although the streams and logged areas are on alluvial fans and floodplains where channel movement and other disturbances are natural occurrences, these systems appeared to be more stable in the past than they are now.

This is not to say that there have been no natural changes. At the two smaller streams, Swamp Creek and the unnamed creek, one can see that there have been natural channel shifts by the spacing between the spruce and the strips of alder and willow along the former and current channels. However, the channels are all well-vegetated and there is no sign of the wide, bare gravel bars that are apparent later.

Quadra and Hanning creeks are larger streams, and greater amounts of bedload material are transported to the alluvial zones from the upstream areas. The 1959 photographs do show naturally wide, bare, gravel bars in the upper ends of these zones. Unlike the present conditions, however, there appears to have been more of a dynamic equilibrium within the stream systems. Downstream from these initial deposition areas, the channels narrow and the wide, bare gravel bars disappear. Interpretation of the photographs at Quadra Creek is difficult because the downstream area was logged the year before, and part of the flow may have been diverted down a logging road. At Hanning Creek, however, the photographs show that most of the downstream gravel bars are narrower and are well vegetated with alder or willow. These pioneer species indicate some past disturbance, but the fact that these bars had revegetated shows that there is greater long term stability than the bare gravel bars upstream. There is some evidence, then, that these systems have been more stable and, we infer, more suitable for fish habitat than they are currently.

It is also possible that the 1964 earthquake caused some channel widening in these systems. After the area was uplifted, the stream channels began to downcut at the new mouths of the streams and cut upstream until a stable gradient was reached or until there was a bedrock barrier (Ken Holbroook USFS Fisheries Biologist, personal communication). One possible scenario is that the banks collapsed as the channels downcut, widening the streams and adding additional bedload material. This may have been the case at Quadra Creek and perhaps at the unnamed creek. At Swamp Creek, most of the sections of wide channels and gravel bars are discontinuous and are well upstream from the downcutting area. At Hanning Creek there is a bedrock outcrop which stopped the downcutting about 300 m from the upper tidal limit. It is not known whether the earthquake affected these systems in any other manner.

Admittedly, it is difficult to determine the causes of the changes in these systems simply from the aerial photographs. The 1959 photographs portray only a single point in time, and the relative stability we attribute to the streams at that time may only have been a brief lull before the next catastrophic event. At Quadra Creek, Swamp Creek, and the unnamed creek, we cannot prove that the stream widening, bank erosion, and lack of pools are due solely to logging. Although these conditions can be caused by the removal of the riparian vegetation (Chamberlin 1982, Murphy 1995), as was the case at all of the streams, there is still the possibility that the 1964 earthquake and the inherent instability of alluvial fans and floodplains were contributing factors.

The effects of the logging at Hanning Creek are much clearer, however. The shifting of the stream down the logging roads is certainly an unnatural event, and the shifts were probably facilitated by the lack of a buffer strip along the former channel. The upper section of the main channel that shifted is still downcutting and widening, adding additional material to the natural load. We can only speculate as to when the channel may return to some state of equilibrium. Judging from the 1959 photographs, the upper part of this section may still need to widen to accommodate the peak flows and store some of the bedload material being transported from upland areas. Perhaps, once the maximum channel width is attained, the riparian vegetation will then be able to stabilize the banks, allowing the system to function as it had previously.

Instream structures

As stated in the introduction, one of our primary mistakes was not recognizing that the main channel of Hanning Creek, and some of the tributaries, are still adjusting to the channel shifts and other changes. In the upper section of the main channel, the stream has downcut about 0.7 m since 1994. Thus, the six structures in that area have all been undermined. Other structures have been buried or partially buried by bedload deposition. It is uncertain whether any structures can be effective in these areas until conditions become more stable. The remaining main channel structures are functioning, but their combined effect is too limited to be meaningful given the size and power of Hanning Creek. Thus, there probably has been no benefit to pink and chum salmon, the primary species of concern for this project.

Another problem was that many of our structures tried to challenge the power of the stream. Frissell and Nawa (1992) reported in their survey that the structures that failed the least were those that "minimally modified the pre-existing channel." Conversely, the log weirs we used for our main channel structures attempted to disrupt the flow, introduce roughness, and create plunge pools. While such structures produce "immediate and more obvious changes in channel morphology and hydraulics" (Frissell and Nawa 1992), they also bear the full impact of the energy of the stream. In hindsight, perhaps less obtrusive structures designed to deflect flows away from the banks may have worked in the areas farther downstream. Such structures would not reduce velocities or store bedload material as our structures were supposed to do, but they might have reduced erosion and given the riparian vegetation extra time to stabilize the banks and begin the re-establishment of the forest.

As mentioned earlier, we had hoped to indirectly assess the cumulative effects of the structures by monitoring changes in substrate size and channel geometry at the downstream study site. MacDonald et al. (1991) recommended monitoring individual pools and riffles to detect substrate changes, which was our intention. However, the radical change of the pool and riffle boundaries caused by the shifting of the stream has masked any effect the structures may have had. The significant decrease in substrate size in the study site appears to be a result of the stream expending its energy as it hits the bank, rather than an overall reduction in stream velocity caused by the structures.

We could not attribute any of the changes in the channel geometry to the structures either. The major change was the creation of a wide, shallow riffle which appears to be the result of the channel shifting and cutting into a former gravel bar. The pool and glide areas that existed in 1994 have been partially filled with the material from the gravel bar. If the structures had functioned as intended, we would have expected to see the export of excess substrate, deepening of the channel, and the reduction of substrate mobilization along the edges of the gravel bars (Lisle 1989). Once the edges stabilize, alder or willow could become established, eventually narrowing the bankfull width (Lisle 1989). This process has not been evident. Although only three years have passed since the completion of the structures, we should have noted the establishment of pioneer vegetation if the gravel bars were not being mobilized or disturbed annually. At one of the structure sites where the bank has been protected, small alders are now growing, so it is not too soon to expect some revegetation.

The habitat structures have created the desired habitat features, and because they were built in smaller tributaries, they have generally survived the high-flow periods. So far, however, only Dolly Varden have been observed using the structures. Juvenile coho salmon have been seen in a debris jam at the downstream study area, but none have been seen farther upstream. There has probably been a limited number of coho salmon in the upper watershed because of the higher velocities and relative scarcity of suitable pool habitat. Although the structures have improved habitat in the tributaries, it may take awhile for coho to colonize the area. Dolly Varden, on the other hand, are probably more prevalent in this section of the watershed since they can utilize a wider variety of habitats, including shallow, higher velocity areas (Dolloff and Reeves 1990, Bugert et al. 1991).

Thus, the overall effect of the structures is rather modest at best. There may be some benefit to Dolly Varden and juvenile coho salmon, but the primary target species, pink and chum salmon, have not been helped by the structures. When this project was started, there was a good deal of enthusiasm for instream structure projects as reported in the literature (House and Boehne 1986, Fuller 1990, Nickelson et al 1992, Crispin et al. 1993). There were, however, long-term assessments which reported mixed results, especially as structures physically deteriorated over time (Frissell and Nawa 1992). Other authors criticized projects for simply trying to create habitat while overlooking the sources of the problems, for example, sedimentation from roads, eroding slopes, water diversions, etc. (Kershner et al. 1991, House 1996). As mentioned in the introduction, there are no upslope problems related to logging or other activities, so we felt that instream structures in the degraded channels could be of some benefit. Unfortunately, the instability of the channel, the power of the stream, and the inability to use heavy equipment at the remote location led to the failure of most of the structures.

Hopefully, however, the current federal and Alaskan regulations governing timber harvest practices will reduce the disturbances in the riparian areas and eliminate the need for extensive restoration efforts in the future. While stream protection measures vary on federal, state, and private lands, buffer strips are generally required along streams with anadromous fish and "best management practices" (BMP's) are enforced by state or federal agencies (Murphy 1995). Murphy (1995) states, however, that the effectiveness of these practices had not yet been fully evaluated. But even if the streams are not fully protected, it appears that simple measures like buffer strips or not building skid trails across the streams would have prevented most of the channel alteration and degradation of fish habitat that occurred at Hanning Creek.

Riparian vegetation thinning

The growth data show greater Sitka spruce growth after thinning, as has been reported in other areas (Smith 1962, Fowells 1965). The effects differ, however, depending on the type of thinning employed. Simply removing the competing species appeared to increase growth only for the first year and is probably ineffective for promoting spruce growth over any extended time. By the time the Hanning Creek site was sampled in 1996, two years after the thinning, the spruce appeared to fill in the gaps where the other species had been removed and may have begun to compete with each other. This was not the case at Swamp Creek and the unnamed creek where the spruce were thinned as well.

There were some problems measuring the growth. Because of the heights of the trees and the crowded stands, it was hard to make accurate measurements in 1995 and 1996. Even with ladders, it was difficult getting measuring devices in place at the tops of the trees. Cutting down trees at Swamp Creek in 1997 enabled us to make more accurate measurements, but at the Hanning Creek site there were not enough trees to allow us to do this. The regeneration of spruce at Hanning Creek is patchy, and there are few areas with large numbers of trees and relatively uniform growing conditions. Because of these problems, our sampling was limited in 1995 and 1996, and we were unable to justify cutting trees in 1997.

There is little published information on the long-term effects of thinning Sitka spruce for the Prince William Sound area or Alaska in general. We did obtain some unpublished data from a project in which thinned plots in southeast Alaska were monitored from 1974 to 1996 (Robert Deal, U.S. Forest Service, Forestry Sciences Laboratory, Juneau, AK). Since the data are somewhat limited and conditions varied among stands, no statistical analysis was attempted. Generally, however, the thinning done with 3.7-m and 4.9-m spacing produced trees with substantially larger mean diameters than unthinned areas (31-42 cm vs 19 cm). The mean heights were more similar (25.6-26.2 m vs. 23.4 m).

The height of the tree is important in determining whether it will be stable once it falls into a stream, while the diameter is important for creating pools, storing bedload material, and resisting abrasion and decay (Murphy and Koski 1989). The size of the stream, gradient, and other factors also determine how big a tree must be to be "effective." For streams with bankfull widths greater than 10 m, such as Hanning Creek, a tree with a diameter of 30-40 cm (Swanston 1991, U.S. Forest Service Region 10 Survey Protocol, unpublished) and height 1.5-2.0 times the bankfull width (Hilderbrand et al. 1997) would generally be effective. Although the growth data from southeast Alaska varied among plots, it appears that trees thinned when they reach 6-9 m could reach this effective size within 15-20 years. Unthinned trees would be nearly the same height, but may take an additional 30-60 years to achieve the same diameter.

The thinning at Swamp, Hanning, and the unnamed creeks was conducted in slightly younger stands than the southeast Alaska thinning, and the spacing varied. Since the spacing was not always as wide, and Sitka spruce growth in Prince William Sound is generally slower than southeast Alaska (Farr and Harris 1979), the trees in our thinned areas will probably take a longer time to reach an effective size. Still, the growth should be faster than in untreated areas. At Quadra Creek, the thinned stands were older and larger to begin with, so an effective size could be reached in 10-20 years.

Thinning is a labor intensive process which requires skilled operators and numerous safety precautions. Given our experience, thinning should be restricted to those areas where all other sources of woody material have been removed and where it is desirable to accelerate the restoration process as much as possible. But again, current timber harvest regulations should reduce the need for thinning in the riparian areas in the future. In Alaska, streams with anadromous fish are protected by 30-m (100-ft) wide buffer strips on federal and most state land, or a 20-m (66-ft) buffer on privately owned lands, with some variances (Murphy 1995). Murphy (1995) estimates that nearly 100% of the trees which will provide large woody material will be preserved with the 30-m buffer, and 82% will remain with the 20-m buffer. Thus, unless there is considerable blowdown, fire, or some other event which allows crowded stands to grow back, there may be no need to thin riparian areas in the future.

Conclusions

This project failed to achieve its main objective: the reduction of stream velocities, bedload movement, and bank erosion in Hanning Creek. This was due to the high rate of failure of the main channel structures over the three-year period. We failed to recognize that the upper main channel of Hanning Creek, where the creek had shifted down an old logging road, was still unstable. The channel probably needs further downcutting and widening to accommodate peak flows and the natural input of bedload material from upstream. Habitat structures in the smaller tributaries were more successful and are providing cover and rearing area as intended.

Thinning of crowded stands of Sitka spruce has accelerated growth in areas where all species were removed. In a stand where only competing willow and Sitka alder were removed, spruce growth showed no significant difference than an untreated area after one year. An unpublished study from southeast Alaska indicates that thinning should substantially reduce the time it takes for the spruce to achieve an effective size for input into the streams.

Current federal and state timber harvest regulations should reduce impacts to streams and riparian areas, and, hopefully, reduce the need for instream structures designed to radically alter flows or other stream characteristics. Where buffer strips are required, the uncut areas should provide sufficient sources of woody debris for the streams in the future. This should reduce the need to thin trees in riparian areas under normal circumstances.

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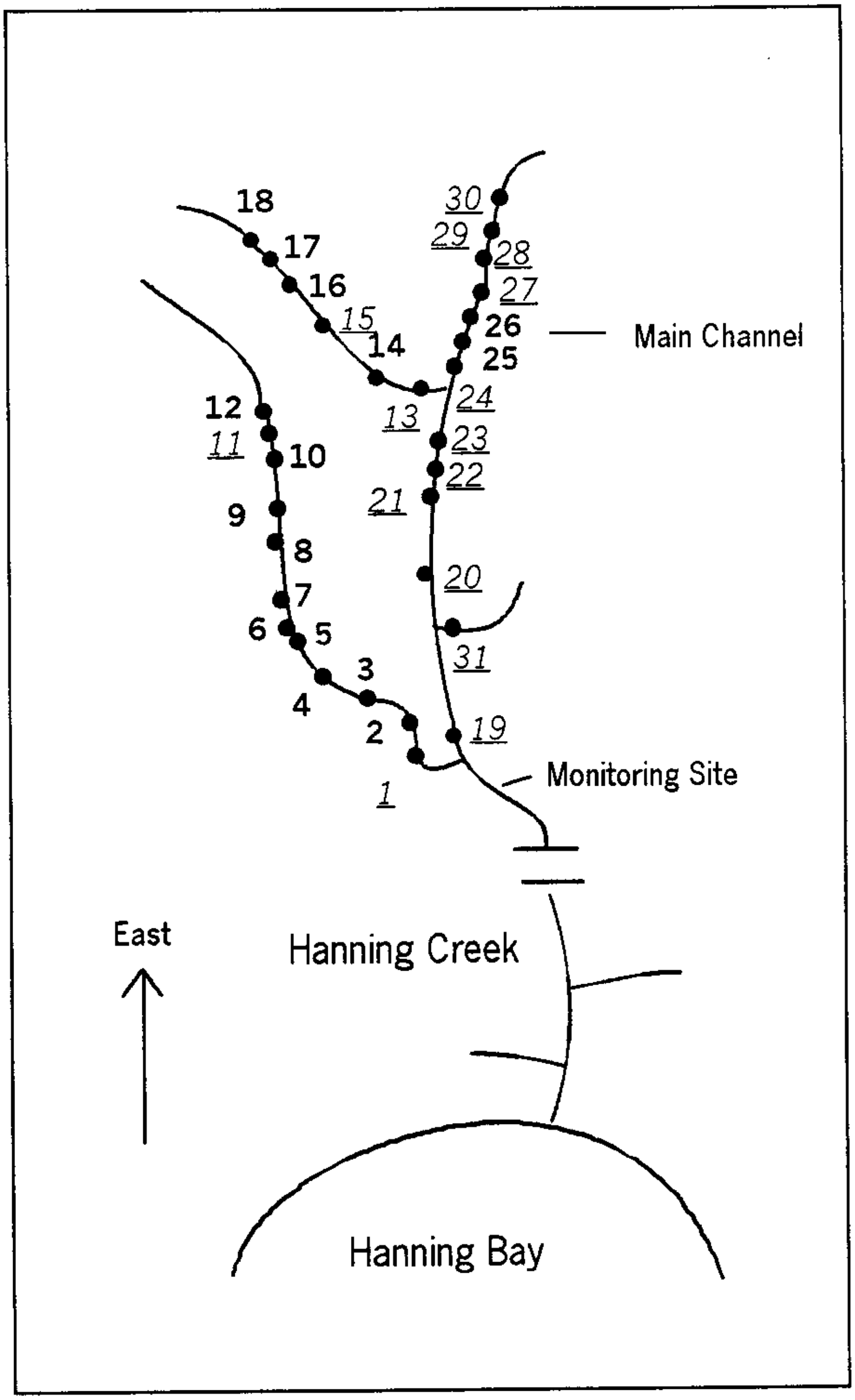
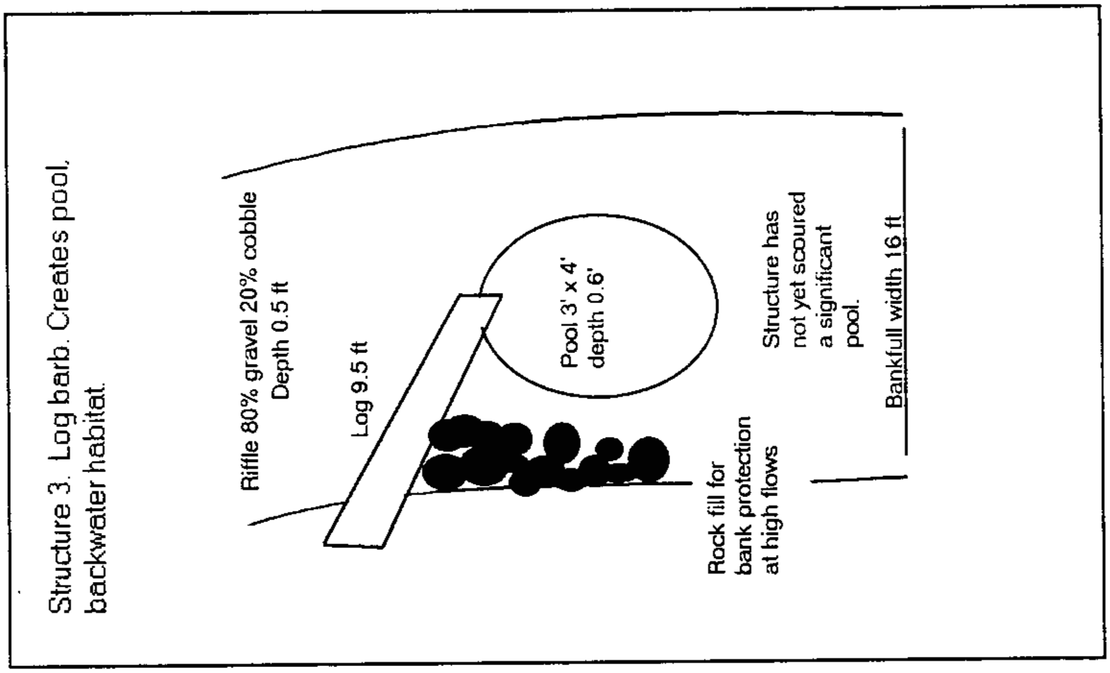
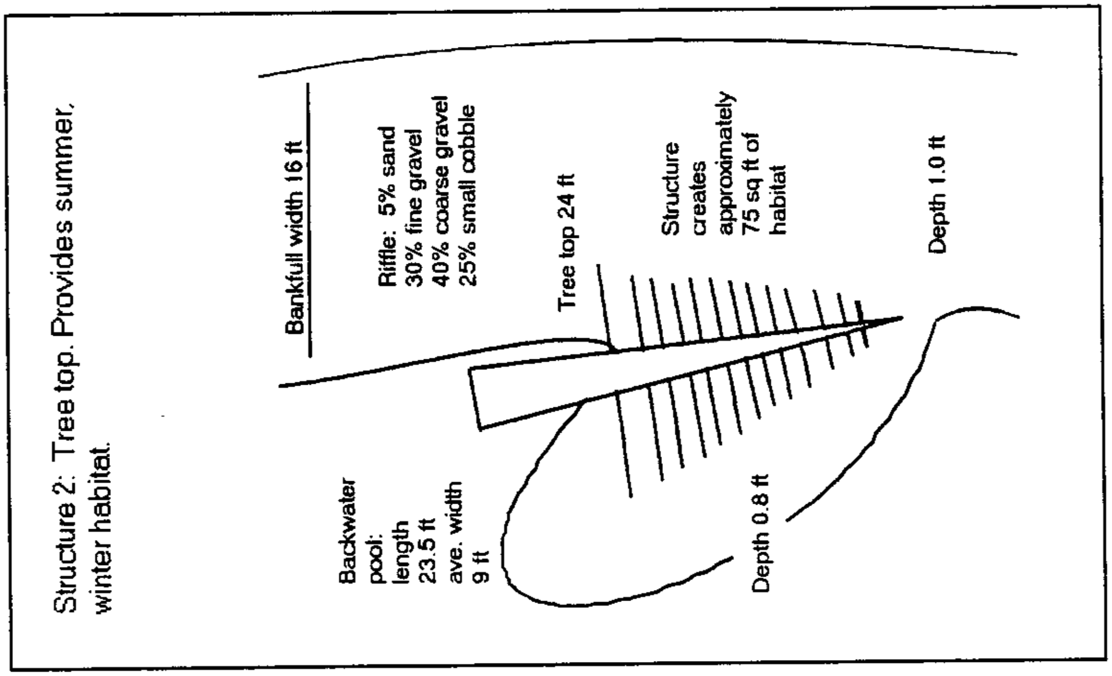
Appendix 1. Location of structures at Hanning Creek. **Bold** numbers indicate structures which are still functioning. *Italic* and *underlined* numbers indicate structures which have failed. One other structure at an unnamed creek failed.



Appendix 2. Diagrams of remaining structures and habitat features. Diagrams of the failed structures are included in the 1994 annual report. Figures not drawn to scale.



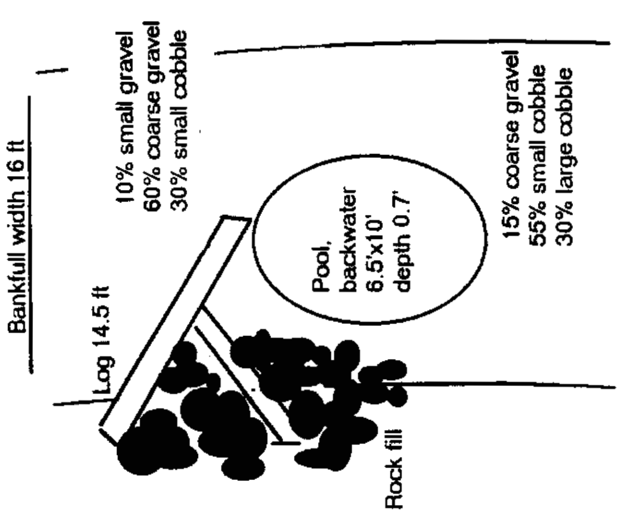
Structure 3. Log barb. Creates pool, backwater habitat.



Structure 2: Tree top. Provides summer, winter habitat.

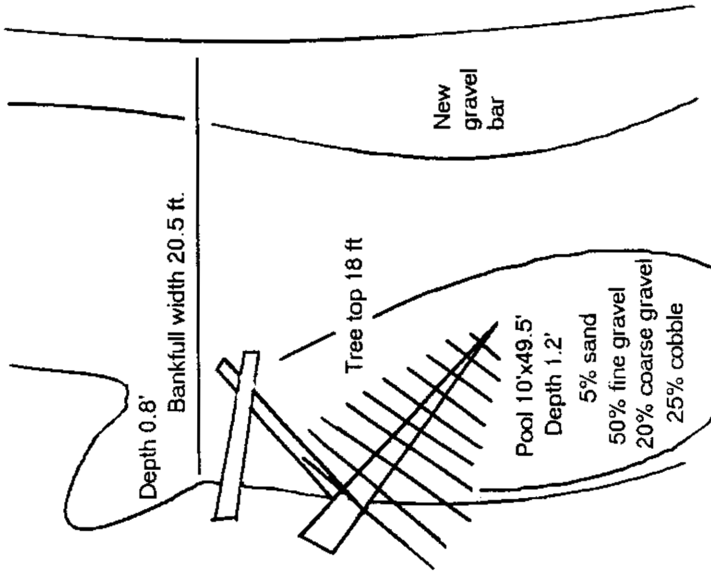
Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.

Structure 4. Wing deflector. Protects bank. Creates backwater habitat.



Structure has created a pool and backwater. Pool has grown from 4'x5' in 1995, so may continue to enlarge.

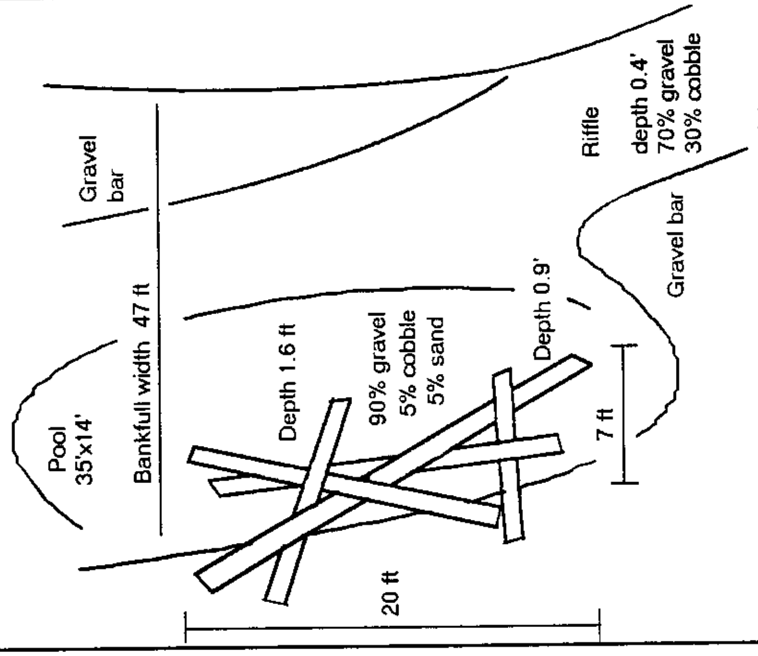
Structure 5. Tree top/logs. Provides cover for existing pool habitat.



Pool has become shallower and thinner. Substrate has changed from 50% cobble in pool to present composition.

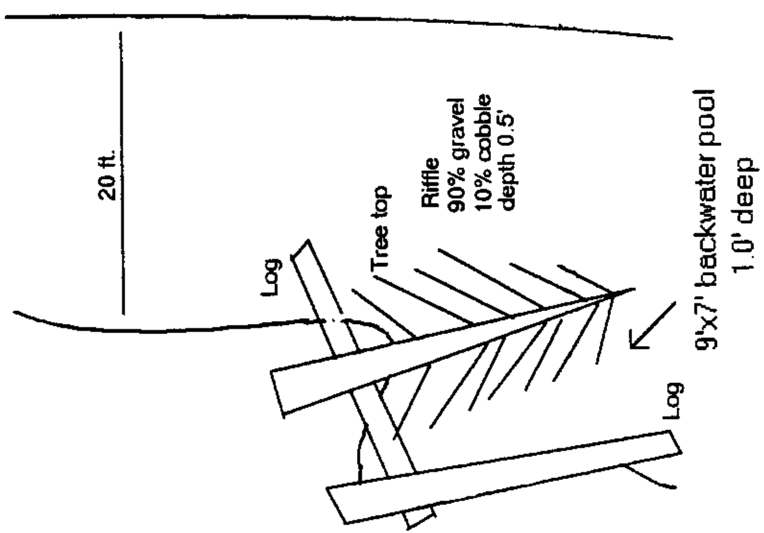
Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.

Structure 7. Log jam. Provides summer and winter rearing area, more complex habitat for existing pool.



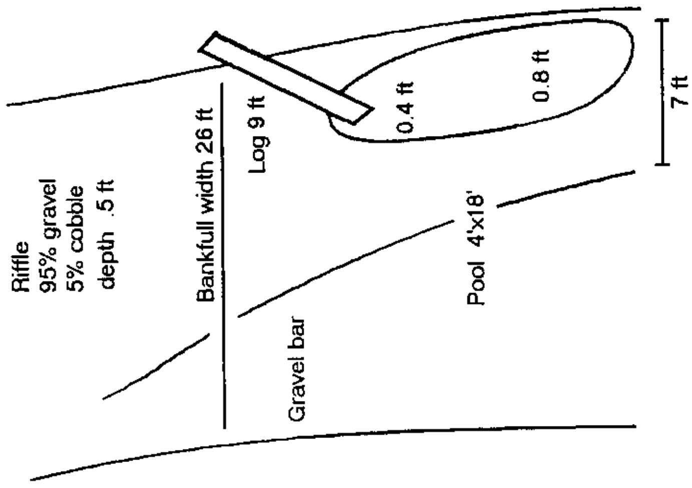
Pool has deepened slightly. Gravel bar on right bank is revegetating and new bankfull width may be about 31 ft.

Structure 6. Tree top, logs. Provides cover and more complex rearing habitat for existing pool.



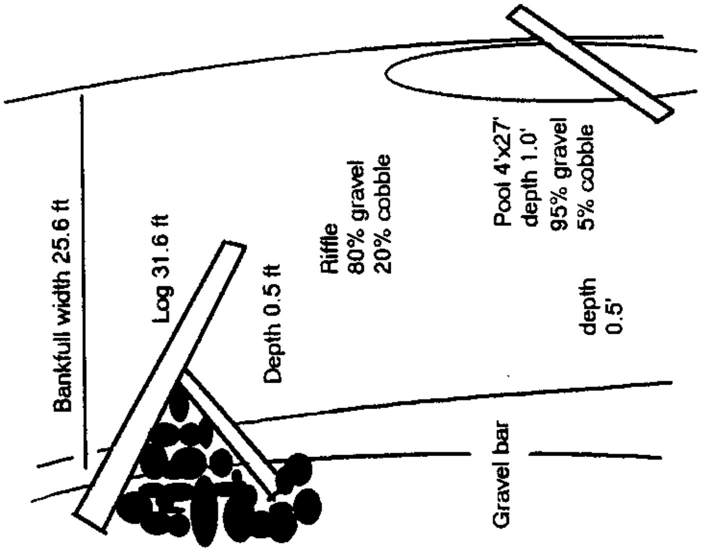
Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.

Structure 9. Log barb. Creates backwater area and scours pool at the end of the log.



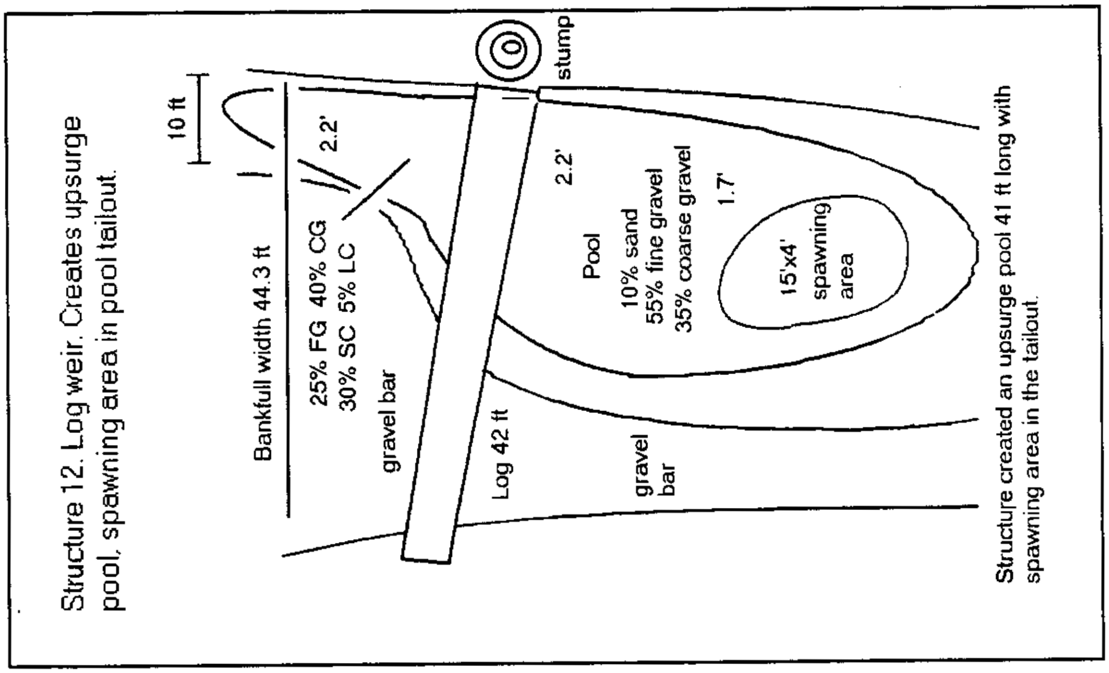
Structure created shallow pool which is enlarging.
Gravel bar has widened, narrowing the channel.

Structure 8. Wing deflector. Intended to create pool and backwater at structure, concentrate flow to maintain and deepen downstream pool.



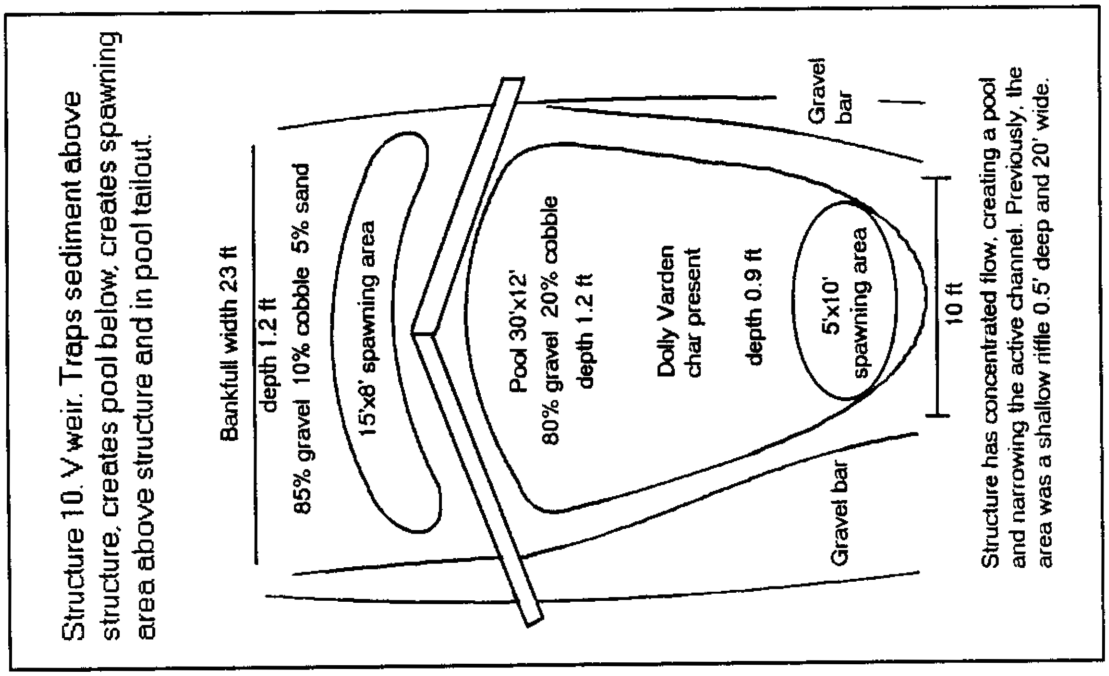
Structure has created shallow backwater area for juvenile rearing, but no pool has formed.
Downstream pool dimensions still the same.

Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.



Structure 12. Log weir. Creates upsurge pool, spawning area in pool tailout.

Structure created an upsurge pool 41 ft long with spawning area in the tailout.

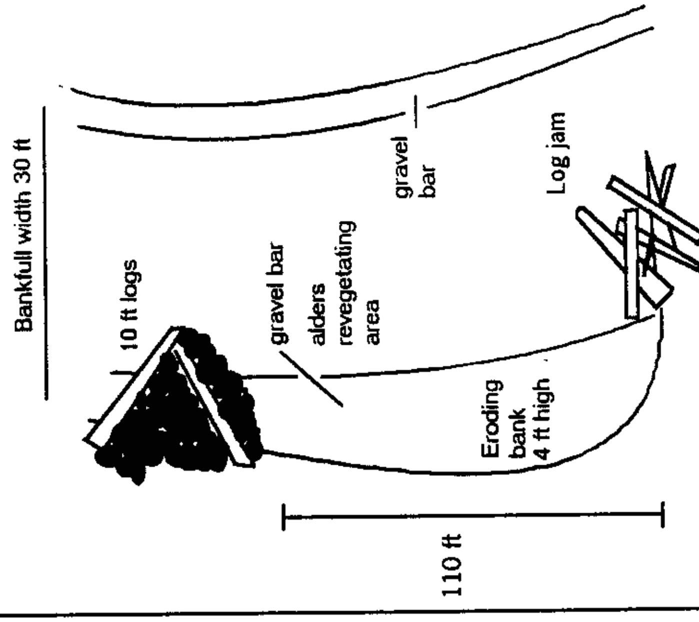


Structure 10. V weir. Traps sediment above structure, creates pool below, creates spawning area above structure and in pool tailout.

Structure has concentrated flow, creating a pool and narrowing the active channel. Previously, the area was a shallow riffle 0.5' deep and 20' wide.

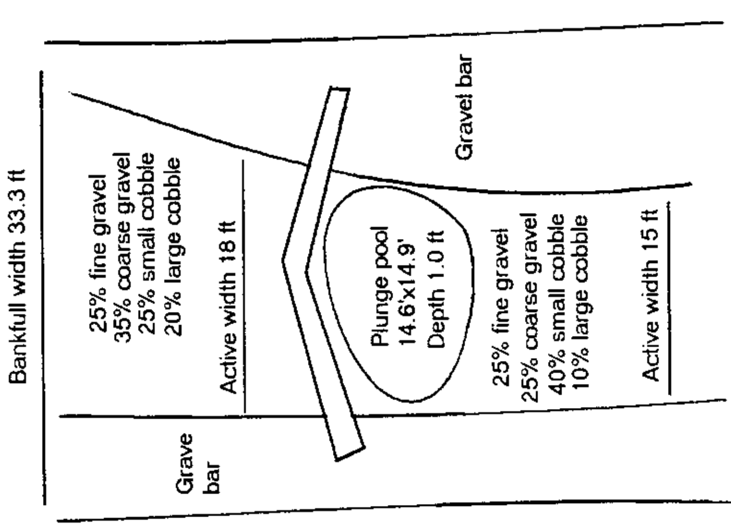
Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.

Structure 14. Wing deflector. Protects eroding bank, allows young trees to become established.



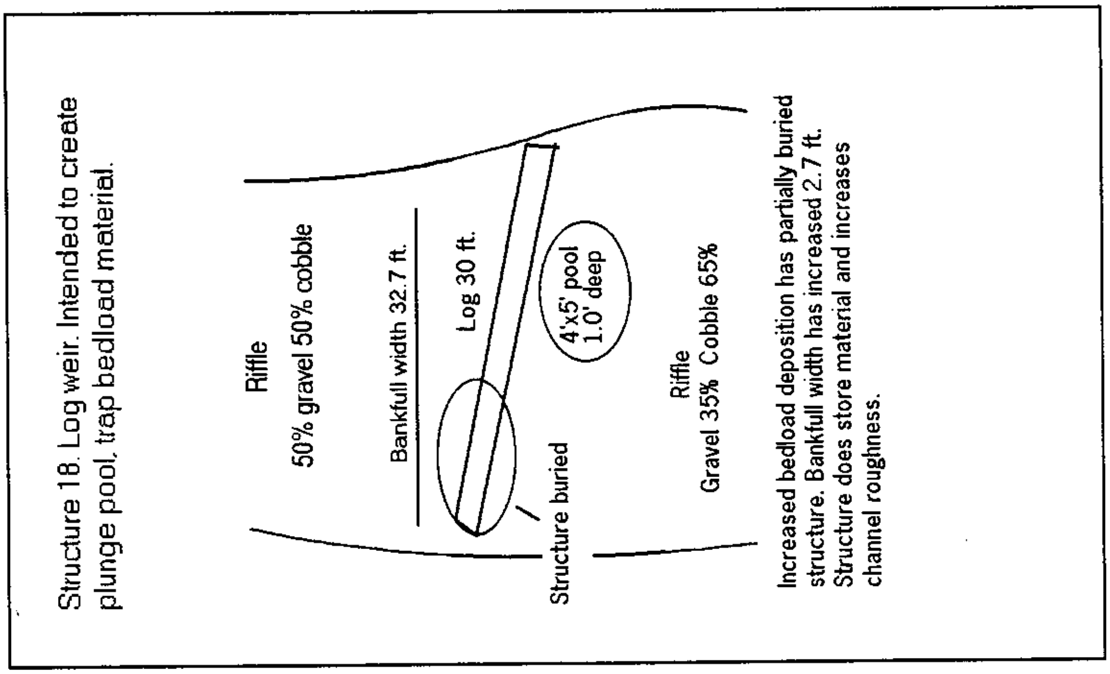
Structure has stopped erosion of bank, protecting young spruce. Alders have colonized gravel bar, indicating greater stability.

Structure 16. V weir. Intended to create pool in flat riffle area, trap bedload material.



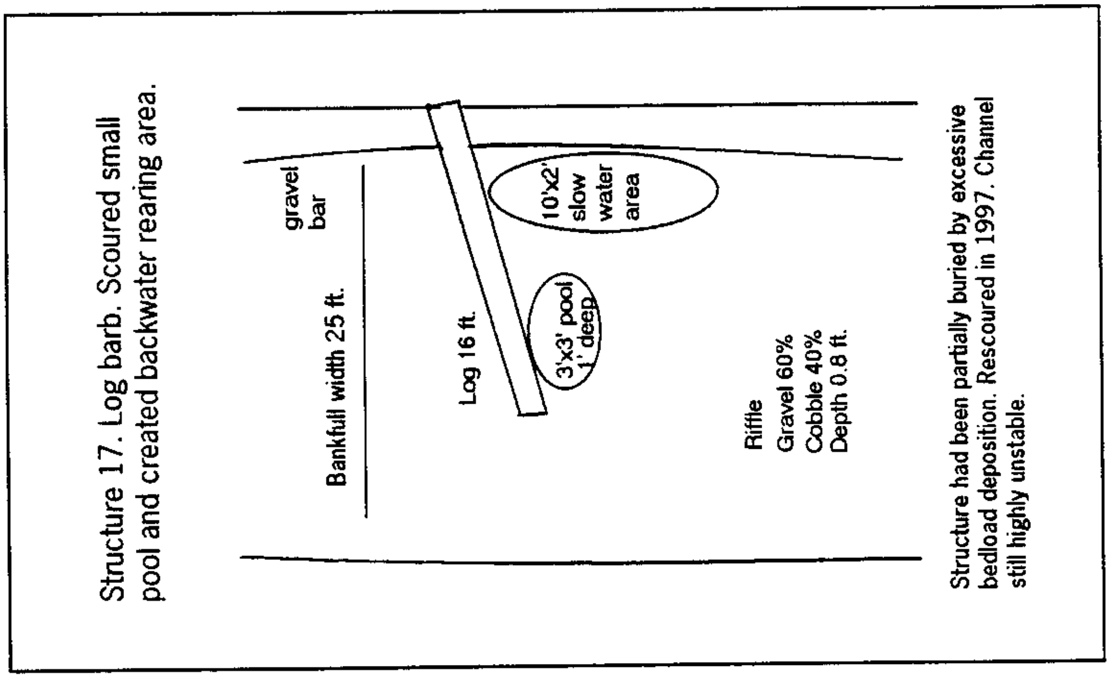
Structure has concentrated flow, creating a pool and narrowing the active channel. No apparent effect on the bankfull width yet. Substrate size has increased above and below the structure. Dolly Varden char observed in pool.

Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.



Structure 18. Log weir. Intended to create plunge pool, trap bedload material.

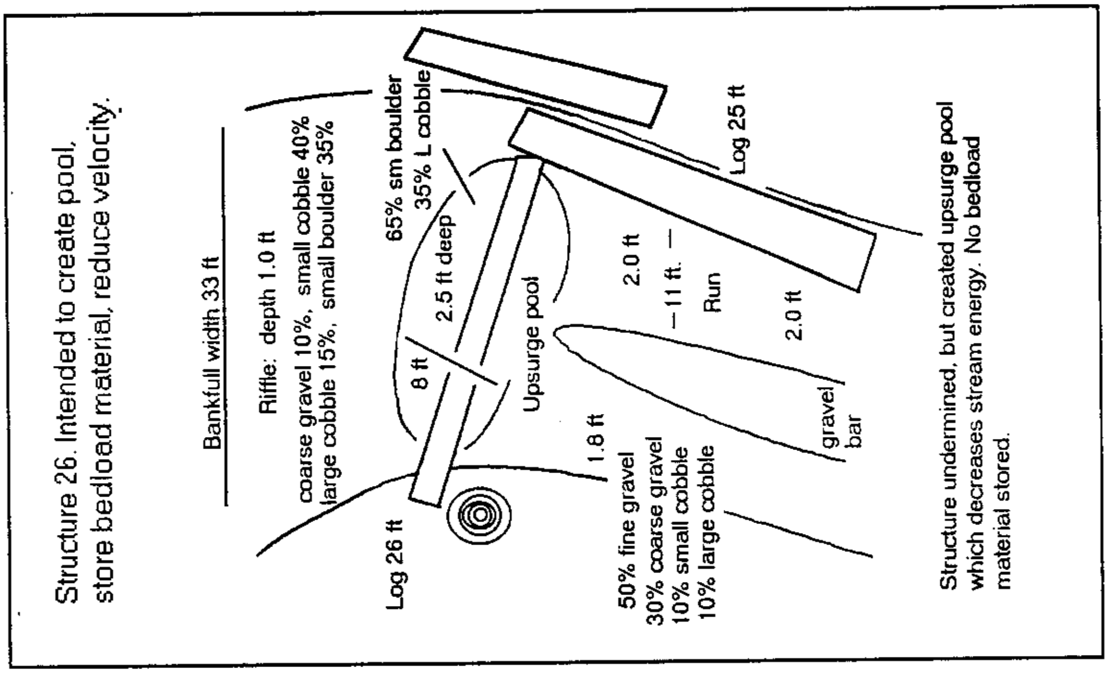
Increased bedload deposition has partially buried structure. Bankfull width has increased 2.7 ft. Structure does store material and increases channel roughness.



Structure 17. Log barb. Scoured small pool and created backwater rearing area.

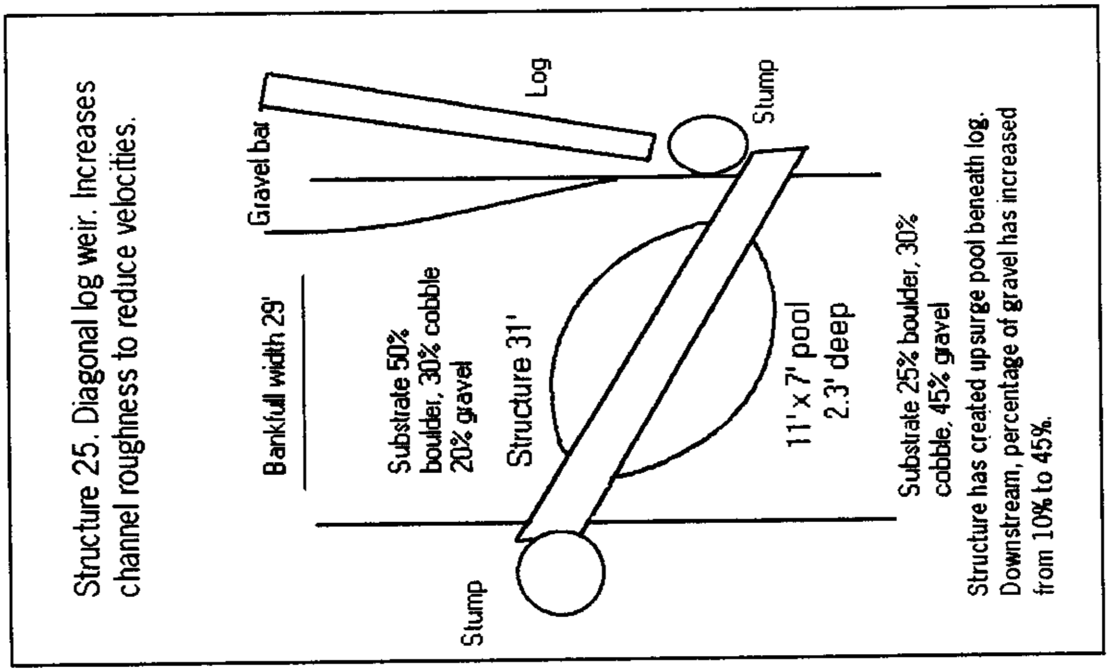
Structure had been partially buried by excessive bedload deposition. Rescoured in 1997. Channel still highly unstable.

Appendix 2 continued. Diagrams of remaining structures, habitat features. Not drawn to scale.



Structure 26. Intended to create pool, store bedload material, reduce velocity.

Structure undermined, but created upsurge pool which decreases stream energy. No bedload material stored.



Structure 25. Diagonal log weir. Increases channel roughness to reduce velocities.

Structure has created upsurge pool beneath log. Downstream, percentage of gravel has increased from 10% to 45%.