LUMMI TRIBAL FISHERIES DEPARTMENT

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U. S. FISH AND WILDLIFE SERVICE

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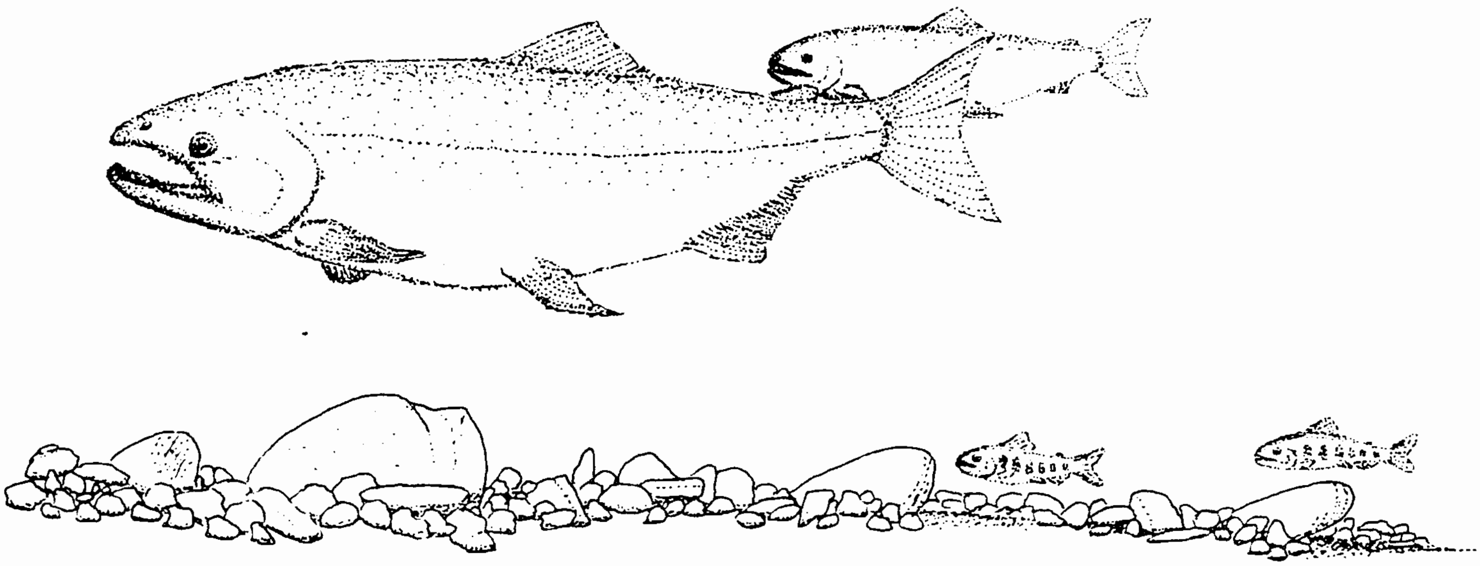
NOOKSACK TRIBAL FISHERIES DEPARTMENT

DEMING, WASHINGTON

AN ASSESSMENT OF THE AVAILABILITY AND QUALITY OF SPRING CHINOOK HOLDING AND SPAWNING HABITAT IN THE SOUTH FORK NOOKSACK RIVER, 1986



AN ASSESSMENT OF THE AVAILABILITY AND QUALITY OF SPRING CHINOOK HOLDING AND SPAWNING HABITAT IN THE SOUTH FORK NOOKSACK RIVER, 1986

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ABSTRACT

Results of an interagency study of spring chinook spawning and holding habitat in the South Fork Nooksack River are presented. Holding habitat appeared adequate for present spring chinook populations. However, much habitat was of poor quality, lacking the water depths and woody debris preferred as cover by spring chinook. Mean pool depth was 5.0 ft which is significantly less than preferred depths. Filling of pools with sediment was documented. Water temperatures were above levels preferred by spring chinook. They were typically above 65 degrees F and exceeded 70 degrees F at multiple stations for seven days. Shallow pool depths, lack of adequate cover and high water temperatures appeared to contribute to stress and mortality from poaching and predation. Almost three million ft of useable spawning habitat capable of supporting an estimated 2889 spawning fish was inventoried. Four percent of the spawning habitat was judged unuseable due to fine sediment embeddedness; however 37% was 25-50% embedded, and may become unuseable if sedimentation increases. Stream stability ratings for most reaches were unstable or moderately unstable. Redd disturbance due to stream channel instability appears to be the most significant cause of mortality in the intragravel stage of development. Considerable redd loss (37.5%) was documented in a winter with moderate storm flows. Sediment sources included 37 inner gorge landslides and extensive areas of eroding stream banks. These sources, together with those in tributary watersheds appear to have exceeded the river's transport capacity, resulting in formation of a wide, shallow and unstable aggraded channel. This channel morphology has resulted in reduced pool depths, higher water temperatures, sedimentation of spawning gravels, and increased redd disturbance due to channel instability.

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INTRODUCTION

This report presents the results of an interagency assessment of spring chinook spawning and holding habitat in the South Fork Nooksack River and the environmental factors affecting habitat abundance and quality. The purpose of this assessment is to provide information on the availability and condition of spring chinook habitat in the South Fork Nooksack River and the relationship between habitat conditions and the currently depressed spring chinook population levels.

The chinook salmon, Oncorhynchus tshawytscha, is the largest of the Pacific salmon. It is a highly valuable species caught in sport and commercial fisheries, and has cultural and religious significance for Northwest Indian Tribes. The spring chinook is a race of chinook salmon characterized by early run timing. Unlike most other salmon, adult spring chinook hold in fresh water for extended periods prior to spawning. Adult Nooksack spring chinook salmon enter the mouth of the Nooksack River from March through June. By August they are observed holding in pools in the vicinity of the spawning grounds. Peak spawning by South Fork spring chinook occurs in the third week of September, two to three weeks later than North Fork spring chinook. Peak fry emergence occurs in March of the following year and scale data indicates that about 90% of the fry have only a brief freshwater residency, entering the ocean as subyearlings (Nooksack Spring Chinook Technical Group 1987).

Although formerly abundant according to historical and anecdotal evidence, the present spring chinook population in the South Fork Nooksack is depressed. An extensive interagency recovery program has been ongoing since 1980 in an attempt to rebuild the population. Appendix I discusses the recovery program.

These studies were conducted as part of the recovery effort by personnel from the U. S. Fish and Wildlife Service, the Lummi and Nooksack Tribes, the Washington Department of Fisheries and the Youth Conservation Corps. The surveys took place between July 24th and September 23rd, 1986, corresponding with the period when spring chinook hold and spawn in the South Fork Nooksack.

Streamflows measured at the USGS gauging station near Wickersham during the study period ranged from 236 cubic feet per second (cfs) on July 24th to 89 cfs on September 7th and 8th. Flows declined gradually during the study period except for slight increases associated with rainfall during the last week in August and the second week in September. The monthly mean flow for August 1986 was 121 cfs with a maximum of 161 cfs and a minimum of 97 cfs.

Mean streamflow was below average for August 1986, compared with past records from 1969-1985 (Appendix II). Consequently, habitat measurements appear representative of years with below average flow, but not of years with above average flow conditions.

Study Area

The South Fork is the southernmost tributary of the Nooksack River (Figures 1 and 2). It is 39.6 miles long from its headwaters in the snowfields of the Twin Sisters Mountain Range south of Mt. Baker to its confluence with the North Fork near Deming. The drainage basin encompasses approximately 180 square miles in southern Whatcom and northern Skagit counties with elevations ranging from 200 to almost 7000 feet. Most of the watershed is characterized by steep, forested, mountainous terrain in federal, state and corporate ownership where forestry and timber harvest is the primary land use. Dairy and rowcrop agriculture is interspersed with rural residential use in the flat floodplain valley along the lower 12 miles of the river.

Extensive streamflow records are available from the USGS gauging station at river mile (RM) 14.5 near Wickersham (Washington Department of Conservation 1960). The relatively low elevation and absence of glaciers in the South Fork watershed contributes to a runoff pattern with high peak flows during winter rainstorms and spring snowmelt and low, clear flows from July until October. This contrasts with the runoff patterns in the Middle and North Forks which are characterized by higher elevation watersheds and extensive glaciers. They have runoff patterns with peaks in mid summer when snow and ice are melting in the higher elevations and generally low flows in the winter except during major storms. Consequently, during the latter portion of the spring chinook holding and spawning period, the South Fork is typically lower, clearer and warmer than the North and Middle Forks which have higher flows of cold, turbid, glacial meltwater.

Average stream channel gradient in the South Fork decreases as the river moves downstream from the headwaters. Gradients average 0.18% from RM 0-15, 0.58% from RM 15-21.5, 1.51% from RM 21.5-27 and 2.24% from RM 27 to 39.6. Below RM 15 the channel is typically broad, containing large, shallow gravel riffles that are often braided, and long slow moving pools and glides. Above RM 15 the valley narrows and the channel is more confined. Here gravel/cobble riffles and pools predominate. Cascades and large boulders are common where the channel is constricted by bedrock canyons.

The South Fork Nooksack is utilized by chinook, coho, chum, pink and a few sockeye salmon; as well as summer and winter steelhead. Anadromous fish also use many of the tributaries. Spring chinook use is documented in Skookum and Hutchinson Creeks. During the study, chinook were observed as far upstream as the canyon at RM 31, but were not observed above this location. It appears that the cascades at RM 31 are probably a barrier to upstream migration, and that work in 1985 to improve passage in the canyon at RM 25 was successful in restoring passage there. Work to improve passage for chinook salmon was done at the RM 25 falls as early as 1928 (Appendix III; letter from Washington Department of Fisheries and Game 1928).

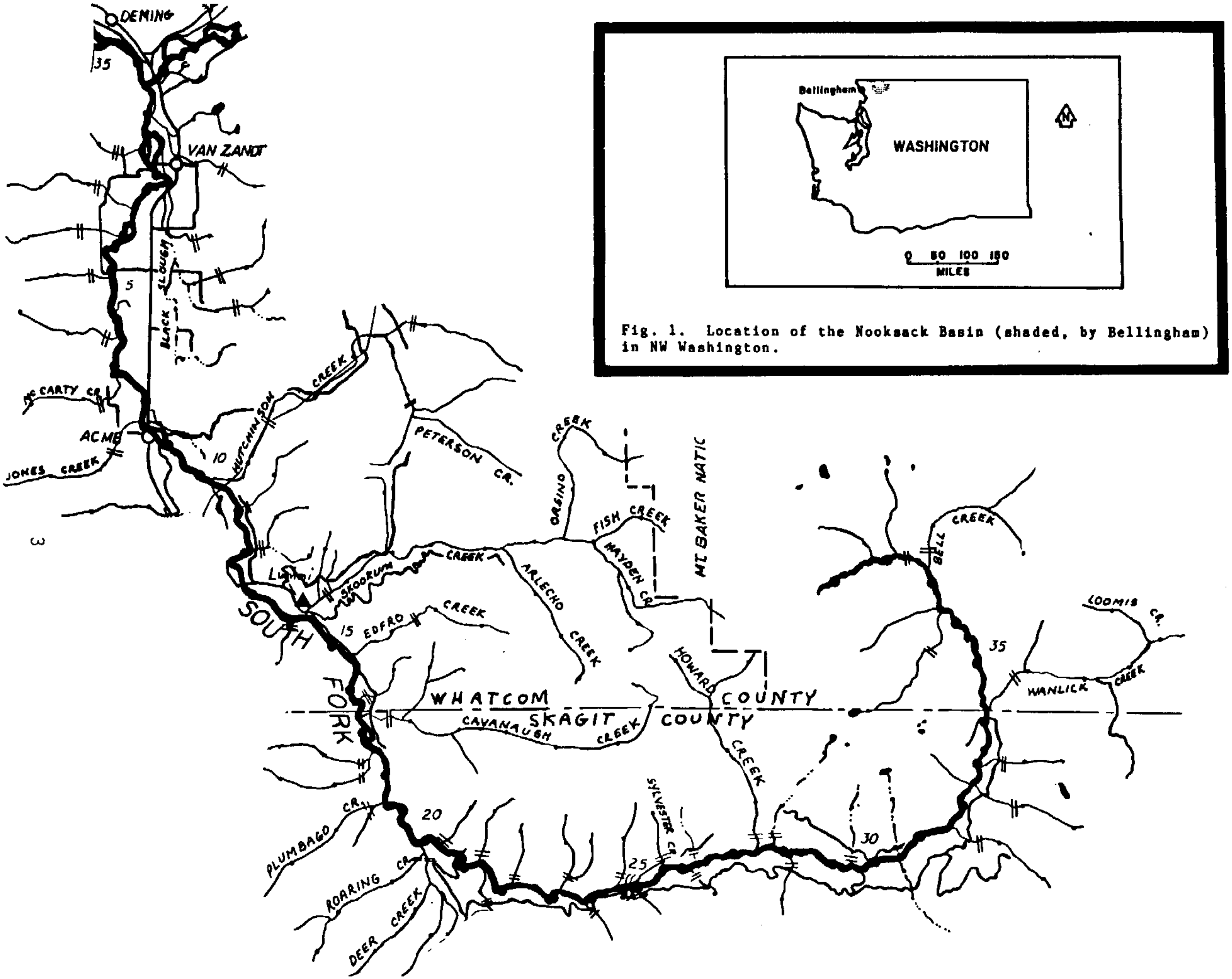


Fig. 1. Location of the Nooksack Basin (shaded, by Bellingham) in NW Washington.

Figure 2. Vicinity map of the South Fork Nooksack River.

Report Organization

The remainder of this report is organized as follows: (1) individual study reports consisting of methods, results and discussion sections; and (2) an overall summary of conclusions reached. References and appendices cited in the study reports are located in the back of the entire report, rather than at the end of the individual study results sections.

HOLDING HABITAT ASSESSMENT

Full protection of the South Fork Nooksack run of spring chinook will depend, in part, on preservation of microhabitat suitable for adult holding fish. An adult spring chinook typically migrates from the ocean during spring, ascends a cold stream until it finds a suitable place to rest, and then holds there for several weeks (Royal 1972). The best information indicates that holding in the South Fork may begin as early as May and lasts at least until mid-August (Nooksack Spring Chinook Technical Group 1987; T. Nesset, personal communication). Preservation of South Fork holding habitat will be difficult without detailed knowledge of the preferred microhabitat. Identification of this microhabitat was one objective of the interagency field study performed in 1986.

METHODS

From July 24 to September 23, 1986, field teams consisting of two to five people gathered data in the lower 34 miles of the South Fork. Holding habitat surveys were performed in a downstream direction during daylight hours. River mile locations where data were recorded were based on mile marks shown on 1980 edition U.S.G.S. 7 1/2 minute topographic maps. Mile marks on the maps were further subdivided into 0.1 mile segments. When data were associated with a stream bank, their orientation was determined by facing downstream. The RM assigned to each point of data collection was estimated to the nearest 0.02 mi from the maps.

One or two team members wore wetsuit, mask, and snorkel to search for holding spring chinook in all potential holding habitats. Spring chinook holding habitat criteria developed by the U.S. Fish and Wildlife Service (Wampler 1986), and prior surveying experience in the South Fork and elsewhere, guided selection of potential holding habitat. When a holding fish was found, the immediate area was measured and described. When the team came to instream habitat that appeared to have potential as holding habitat, regardless of presence or absence of holding spring chinook, that habitat was also measured and described. Habitat was considered to have holding potential if it contained sufficient water depth and provided some form of protective, instream, overhead cover. Protective cover was defined as any instream feature that provided a sufficient amount of overhead cover to partially conceal the presence of at least one spring chinook. Cover was categorized as: bedrock; boulder; undercut bank; surface turbulence; woody debris (smaller tree limbs or floating pieces of wood debris); large organic debris (large logs); and root wads.

A potential holding area, referred to as a site, was examined by wading and snorkeling. Next, the deepest point in the site was found and marked, usually by dropping a lead weight with an attached float at the water surface. If the site was considered too small to warrant detailed measurement, it was described as a single cell and referred to as a small site. Small site measurement consisted of maximum depth, mean width, mean length, and presence or absence of protective cover types.

Multi-celled sites were larger and sometimes contained several cover types. As in the single-celled sites, upper and lower boundaries were marked with flags to include the major cover types. The thalweg divided the site longitudinally. Instream transects, perpendicular to the direction of flow, were located at the upper and lower bounds as well as at the deepest point. The distances from each transect's endpoints to the respective transect thalweg point were measured, as was the depth at each transect's thalweg. Distances between adjacent transect thalwegs were recorded also. The site's outer boundaries, the thalweg line, and the transects together defined a series of from four to eight cells, depending on whether any additional transects were needed to describe contained cover features or the channel configuration. Endpoints of transects were located at the outer edge of cover features or at a water depth considered sufficient to protect at least one holding adult fish. This was normally set at two feet depth or greater.

Appendix IV illustrates the field sheet format used to record most data. In addition, rough sketches of multi-celled sites were drawn, including the locations and types of protective cover features observed within cells. An example sketch is shown in Figure 3. The locations of observed holding fish were also recorded in the respective cell(s).

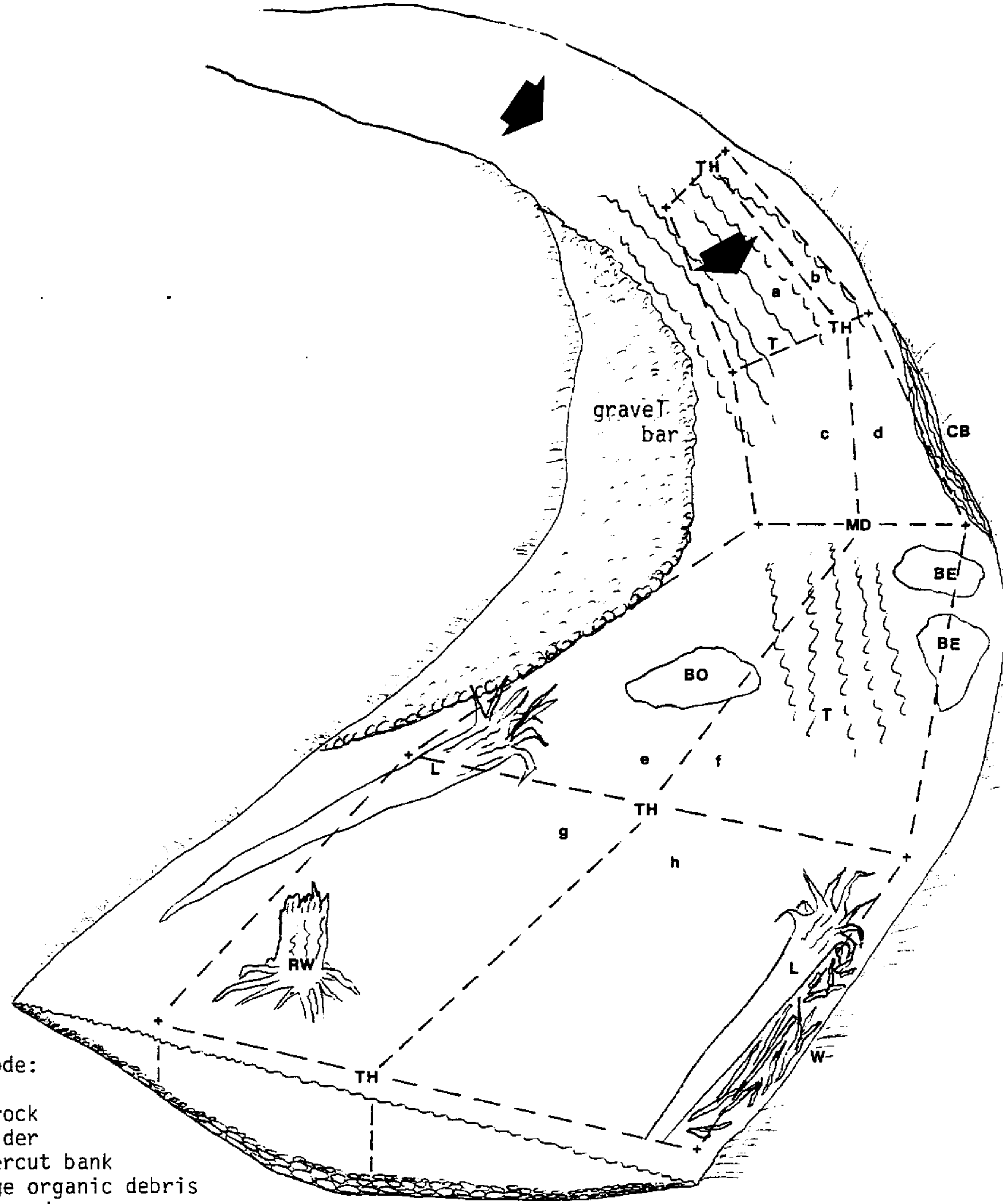
The data were then placed on a computer spreadsheet file organized by RM location, permitting visual associations of site cells with water depth, cover type presence, fish presence and site dimensions.

RESULTS

The field team surveyed nearly all suitable holding habitat in the mainstem South Fork, from RM 33.6 to the mouth. Not included was a 2.4 mi inaccessible reach located immediately upstream of what is now thought to be the uppermost barrier to migration, at RM 30.8. Prior to this study it was unknown if fish were blocked at Sylvester Falls (RM 25.3).

A total of 282 small and 147 multi-celled holding sites were identified and recorded. Table 1 lists all sites, combined by ascending 5-mile reaches, and respective combined site volumes.

Data for the presence of holding spring chinook show that relatively few sites contained fish. Among the 282 small sites, only 9 sites, or about 3%, contained holding fish. Among the 147 multi-celled sites, 33 sites, or about 22%, contained holding



Cover code:

BE bedrock
BO boulder
CB undercut bank
L large organic debris
RW root wad
T surface turbulence
W woody debris

Figure 3. Example sketch of a large site, containing eight cells. Cells (a to h) are bounded by: transect lines, i.e., + to TH (thalweg) to +; the thalweg line, i.e., TH to TH or TH to MD (maximum depth); and the outer boundary, i.e., + to +.

Table 1. Number of suitable holding sites, calculated total volume of sites, and number of fish in sites, listed by ascending 5-mile reaches in the South Fork Nooksack River.

	Small sites			Multi-celled sites			All sites		
River mile	Number	Total volume (cu.ft.)	Fish	Number	Total volume (cu.ft.)	Fish	Number	Total volume (cu.ft.))	Fish
0 - 5	46	65629	1	11	136919	0	57	202548	1
5 -10	57	37342	0	18	211641	13	75	248983	13
10 -15	17	19668	2	31	565458	51	48	585126	53
15 -20	31	35402	2	32	452732	16	63	488134	18
20 -25	42	28607	1	18	172816	12	60	201423	13
25 -30	53	142315	2	23	298363	2	76	440678	4
30 -33.6	37	40342	6	6	27148	6	43	67490	12

fish. In terms of fish numbers, 14 holding fish were found in small sites while 100 fish were found in multi-celled sites.

Table 1 also shows the distribution of observed holding fish by ascending 5-mile reaches and by type of holding site. Far more holding fish were observed in the RM 10-15 reach than any other. This is the reach that typically contains a higher concentration of fish returning to the hatchery, as evidenced by the high percentage of adipose-clipped fish there (Nooksack Spring Chinook Technical Group 1987).

We suspected that water depth, water volume, protective cover, or some physical measure in holding sites was related to number of observed holding fish. For example, the results show that the 5-mile reach having the greatest combined water volume in holding sites, RM 10-15, also contained the most holding fish (Figure 4, Table 1).

We compared the data in the spreadsheet for maximum depth and instream wood cover in occupied cells within multi-celled sites (n=100). We assumed that fish held in specific cells due to their natural preference for microhabitat features (Wampler 1986). The comparison showed that 85 fish (85%) were found in cells containing the maximum site depth (Table 3). Among these 85 fish were: 39 fish in cells also containing more than one type of instream wood cover; 6 fish in cells also containing one type of instream wood cover; three fish in cells containing no instream wood cover; and 37 fish in sites (rather than in cells) containing no instream wood cover. Among these 37 fish, 31 were found in cells containing two or three other types of cover.

We looked further at protective cover in the cells where holding fish were found. Cells were examined rather than sites, because cells should more accurately show the microhabitat fish selected. Among the 55 cells where holding fish were observed (Figure 5), boulder and surface turbulence cover occurred most frequently (53%). Large organic debris followed closely in frequency of occurrence (42%). Only two cells did not contain at least one type of cover (Table 2). For comparison, 55 cells that did not contain holding spring chinook were selected randomly from the data to see what cover they contained. These cells contained 37% less cover than the cells with fish, and 14 of these 55 cells contained no cover.

Relative Importance of Habitat Features

Physical measures recorded where holding fish were found are listed along with numbers of fish, by RM, in Table 3. Looking at the variations in number of holding fish in sites and corresponding values for maximum site depth, site surface area, and site volume did not indicate any obvious relationship. Testing for possible relationships between numbers of fish and physical factors, we applied stepwise multiple regression with number of holding fish in all South Fork sites (n=42) serving as the dependent variable. In the same test we included a separate

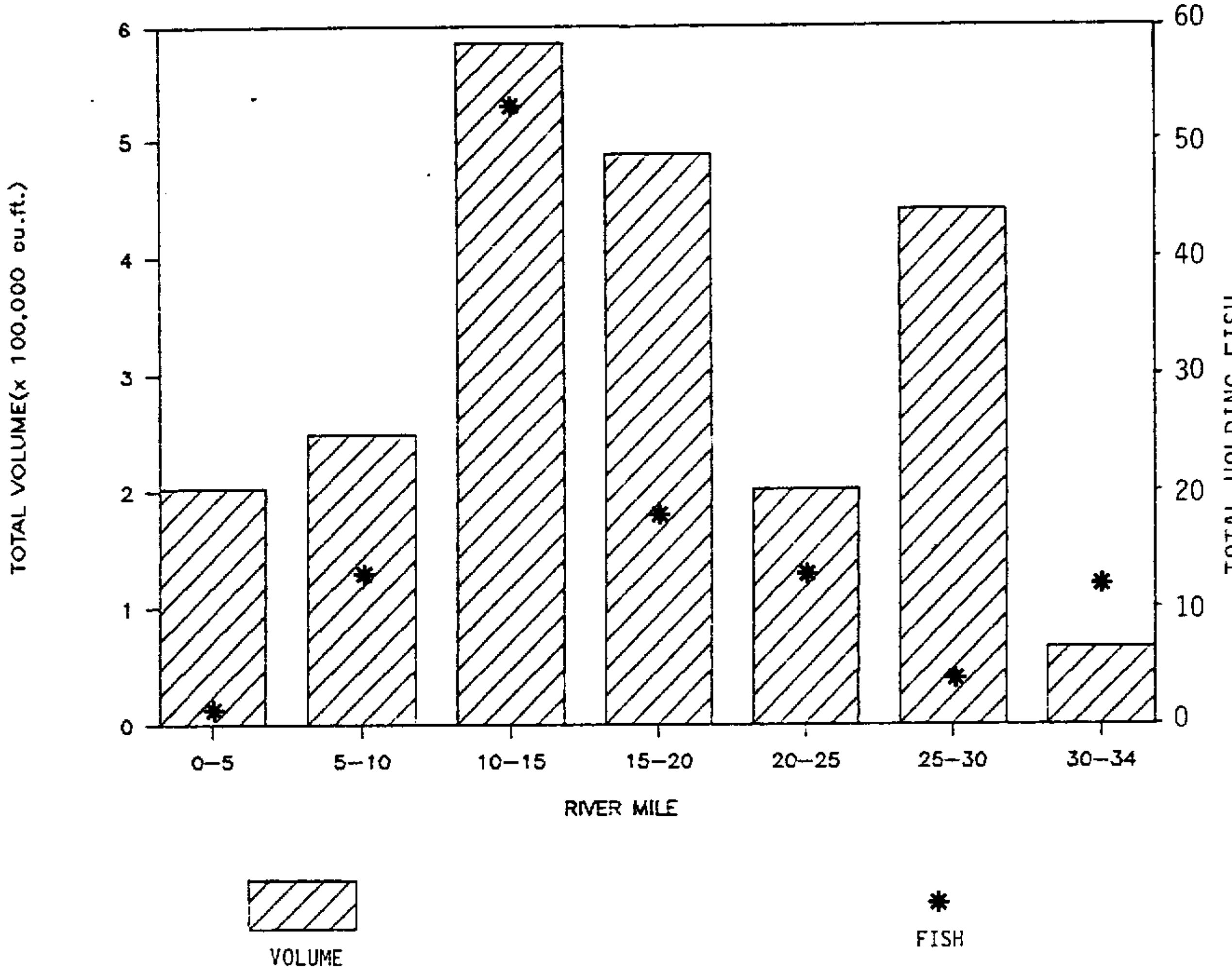
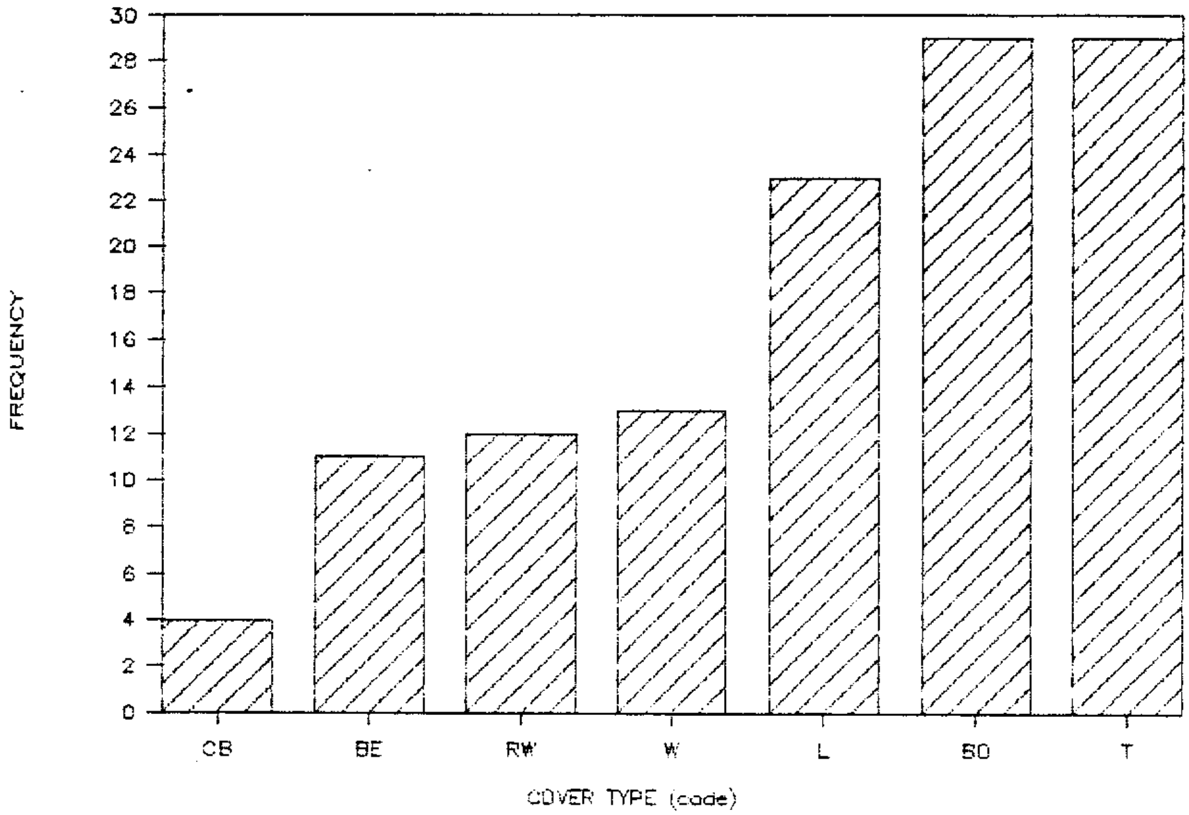


Figure 4. Compared total site volume with total holding fish.



Cover Codes:

CB undercut bank

BE bedrock

RW root wad

W woody debris

L large organic debris

BO boulder

T surface turbulence

Figure 5. Frequency of occurrence of cover types in cells containing spring chinook salmon.

Table 2. Presence or absence of protective cover in cells where spring chinook were observed in the South Fork Nooksack River.

River mile	Number of fish in cell	Cover types present in cell* T	BO	L	W	RW	BE	CB	Cover absent in cell
2.0	1			x		x			
7.1	3			x		x			
8.7	1		x	x					
9.0	1	x		x	x				
9.0	5	x		x	x				
9.6	3			x	x				
11.4	1			x	x	x			
12.3	1			x		x			
12.3	1			x	x	x			
12.3	5			x	x	x			
12.3	5			x		x			
13.1	4		x	x	x				
13.4	1								x
14.0	6	x	x						
14.0	6	x	x						
14.0	6	x	x						
14.0	6	x	x						
14.0	3		x	x		x			
14.1	1	x			x				
14.2	1		x	x	x				
14.3	1	x		x					
14.4	4						x	x	
14.8	1	x		x	x				
16.0	1	x	x	x		x			
16.1	2						x		
16.3	3			x		x		x	
16.4	1		x				x		
16.4	1		x						
17.9	2		x						
17.9	1	x	x				x		
19.4	2	x		x	x			x	
19.4	2	x		x				x	
19.4	1	x		x					
19.6	1		x		x				
19.7	1	x	x				x		
20.2	1	x	x						
20.2	1	x		x	x	x			
20.4	1	x		x				x	
23.7	5	x					x		
23.8	2	x	x				x		
23.8	1	x	x				x		
23.9	1	x	x						
24.4	1	x					x		
25.3	1						x		
25.3	1						x		
29.5	1								x
29.6	1		x						
30.2	2		x			x			
30.4	1	x	x						
30.4	1	x	x						
30.4	2	x	x						
30.4	2		x						
30.6	2	x	x						
30.7	1	x	x						
30.7	1	x	x						

(*) Cover code: T = surface turbulence; BO = boulder; L = large organic debris; W = woody debris; RW = root wad; BE = bedrock; CB = undercut bank

Table 3. Number of fish, maximum depth, surface area, and water volume in spring chinook holding sites.

River mile	Fish	Maximum depth (ft)	Surface area (sq.ft.)	Volume (cu.ft.)
2	1	5.5	80	281
7.1	3	7.7	5671	29048
8.7	1	7.3	3528	16523
9	6	7.8	5368	22156
9.6	3	8.8	4288	21411
11.4	1	4.5	3206	9578
12.3	2	7.7	13339	53531
12.3	10	8.8	7315	28629
13.1	4	5.4	13024	37881
13.4	1	3	4500	8613
14	24	5.6	5400	19564
14	3	9.4	12576	43392
14.1	1	2.5	140	223
14.2	1	3.2	1796	4245
14.3	1	2.2	693	1367
14.4	4	7	10590	35704
14.8	1	2.7	823	1754
16	1	7.9	1916	9124
16.1	2	5.5	1744	5994
16.3	3	6.5	2569	10614
16.4	2	7.6	5984	25597
17.9	2	4.7	600	1799
17.9	1	4.8	2736	8812
19.4	5	7.6	3461	12884
19.6	1	5.2	312	1066
19.7	1	5.3	4416	13745
20.2	2	5.8	3064	10907
20.4	1	6.7	5023	20012
23.7	5	8.4	5328	29224
23.8	3	8.7	2953	13535
23.9	1	7.9	622	2990
24.4	1	9	900	5167
25.3	1	4.8	450	1378
25.3	1	9	1500	8613
29.5	1	5.5	1400	5430
29.6	1	6	2125	6086
30.2	2	2.5	16	25
30.4	1	4	160	408
30.4	5	4.3	198	729
30.6	2	4.6	961	2820
30.7	1	3.5	48	107
30.7	1	4.8	1715	6402

independent variable for each cover type, consisting of the percent of an occupied site's cells that contained that cover type. Finally, we included an independent variable for the sum of the instances of all cover types per occupied site. The resulting stepwise regression model selected only the latter variable, sum of the cover instances (shown as sumco, in Appendix V), to explain 26% of the variation in fish holding distribution.

We considered other regression tests to compare isolated reaches of the river, e.g., to compare holding behavior of assumed wild stock fish with assumed hatchery stock fish. However, there were insufficient data to permit other statistically sound regression tests.

Another approach to this analysis was initiated by the Northwest Indian Fisheries Commission at the request of the Lummi Tribe (Newman 1987). They derived estimates of habitat factor preference by spring chinook. We modified their estimates to more accurately reflect those consistent throughout the data collection (Appendix VI). The analysis showed that fish preference for water depths equal to or greater than 5 ft was nearly three times that for the next most preferred factor, water turbulence. Of eight possible habitat factors, only undercut banks had a preference estimate of less than 1.0, thus indicating that it was not preferred.

DISCUSSION

Holding Habitat Data Assumptions

Certain assumptions are required regarding the validity of the holding data before it can be used to guide future management decisions. Our data reflect fish presence or absence at sites on only one day during the holding period. It is possible that some fish we observed had not completed their migration to a preferred holding site. Moreover, it is possible that many fish migrated both upstream and downstream several times before entering a more permanent holding behavior stage. Lacking information on holding fish movements, we assume that an observation of a holding fish represents its preference for holding microhabitat.

Other assumptions we make in this report are: that the habitat criteria we applied to determine which were suitable holding sites were appropriate; that the spring chinook run was depressed in 1986; that holding fish were not incorrectly associated with the wrong microhabitat because they had been frightened by the survey team; and that river flow during the period of data collection underwent a normal rate of decrease and did not alter normal holding behavior.

Holding Habitat

Analysis of the holding habitat data indicated that spring chinook needed instream cover to successfully hold in the South Fork until they entered the spawning stage (Figure 5, Table 2). The analysis showed that holding fish were most concentrated in the RM 10-15 reach adjacent to the hatchery. This was expected, since a majority of those fish were presumed to be of hatchery origin. While the highest concentration of water volume in suitable holding sites was also found in this 5-mile reach (Figure 4), a direct relationship between holding fish and site water volume was not observed in the regression for other 5-mile reaches. Also, there were fewer total sites in the RM 10-15 reach compared to those in most other 5-mile reaches.

Documentation of microhabitat features used by holding spring chinook (Wampler 1986) showed that they prefer: the greatest water depth available to them; water velocities ranging from 0.0 to about 4.0 ft/sec; cobble substrate; and instream wood for protective cover. The mean maximum depth in sites was about 5.0 ft (n=429). However, holding fish were usually found at greater depths. Among the sites occupied by holding fish (n=42), the mean maximum depth was 5.9 ft. Among the cells occupied by holding fish (n=114) the mean maximum depth was 6.2 ft. These values support the conclusion that holding fish seek the greatest water depth available.

Holding velocity data were not collected in the South Fork, so a comparison between actual holding site velocities there and elsewhere is not possible.

The instream cover types found most frequently in South Fork occupied cells were surface turbulence and boulder, while large organic debris occurred next most frequently (Figure 5). Turbulence and boulder cover occurred together in about 31% of the occupied cells (Table 2). Wampler (1986) observed that in the absence of their preferred cover type, spring chinook used other types of cover, and that less than 1% of the fish were holding without cover nearby. In the South Fork less than 2% of the fish were holding without cover nearby (Table 2). It is likely that South Fork fish were selecting the best cover types available to them.

The results of our multiple regression test, and our results in general, showed the importance of instream cover for holding fish in the South Fork. The fact that about seven times more fish were holding in multi-celled sites than in small sites also indicated that some combination of features in large sites better satisfied holding fish requirements.

The occurrence of 85% of these holding fish in cells containing maximum depth is verification that these fish preferred to hold in the deepest water available. Also indicated is their preference for instream wood cover over other types. Only 12% of the fish selected cells containing neither maximum depth nor instream wood cover.

One of the principal causes of the run's depressed condition is habitat degradation, and in particular, degradation of holding pool habitat (R. Wunderlich, personal communication). This conclusion is partially based on observations of decreased water depth in South Fork holding pools. Information from several sources indicate that maximum depths in South Fork pools have decreased in recent years. Snorkel surveys performed by tribal and U. S. Fish and Wildlife Service biologists showed that certain pools, favored by holding fish, had filled to the extent that fish use was much reduced. Measured changes in one pool bottom profile, between 1985 and 1986 (Figure 10), showed that it had filled 6 ft. Also, according to a reliable observer who resided near the South Fork for several decades, certain pools once contained water depths of approximately 30 ft (Tom Nesset, personal communication). Review of our data for all sites showed that the maximum depth found in the South Fork was about 13 ft.

When combined, the evidence of pool filling suggests that the South Fork has become relatively unstable. The stream channel stability indices developed as part of this study confirmed that all of the sampled reaches, representing most of the South Fork, were in an unstable condition (Table 10).

In stable channels, bed material may be transported annually and bars and meanders may shift, but bed elevation changes little from year to year (Sullivan et al. 1987). Large bed elevation changes and pool filling over the years indicate that certain processes have been at work in the upper South Fork watershed that caused instability. Poor forest management can affect channel morphology by changing the amount of sediment or water entering the stream, thus disrupting the balance of sediment input and removal (Sullivan et al. 1987). Excessive input of coarse sediments can smooth the channel gradient by filling pools. The resulting loss of habitat diversity then directly degrades the microhabitat required by fish species, and in this case, for spring chinook. As long as the river remains unstable, it is likely that the tendency will continue for pools to fill and gradually lose depth. A reversal of this process of habitat degradation will require reestablishment of a stable watershed through sound forest management.

Relations Between Holding and Spawning Habitat, and Redd Frequency

We looked at the relations between number of fish and total water volume in holding sites (Figure 4), total area of suitable spawning habitat (Figure 6), and number of redds (Table 8), by 5-mile reaches of the South Fork. While number of fish, water volume in sites, and number of redds all peaked within the RM 10-15 reach, area of suitable spawning was much reduced in this reach. This could simply be a factor of a high pool to riffle ratio in this reach, and high number of redds could be attributed to the large number of hatchery fish in this reach.

Interestingly, number of redds per 5-mile reach tended to vary most directly with volume in holding sites, up through RM 25. Instead, we would expect number of redds to vary most directly with either area of suitable spawning habitat or number of fish. One explanation is that fish, and therefore redds, were most concentrated in the vicinity of the hatchery and this happens to be where volume in holding sites also occurs at the highest level.

Above RM 20, redds were relatively evenly dispersed over the 5-mile reaches, suggesting that those redds were made by wild stock fish that were also spread evenly in those reaches.

Holding Habitat as a Limiting Factor

Was there a sufficient amount of suitable holding habitat in the South Fork? Caution should be used in interpreting our data because the spring chinook run was depressed in 1986. Our data show, assuming our criteria were appropriate, that there was far more suitable holding habitat than fish to occupy it. Only about 10% of all holding sites contained one or more holding fish. We cannot conclude that holding habitat was limiting for the run in 1986, but certain combinations of microhabitat features that spring chinook apparently prefer were rarely available, e.g., water depths approaching 14 ft and instream wood cover.

Although we conclude that holding habitat does not at present limit the run size, there are conditions in specific reaches, particularly RM 0-10 and RM 20-25, that appear to limit use by holding fish. In both of these reaches the reduced number of multi-celled holding sites likely diminishes their use. We also suspect that elevated water temperature in the lower river miles may stimulate fish to continue searching upstream for more acceptable conditions for holding. Moreover, there were indications that combined elevated temperatures and low flow caused some fish to be stressed in 1986. Such extremes in some years may limit holding success.

Any substantial increase in the size of the spring chinook run in coming years will likely result in a holding fish distribution similar to that observed in 1986 (Table 1). A majority of the hatchery stock fish would again hold in the general vicinity of the hatchery. The quantity of holding habitat in these reaches would be adequate up to some level, but increased fish could add additional stress due to fish interactions. Wampler (1986) observed large numbers of fish holding in pools together, however those pools were comparatively deeper than in the South Fork. The shallower pools in the South Fork could force holding fish to either be exposed to more hazards there, e.g., increased poaching and predators, or to migrate to other reaches that are less crowded.

The increased stress placed on crowded fish would be intensified by elevated water temperatures like those observed in 1986. Water temperature problems and lack of sufficiently deep pools could combine to limit the number of fish that can successfully hold. It is evident that the restoration of deep pools and lower water temperatures in the South Fork would better insure larger runs in the future.

SPAWNING HABITAT ASSESSMENT

We inventoried and evaluated the amount and quality of available spawning habitat for spring chinook to determine whether spawning habitat is a limiting factor and for use in developing a habitat-based escapement goal. We also measured depth, velocity and substrate at redd locations to help verify the spawning habitat criteria used in the spawning habitat assessment. We documented spawning gravel composition in the major South Fork Nooksack spawning areas to determine quality of available spring chinook spawning habitat and the degree and extent of fine sediment accumulation. We performed stream channel stability indices on seven stream reaches between RM 8.6 and 30.1 to document the magnitude and extent of unstable stream channel conditions and to provide an indication of potential intragravel mortality due to unstable channel conditions. We measured streambed profiles at several locations to document changes in streambed elevations. When repeated over time, streambed profiles provide an indication of the rate and degree of aggradation or scour of the streambed substrate at the study site. This study was initiated in response to concern about the filling in of holding pools and the burial of redds due to an increase in bedload sediment deposition.

METHODS

Spawning Habitat Inventory

We inventoried spawning habitat in the South Fork from the mouth to RM 33.6, except for a 1.25 mile section between RM 30.9 and 32.15. Surveys were conducted on foot by a survey team that mapped potentially suitable spawning area locations, measured their lengths and widths, and collected data on velocity, depth, and substrate composition. We identified potentially suitable spawning habitat using depth, velocity, and substrate criteria (Table 4). Habitat rated as optimal had to have velocity, depth, and substrate measurements that all fell within the optimal ranges shown. Marginal and unsuitable ratings were similarly assigned, however, if any one criterion was observed to be marginal or unsuitable. For example, a spawning habitat area was assigned a rating of unsuitable if its velocity exceeded 4.0 ft/sec, despite having optimal depth and substrate characteristics. Criteria were based on work reported by Chambers et al. (1955), Graybill et al. (1979), and Stempel (1984).

Width, depth, velocity and substrate data were recorded along transects for areas with depth over 0.4 ft, velocity over 0.5 ft/sec, and dominant substrate between 0.5 and 12 inch diameter. In situations where these features varied within the riffle, the riffle was subdivided into separate units and measurements were taken at additional transects or stations along the transects as needed to adequately characterize the habitat.

Table 4. Criteria chosen to identify and distinguish between optimally suitable, marginally suitable, and unsuitable spawning habitat area.

Rating	Velocity (ft/sec)	Depth (ft)	Dominant Substrate Diameter (in)	Code
Unsuitable	<0.5	<0.4	<0.5	0,1,2,3
Marginal	0.5-1.25	0.4-1.0	0.5-1.5	4
Optimal	1.25-3.0	1.0-2.5	1.5-3.0	5
			3.0-6.0	6
Marginal	3.0-4.0	>2.5	6.0-9.0	7a
Unsuitable	>4.0		9.0-12.0	7b
			>12.0	8,9

Lengths and widths of suitable areas were measured with range finders or fiberglass tapes. These data were used to calculate the square footage for each unit of available habitat.

Water velocity was measured with a Swoffer flow meter at 0.5 ft above the substrate level, representing the depth where spawning fish would be located. Water depth was recorded from the wading rod.

Table 5. Modified substrate code.

Code	Substrate Description	Size (mm)	Size (in)
0	Organic detritus	<2	<0.1
1	Silt and clay	<2	<0.1
2	Sand	<2	<0.1
3	Small gravel	2-12	0.1-0.5
4	Medium gravel	12-38	0.5-1.5
5	Large gravel	38-76	1.5-3.0
6	Small cobble	76-152	3.0-6.0
7A	Medium cobble	152-228	6.0-9.0
7B	Large cobble	228-305	9.0-12.0
8	Boulder	>305	>12.0
9	Bedrock	>305	>12.0

Substrate characteristics were determined visually, using a modified version of the three digit code developed for instream flow work in Washington State (Young 1983). The number in the first digit represents the dominant, or most common, particle size; the second digit represents the subdominant or second most common particle size, and the third digit, to the right of the decimal point, represents the percentage of the dominant substrate (Table 5).

A separate rating code was used to describe embeddedness in conjunction with the substrate size-class evaluation. Embeddedness is the degree to which the large particles are surrounded and covered by fine sediment. Table 6 (from Platts et al. 1983 in Hamilton and Bergersen 1984), describes the embeddedness rating system.

Locations of potential spawning areas were mapped on DNR 1/4 Township orthophoto maps. Due to the recent photography and good resolution (1:12,000 scale) many areas could be accurately located.

Table 6. Embeddedness rating system for channel materials (from Platts et al. 1983).

Rating	Rating Description
5	Gravel, rubble and boulder particles have less than 5% of their surface covered by fine sediment.
4	Gravel, rubble and boulder particles have between 5% and 25% of their surface covered by fine sediment.
3	Gravel, rubble and boulder particles have between 25% and 50% of their surface covered by fine sediment.
2	Gravel, rubble and boulder particles have between 50% and 75% of their surface covered by fine sediment.
1	Gravel, rubble and boulder particles have more than 75% of their surface covered by fine sediment.

Redd Measurements

The field team surveyed the South Fork during September, 1986, for redds made by spring chinook salmon. The team walked and waded downstream through predetermined reaches of the river to survey for redds. Recognition of redds was based on previous experience in performing similar redd surveys in the Nooksack River system and elsewhere. Patches of disturbed gravel caused by test probings of salmon were not recorded as redds. Our procedure for recording a redd did not require that spring chinook be sighted, but that redd area be sufficiently large and disturbed to a depth that would indicate successful egg deposition.

The data recorded for each observed redd included: river mile, estimated to the nearest hundredth mile; water depth, measured just upstream or to the side of the redd; flow velocity, to the nearest hundredth foot per second, measured at the same location(s) as water depth; substrate type, recorded as dominant, sub-dominant, and percent of dominant for the immediate surface area (Young 1983); distance to the nearest stream bank; adjacent stream width; and relative position of the redd in relation to the prevailing stream habitat type, e.g., the tail of a pool. After the redd surveys were completed, the data were retabulated, placed on computer file, and then analyzed.

One potential product attainable from redd data is a set of habitat criteria curves for spring chinook spawning. Criteria curve data could be reliable for curve development if taken during a single season in the same stream. To some extent the credibility of such criteria is questionable if the data are not collected on confirmed, active redds. Time available for this survey did not permit confirmation of the presence of spawners near redds. However, we otherwise collected data in a manner appropriate for curve development (Bovee 1986). Accordingly, we performed frequency analysis on data sets for depth, velocity, and dominant substrate, respectively. We then normalized each respective data set by finding the nonparametric tolerance limits, at the 95% confidence level, from Somerville's tolerance limits table (Bovee 1986). Bovee supports this nonparametric approach to derive utilization curves, stating that it is not influenced by irregularities in frequency histograms. This provides more justification for acceptance of these curves in South Fork applications.

The remaining analysis of redd data consisted of: calculating the mean redd distance to the nearest stream bank, by 5-mile reach; calculating mean stream width at redd locations by 5-mile reach; and performing a frequency analysis of data for stream location of redds in relation to major habitat types.

Spawning Gravel Fine Sediment

Spawning gravel samples were taken at three locations in late August just prior to the South Fork Nooksack spring chinook spawning period. Three reaches were chosen for sampling where significant spring chinook spawning had occurred in the past. Five to eight samples from adjacent riffles in each reach were taken using a 6-inch diameter McNeil gravel sampler with a plunger to capture suspended sediments (Cederholm and Salo 1979). The sampler was inserted to a depth of 9 inches and samples were transferred to five gallon buckets for transport. Each sample was wet sieved through 12-inch diameter Tyler sieves with screen sizes (in mm) of: 77.0, 26.9, 6.7, 3.35, 1.7, 0.85, 0.425, and 0.106. After sieve contents were allowed to drain to remove excess water, the material was placed in a volume displacement flask for volumetric measurement. Silt passing through the finest sieve was collected and allowed to settle one hour before its volume was read.

Stream Channel Stability Indices

Stream channel stability indices were done according to methods developed by the U. S. Forest Service (1978) as modified by Rickert et al. (1978). The index rates a stream's capability to maintain stable channel characteristics under the flow and sediment regime it is subjected to. Numerical values are given to 15 physical characteristics of the stream bank and channel bottom relating to stream bank erosion and stability of bottom materials. The stream reaches rated were chosen to encompass characteristic sections of the South Fork. Appendix VII contains the survey form and shows characteristics rated, criteria for the ratings, and the scoring system. Items were visually rated while walking the survey section. A representative channel cross-section was measured to obtain the channel capacity rating.

Streambed Profiles

Streambed cross-section measurements were taken at two locations on the South Fork; RM 19.9 (Tether Hole) and RM 14.5 (Skookum Hole). Two cross-sections were done at each location, one through the deepest part of the hole, and one at an adjacent spawning riffle. Cross-sections were identified with permanent markers on both sides so they could be relocated, and a permanent elevation marker was established. A tape was then stretched across the channel between the markers on both sides. Elevations along the tape were measured with a surveying level and rod. Cross-sections were measured during the summer low flow period.

RESULTS

Spawning Habitat Inventory

The field team surveyed all potentially suitable spawning habitat in the South Fork from the mouth upstream to RM 33.6. The surveys were performed while the river was at a low flow stage. About 900 spawning habitat sites were measured and recorded. Appendix VIII lists the data by ascending river mile. In addition to the recorded field measurements, it also lists calculations of total surface area for each site.

Table 7 and Figure 6 compare calculations of total available area of suitable spawning habitat between 5-mile reaches of the South Fork, based on the criteria in Table 4. The reach from RM 20 to 25 contained the most optimal habitat, 347,681 sq ft, while the reach from RM 15 to 20 contained the most marginal habitat, 509,292 sq ft. Relatively little suitable habitat is found upstream of RM 25.

The suitable habitat calculations in Table 7 were adjusted for embeddedness, i.e., the percent of the substrate surface embedded by sediment fines. Bell (1984) reported that salmonid eggs suffer 85% mortality when 15 to 20% of the interstitial spaces in stream bed substrate are filled by fine sediment. Bovee (1986) demonstrated that 50 to 75% fines completely fill spaces between dominant-sized stream bed materials. Given these facts, we concluded that our coding of less than 3.0, equivalent to 50 to 100% fines, represents conditions that can be expected to suffocate salmon eggs. The suitable habitat calculations in Table

Table 7. Compared availability of optimal, marginal, combined optimal and marginal, and unsuitable spawning habitat in the South Fork. Embedded habitat (shown in parentheses) is subtracted from optimal, marginal and combined values to derive suitable habitat (noted with an asterisk).

River mile	Spawning habitat surface area (sq ft)			
	Optimal	Marginal	Combined suitable	Unsuitable
0-5	291662 - (0) 291662 *	390505 -(7660) 382845 *	682167 -(7660) 674507 *	44161
5-10	296308 -(11403) 284905 *	389907 -(20323) 369584 *	686215 -(31726) 654489 *	96988
10-15	168226 -(4396) 163830 *	199433 -(19442) 179991 *	367659 -(23838) 343821 *	73155
15-20	150153 -(9648) 140505 *	509292 -(45097) 464195 *	659445 -(54745) 604700 *	297940
20-25	347681 - (0) 347681 *	137156 -(4567) 132589 *	484837 -(4567) 480270 *	6739
25-30	2348 - (0) 2348 *	35360 -(4514) 30846 *	37708 -(4514) 33194 *	12107
30-33.6	5434 - (0) 5434 *	51931 -(2327) 49604 *	57365 -(2327) 55038 *	2327

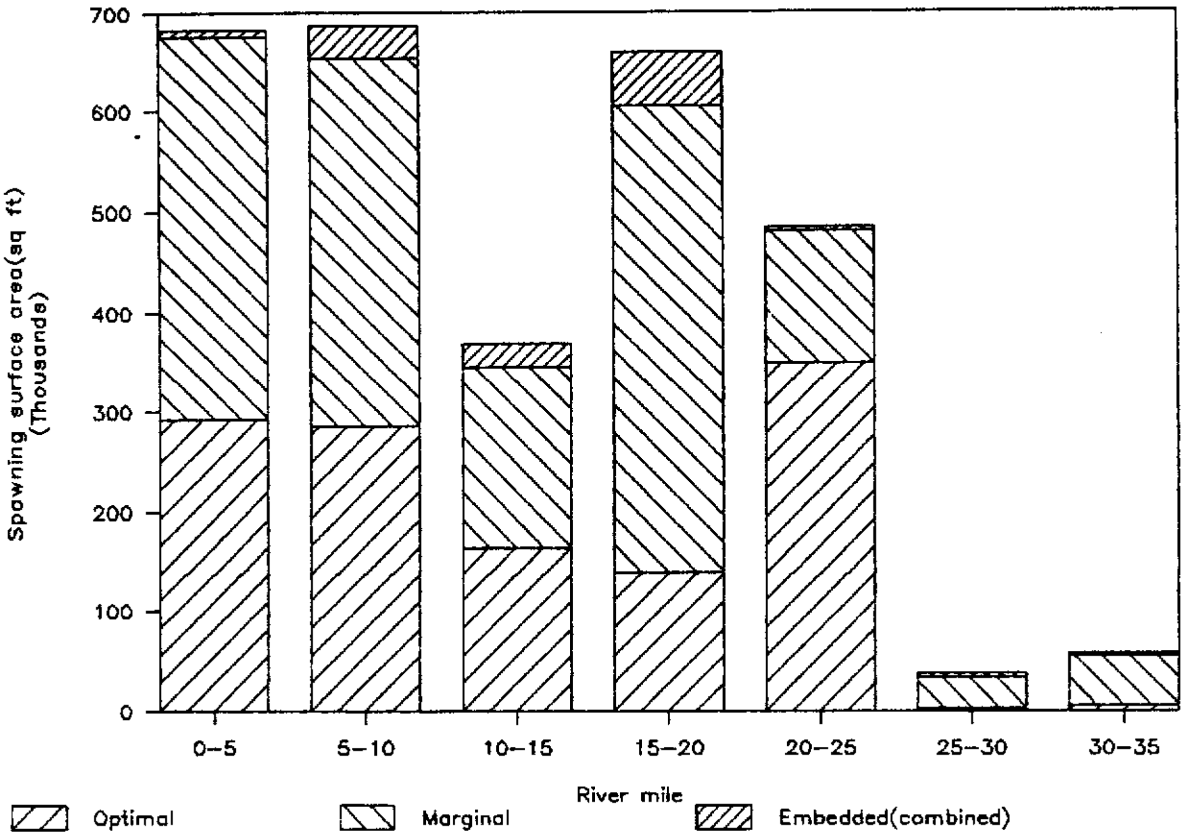


Figure 6. Available optimal and marginal spawning habitat compared with combined embedded spawning habitat.

7 reflect elimination of areas assigned a code of less than 3.0. The values for unsuitable habitat include respective increases caused by embeddedness.

Figure 6 shows the relative losses of otherwise suitable spawning habitat caused by the effects of severe embeddedness in optimal, marginal, and combined suitable habitat, respectively. Losses to embeddedness are more widespread in habitat rated as marginal, although losses in habitat rated as optimal are quite important due to its greater value to fish. Table 7 and Figure 6 show that the largest loss occurred in the RM 15-20 reach. After accounting for the effects of embeddedness, the reach containing the most optimally rated spawning habitat was still RM 20 to 25. When summed over all 5-mile reaches, there were 2,975,396 sq ft of combined suitable spawning habitat and 129,377 sq ft of habitat lost to embeddedness. The loss to embeddedness was about 4% of the potential total for spawning habitat.

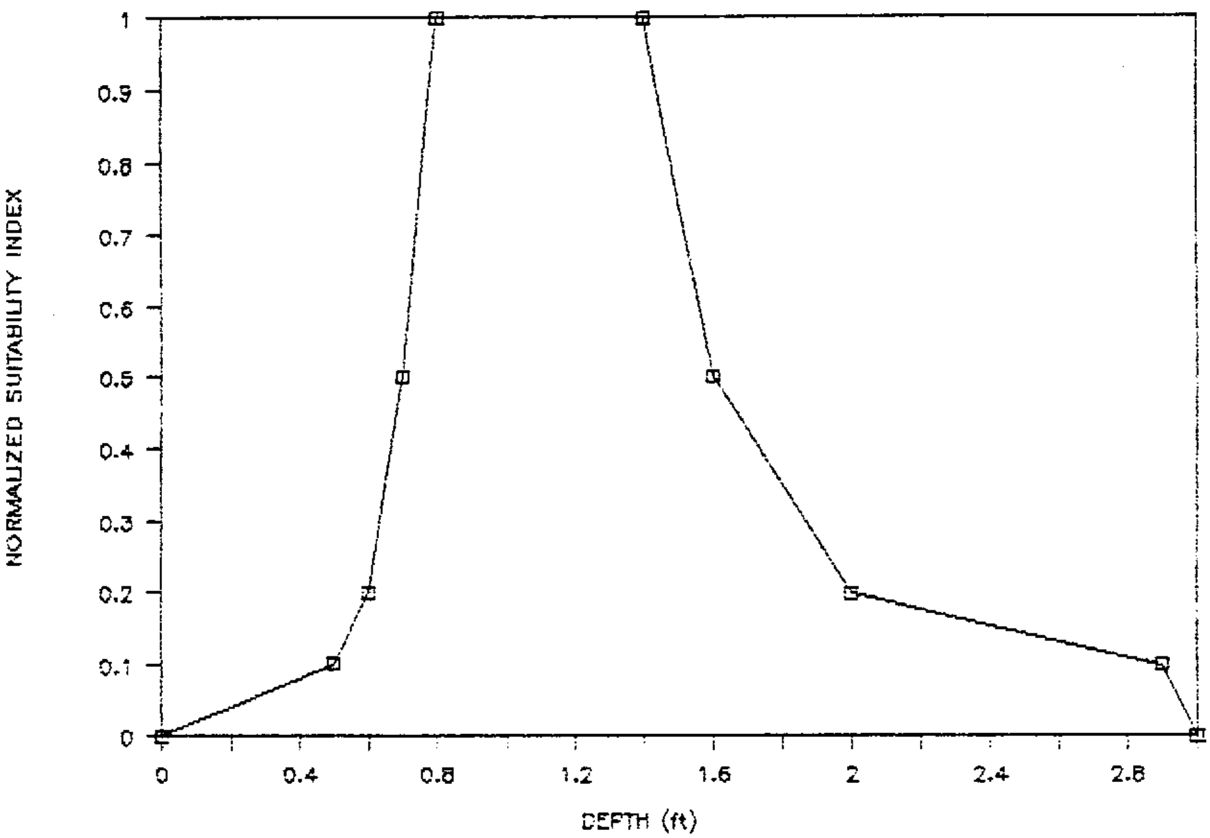
Redd Measurements

A total of 150 redds were identified and recorded (Appendix IX). When we compared number of redds per 5-mile reach of the South Fork, the largest number, 54 redds, were found between RM 10-15 (Table 8). The next greatest concentration, 44 redds, were found between RM 15-20. Relatively few redds were found in the remaining 5-mile reaches. Annual redd counts in index areas from previous years were few in number, but they showed similar redd concentrations per river reach (M. MacKay, Lummi Fisheries, personal communication).

Table 8. Number of observed spring chinook redds per 5-mile reach in the South Fork Nooksack River from September 9-23, 1986.

River mile	Number of redds
0-5	7
5-10	4
10-15	54
15-20	44
20-25	13
25-30	12
30-35	16

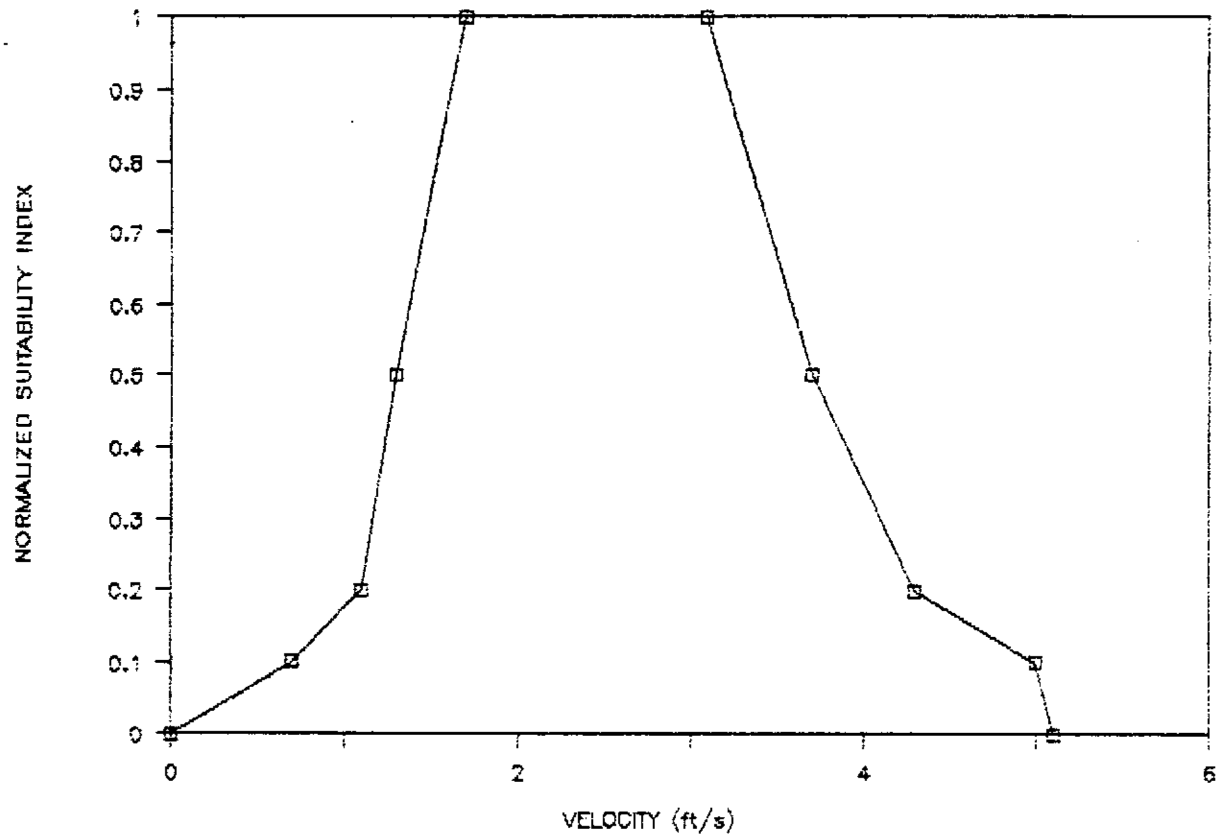
Figures 7, 8, and 9 present the utilization curves that we constructed for spring chinook spawning depth, velocity, and dominant substrate, respectively. Curve peaks occurred: between 0.8 and 1.4 ft water depth; between 1.7 and 3.1 ft/sec water velocity; and between 1.5 and 6.0 inches substrate diameter. Other analyses of survey data showed that: the mean distance of redds to the nearest stream bank (Appendix X) was 17.2 ft (n=143, standard deviation=9.515); the mean stream width at the location



Coordinates

X	0.0	0.5	0.6	0.7	0.8	1.4	1.6	2.0	2.9	3.0
Y	0.0	0.1	0.2	0.5	1.0	1.0	0.5	0.2	0.1	0.0

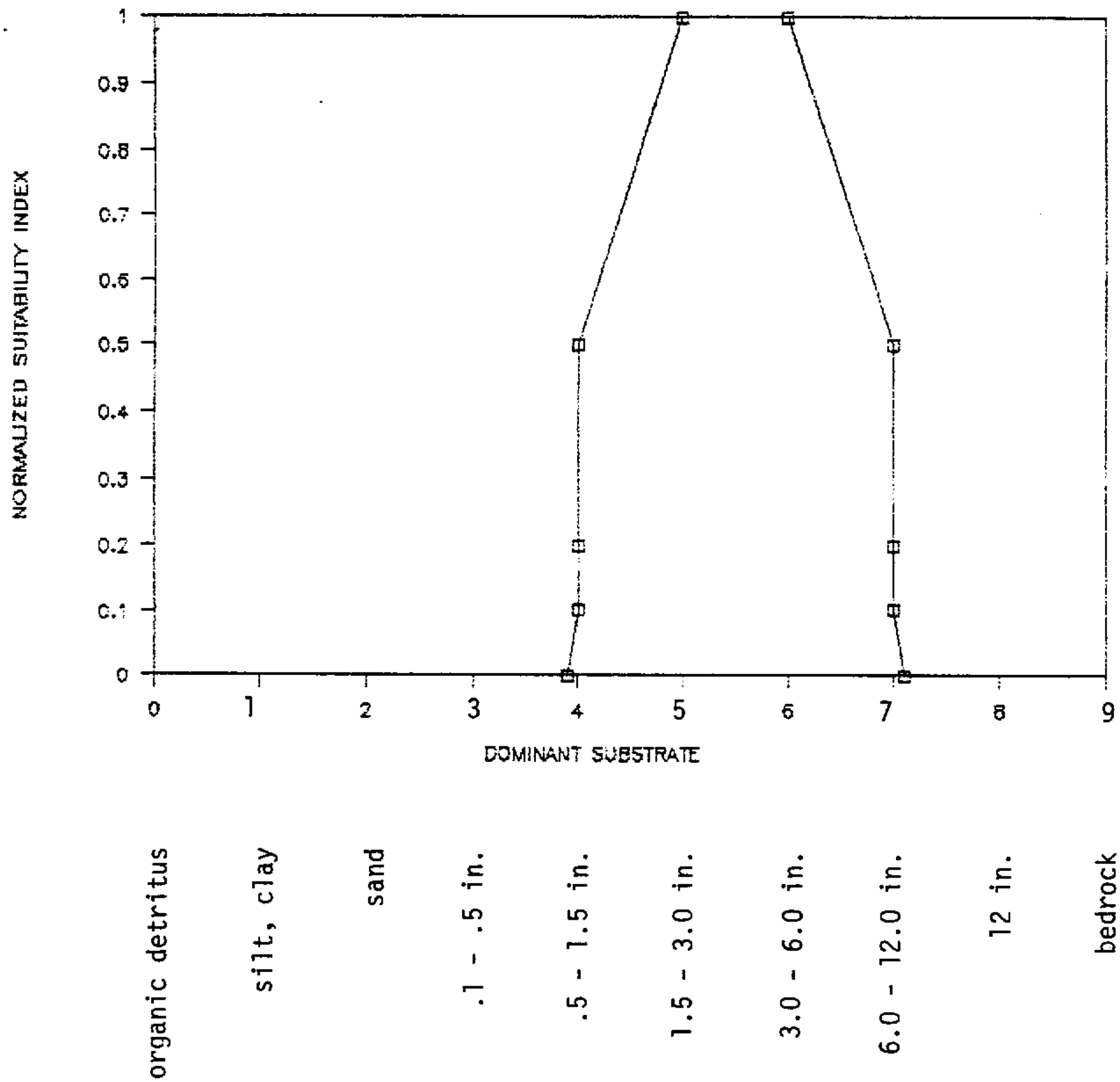
Figure 7. Utilization curve for spring chinook spawning depth.



Coordinates

X	0.0	0.7	1.1	1.3	1.7	3.1	3.7	4.3	5.0	5.1
Y	0.0	0.1	0.2	0.5	1.0	1.0	0.5	0.2	0.1	0.0

Figure 8. Utilization curve for spring chinook spawning velocity.



Coordinates

X	3.9	4.0	4.0	4.0	5.0	6.0	7.0	7.0	7.0	7.1
Y	0.0	0.1	0.2	0.5	1.0	1.0	0.5	0.2	0.1	0.0

Figure 9. Utilization curve for spring chinook spawning substrate.

of redds (Appendix XI) was 64.6 ft (n=131, standard deviation=23.311); and redds occurred most frequently in riffle habitat (Appendix XII).

If we compare the criteria that we used (Table 4) with the spawning suitability curves constructed from our redd data (Figures 7 to 9), we observe some differences. For spawning depth, the optimum range of the suitability curve is shifted partially downward in relation to that for our criteria. This may reflect an actual difference between the criteria and Nooksack spring chinook behavior, or it may have been due to either (1) greater depth in the river when the majority of redds were under construction than when we made measurements, or (2) a reduced river stage due to lower than normal precipitation during the spawning period. For spawning velocity, the optimum range of the suitability curve is slightly more narrow but similar to our optimum criteria, and the marginal range of the curve is shifted to a slightly higher range than that for our criteria. These differences appear relatively insignificant, but suggest that more data may be needed to better define the suitability curves. Finally, for spawning substrate, the optimum ranges of the suitability curve and our criteria are identical, and the marginal ranges are only slightly different. Overall, we remain confident that our chosen criteria were appropriate for classifying spawning habitat suitability.

Spawning Gravel Composition

Spawning gravel compositions were analyzed to determine the percentage of particles less than 0.85mm in diameter. Fine sediments of this size range have been documented to have a detrimental effect on salmonid egg and alevin survival (Cederholm et al. 1980). Table 9 presents the fine sediment levels (<0.85 mm) documented at four locations between 1982 and 1987. The complete results of the spawning gravel composition analysis for all particle sizes are in Appendix XIII.

In 1986 average fine sediment levels increased in an upstream direction, from 9.76% in the Acme Vicinity reach, to 10.47% in the Edfro/Skookum reach and 13.17% in the Larson's Bridge reach. Fine sediment levels were greatest in the reach with the highest gradient. Since fine sediment deposition is often greater at lower gradient sites, this was unexpected. Fine sediment levels of 12.47% were recorded at the Strand Road site in 1987.

Spawning gravel samples have been taken at the Larson's Bridge site for five years. For the first three years, 1982-84, average fine sediment levels remained relatively constant at approximately 10.5%. In 1985 levels increased to over 13% and remained at that level in 1986. This indicates an increase in deposition of fine sediment in this reach in the last two years. In the Skookum/ Edfro reach, fine sediment levels decreased from 13.31% in 1985 to 10.47% in 1986 which may indicate a flushing trend in this reach. Only one year of data was available for the Acme Vicinity and the Strand Road sites, so no analysis of trends was possible.

Table 9. Spawning gravel fine sediment levels (<0.85 mm) for four reaches of the South Fork Nooksack River.

Reach	Rivermile	Stream Gradient	Date	% Fines <0.85mm
Larson's Bridge	19.7-20.0	0.57%	1986	13.17
"	19.7-20.0		1985	13.23
"	19.7-20.0		1984	10.70
"	19.7-20.0		1983	10.45
"	19.7-20.3		1982	10.67
Skookum/Edfro	14.5-15.3	0.38%	1986	10.47
"	14.5-15.3		1985	13.31
Acme Vicinity	9.5-9.7	0.30%	1986	9.76
Strand Road	3.8-4.2	0.001%	1987	12.47

Stream Stability Indices

The results of the stream stability indices for the seven South Fork Nooksack stream reaches are given in Table 10.

Table 10. South Fork Nooksack 1986 stream stability results.

River Mile	Location	Stability Score
8.6-10.1	Acme Br. - Hutchinson	94
14.8-15.5	Guaging St. - Edfro Is.	96
19.8-20.0	Plumbago Cr. - upriver	112
25.1-25.2	Below Sylvester Canyon	84
27.1-27.5	Howard Cr. - downriver	126
28.4-28.6	0.6 RM above McGinnis	115
30.0-30.1	RM 30 bridge - upriver	95

None of the reaches were rated stable. Four areas rated moderately unstable and three reaches rated unstable. The most serious factors were inadequate channel capacity (all but one location), bank cutting (four of the seven reaches had almost continual bank cutting), scouring and deposition (at most reaches 30-50% of the channel bottom was affected), and bottom size distribution (at five locations less than 50% of the bottom materials were judged to be stable). Two sites had serious mass wasting.

The most unstable reach was immediately below Howard Creek, where an 8 to 15 ft high debris fan of sediments from the creek was evident for 1/4 mile downstream. The mouth of Howard Creek towered 20 ft above the South Fork due to a large depositional fan. The reach below Sylvester Canyon was the most stable reach indexed, having a score of 84. A large gravel deposition area (roughly 500 ft long and 200 ft wide) exists above the narrow opening to Sylvester Canyon. It may be that a significant portion of the sediment load the South Fork carries above this point is in temporary storage here. This factor in combination with the stream energy dissipation provided by the series of small falls in Sylvester Canyon likely contributed to the low score.

Streambed Profiles

Figure 10 presents the Tether Hole cross-section (CS#1, RM 19.9) for 1983, 1985 and 1986. The depth of the pool at the cross-section varied considerably during the four-year study period, increasing in depth approximately 4 ft between 1983 and 1985, before filling in about 6 ft in one year between 1985 and 1986. The channel at this cross-section widened by almost 20 ft over the four-year study period. In contrast, an adjacent riffle (CS#2, RM 19.9) remained relatively stable over the same four-year period. There is evidence of about 1 foot of slight downcutting at the extreme right side of the cross-section (Figure 11).

Only two years of data are available for Skookum Hole (CS#1, RM 14.5). Pool filling of less than 1 foot occurred between 1985 and 1986 (Figure 12). The elevation of the adjacent riffle (CS#2, RM 14.5) remained relatively constant over the two-year period, with slight elevation changes along the banks on both sides of the channel (Figure 13).

DISCUSSION

Spawning Habitat Availability

The levels of combined suitable spawning habitat that were found in all 5-mile reaches downstream of RM 25 appear to be more than sufficient for the present size of the spring chinook run (Figure 6). Among adjacent reaches, the relatively lower amount of suitable spawning habitat in the reach where the most fish typically hold, i.e., RM 10-15, once more suggests that most of these fish are there because they are attempting to return to the hatchery, and not because they are attracted by abundant spawning habitat. The relatively low levels of spawning habitat found upstream of RM 25 could be a condition that will restrict future attempts to enhance the wild stock portion of the run there. It is reasonable to assume that those upper miles of the river will always support a comparatively small fraction of the total run due to the relatively small amount of suitable spawning habitat found there. Moreover, efforts to eliminate the effects of embeddedness there would not add significantly to the habitat.

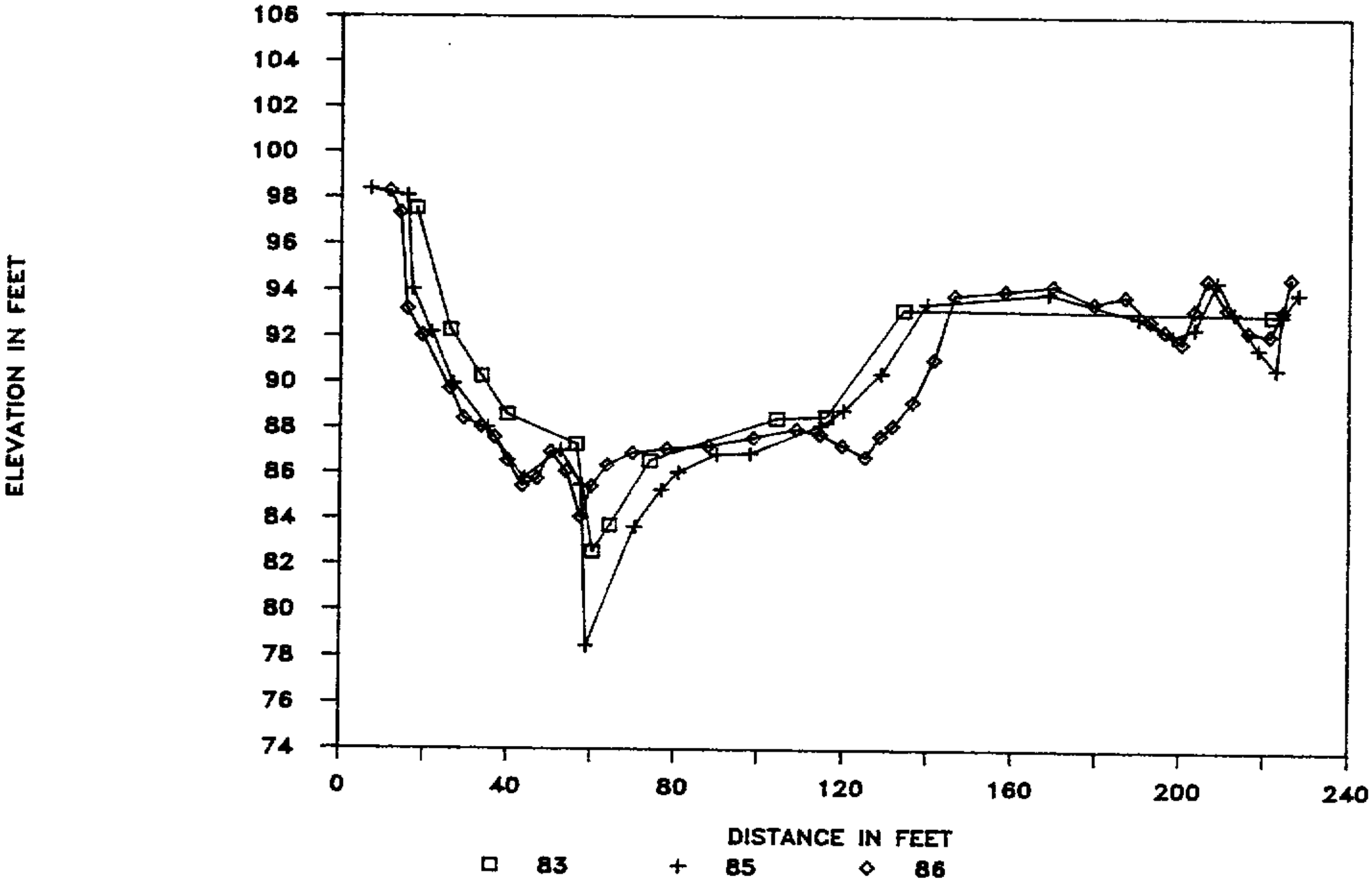


Figure 10. South Fork Nooksack cross-section #1 at RM 19.9 (Tether Hole), 1983, 1985 and 1986.

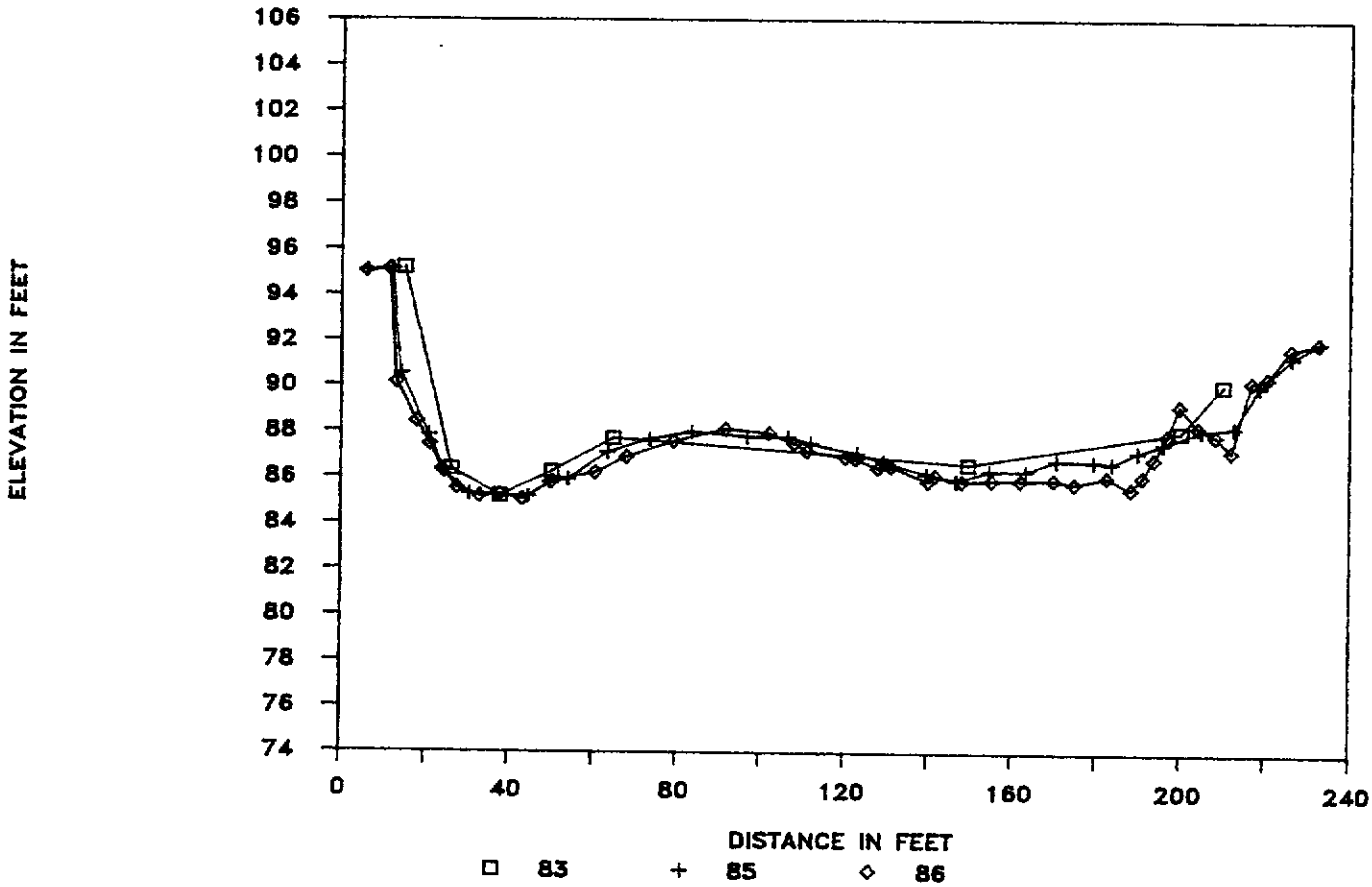


Figure 11. South Fork Nooksack cross-section #2 at RM 19.9 (adjacent riffle), 1983, 1985 and 1986.

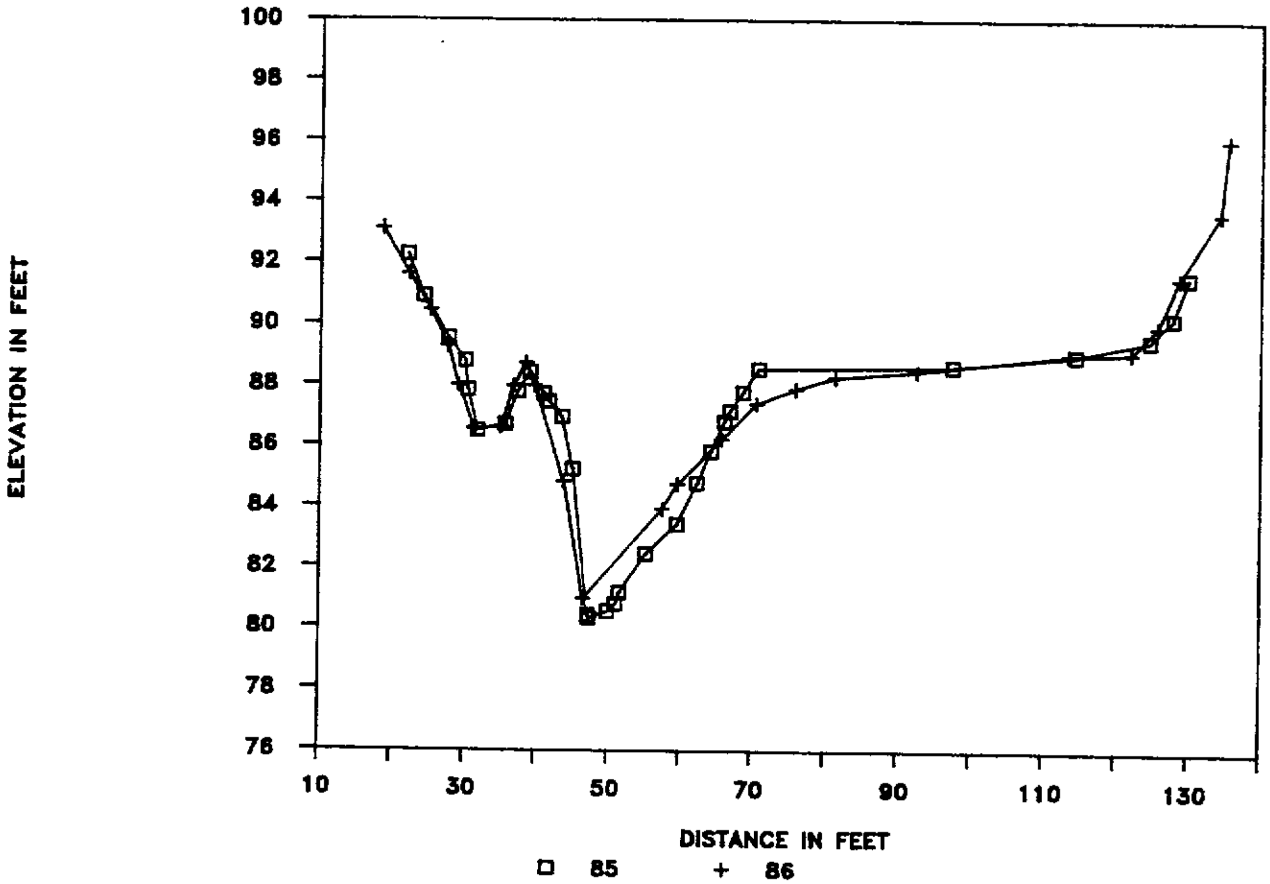


Figure 12. South Fork Nooksack cross-section #1 at RM 14.5 (Skookum Hole), 1985 - 1986.

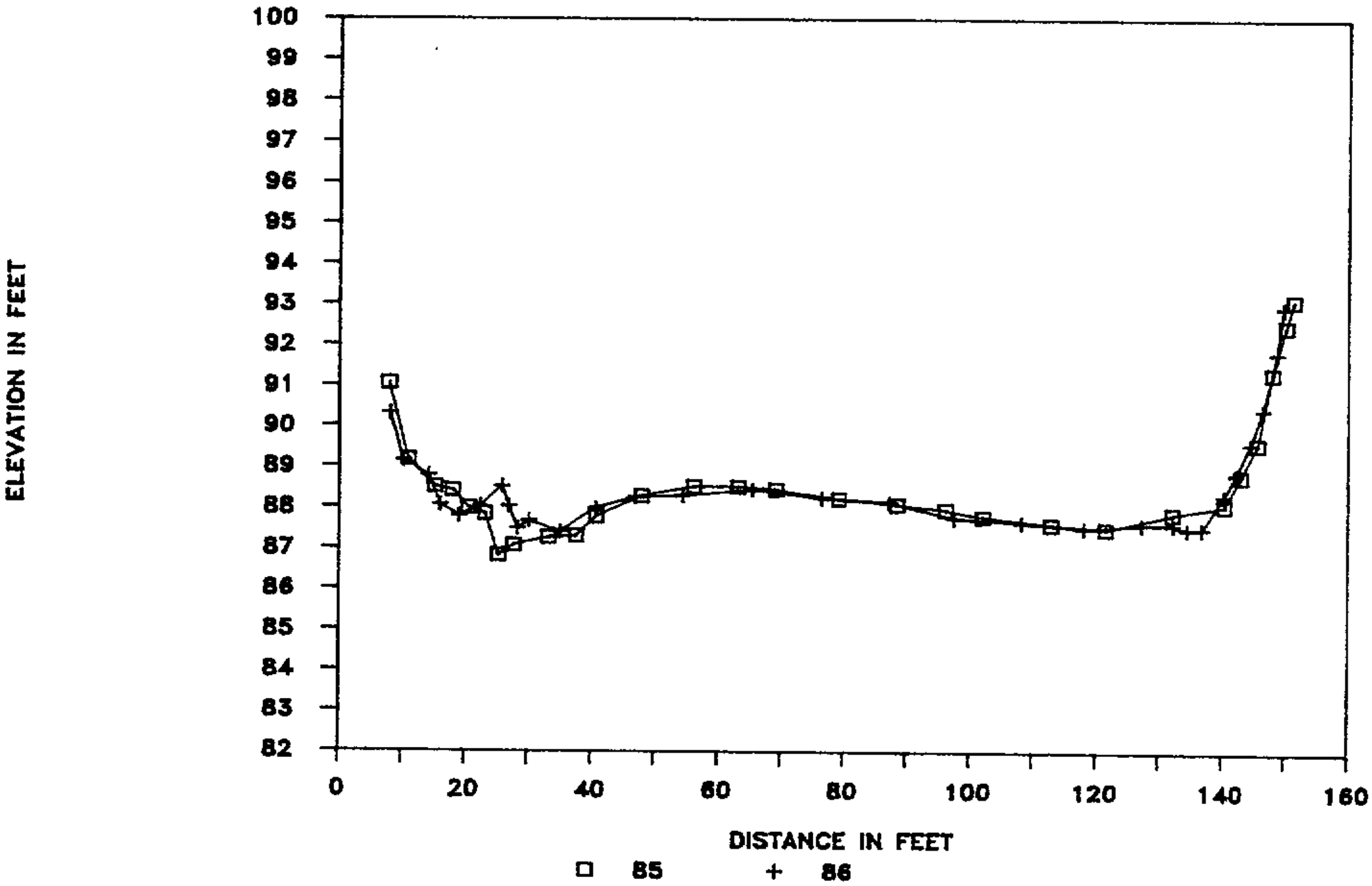


Figure 13. South Fork Nooksack cross-section #2 at RM 14.5 (adjacent riffle), 1985 - 1986.

There appears to be an opportunity to better use the high level of optimal spawning habitat found between RM 20 to 25. While the amount of holding habitat here is only moderate (Figure 4), it might be enhanced through future rehabilitation.

One concern of managers has been the comparatively small number of spring chinook that are observed using the habitat in the lower South Fork. We found that the highest rates of suitable spawning habitat were located downstream of RM 10 (Figure 6). Yet it was in these same 5-mile reaches that the least numbers of spring chinook redds were observed (Table 8). This contrast in numbers may reflect the presence of a combination of factors that fail to satisfy holding fish habitat requirements. Despite the greater area and volume of water found in the lower miles of the river, the rates for total volume in holding sites were relatively low (Figure 4). The lower miles of the South Fork are characterized by increased width, an increased rate of insolation, and increased water temperature at low flow. Taken in combination, it appears that such factors force migrating fish to continue their search for suitable holding habitat further upstream. If so, this represents a sizeable reduction in the potential spring chinook run size. One way to attempt to increase the useability of these lower miles is by improving upper watershed conditions that now promote increased water temperature during low flow. By reducing the background or base temperature of water arriving at the lower river it may be possible to provide a range of acceptable temperatures for holding fish.

Spawning Gravel Composition and Fine Sediments

The particle size composition of spawning gravels is an important characteristic which is related to the survival of salmonids during the intragravel lifestage. Gravel that is relatively free of fine sediments (clay, silt and sand) is essential for good survival. Excessive concentrations of fine sediment can cause mortality to salmonid eggs and alevin during the time they live in the gravel. Mortality occurs in two ways. Fine sediment particles can clog the intersticial spaces between the larger pieces of gravel, reducing or eliminating the flow of oxygen-bearing water through the gravel to the eggs, resulting in mortality due to oxygen starvation. Fine sediments can also form a cement-like coating which seals the surface of the redd. This condition reduces or prevents fry from emerging from the gravel when they are ready, entombing them below the surface where they die of starvation when the food supply in their yolksacs is consumed (Koski 1966).

Numerous studies have documented the inverse relationship between salmonid survival to emergence and fine sediments, although the precise definition of fine sediment has varied (Shirazi and Seim 1979). Cederholm et al. (1982) documented the intragravel survival of coho salmon and steelhead trout in gravel containing varying amounts of fine sediments having diameters of less than

0.85mm. Relatively good survival to emergence was documented when fine sediment volume was less than 10%. Survival was highly variable but declining between 10% and 20%. Survival was uniformly poor when levels were above 20%.

When the fine sediment percent volume levels in the South Fork Nooksack are compared with the results of the Cederholm study, generally good survival to emergence is indicated. The site near Acme, which had fine sediment levels averaging 9.76%, would be expected to have minimal mortality due to fine sediments. At the site between Skookum and Edfro Creeks, where levels declined from 13.3% in 1985 to 10.5% in 1986, fine sediment levels would also not be expected to be a significant source of mortality. After remaining relatively stable between 10% and 11% from 1982-1984, fine sediment levels at the site near Larson's Bridge have averaged above 13% in 1985 and 1986. Although this is well below the 20% level where uniformly poor survival would be predicted, it indicates that some mortality from fine sediments is probably occurring. The trend of increasing fine sediment levels at this site is of particular concern because this reach is heavily utilized by the remaining native spring chinook population. Further increases in fine sediment levels to the 15-20% range could cause a significant decline in intragravel survival to emergence. Further monitoring of conditions at this site is recommended.

Substrate Embeddedness

Another measure of fine sediments was the embeddedness rating. This rating describes the degree to which the large particles on the surface of the streambed are covered or surrounded by fine sediments. According to Hamilton and Bergersen (1984), "This rating allows better evaluation of the channel substrate's suitability for spawning, egg incubation, and rearing and of habitats for aquatic invertebrates and young, overwintering fish." The degree of embeddedness is also an indicator of the formation of a compacted barrier of fine sediment particles which restricts the exchange of water between the stream and the intragravel environment and impedes emergence of fry from the gravel.

Table 11 shows the amount of potentially useable habitat affected by embeddedness. Of the 2,975,396 sq ft of useable habitat identified in the South Fork based on flow, depth and substrate characteristics, 4.4% or 129,377 sq ft had over 50% embeddedness. In some localized reaches embeddeness appears to significantly reduce the amount of available habitat. In the reach between RM 25 and 30, nearly 12% of the potentially useable spawning habitat had embeddedness >50%. This reach had the least amount of habitat available to spring chinook so the loss of 12% is particularly significant.

Large amounts of habitat in all reaches had embeddedness levels of 25-50%. Overall, 37.3% of all useable spawning habitat exhibited this level of embeddedness. It was particularly common in the reaches from RM 25-30 (84.2%), RM 0-5 (71.7%) and RM 30-35

(53.1%). We did not remove habitat in this category from the useable habitat base, however this degree of embeddedness probably reduces productivity in some instances. Some habitat in this category was observed to be highly compacted, which probably affects both its suitability for spawning and the ability of fry to successfully emerge after incubation. The large amount of habitat in this category also indicates a widespread sensitivity to additional fine sediment deposition that could in turn result in a large decrease in the amount of useable habitat if sedimentation increases.

Table 11. Amount of available spawning habitat potentially affected by embeddedness.

River Mile	Useable Habitat	Useable Habitat Embedded >50%	Percent Useable Habitat Embedded >50%	Useable Habitat Embedded 25-50%	Percent of Useable Habitat Embedded 25-50%
0-5	682,167	7,660	1.1%	438,727	71.7%
5-10	686,215	31,726	4.6%	279,967	42.8%
10-15	367,659	23,838	6.5%	61,673	17.9%
15-20	659,445	54,745	8.3%	181,997	30.1%
20-25	484,837	4,567	0.9%	91,759	19.1%
25-30	37,708	4,514	12.0%	27,960	84.2%
30-33.4	57,365	2,327	4.1%	29,199	53.1%
Total	2,975,396	129,377	4.4%	1,111,282	37.3%

Stream Channel Instability

The stability of the stream channel has a direct effect on the productivity of spawning habitat. A stable intragravel environment free from mechanical disturbance is required for successful incubation of salmon eggs. Disturbance of eggs can cause significant mortality. Scouring of the streambed gravel can wash away or damage the eggs, or they may be crushed or buried under deposits of sediment (both fine or coarse sizes) and debris. Losses of 50% to 95% of eggs and alevin due to scouring and deposition were documented by McNeil (1966) in southeast Alaska. Mortality also occurs due to channel shifting which dewaters sections of the stream channel (Cederholm and Koski 1977). These conditions occur most frequently during high flow events and in stream channels transporting large amounts of bedload sediment or debris.

Several of the measurements collected in the South Fork Nooksack in 1986 and earlier years provide a useful indication of the degree of mortality due to stream channel instability. Stream channel stability index measurements taken at seven sites between the Acme Bridge and RM 30, the upper limits of spring chinook sightings, documented moderately unstable to unstable conditions at all sites. An average score of 95, which is at the high end of the moderately unstable range, is currently typical of South Fork spawning reaches. The most unstable reaches appear to occur where there is a large input of sediment, such as below Howard Creek.

Karanka et al. (1981) found that stability indices in British Columbia corresponded with suspended sediment levels. Higher levels of suspended sediments occurred in reaches rated as unstable. It is likely that unstable channel conditions increase suspended sediment levels, thus contributing to turbidity problems in the South Fork.

To our knowledge, the stream stability index has not been directly correlated to fish production or survival. Schuett-Hames and Schuett-Hames (1984) identified four factors in the index (debris jam potential, channel capacity, bottom size distribution and percent stable materials, and scouring and deposition) which would relate to redd survival. All but debris jam potential were found to be significant concerns in the South Fork.

Stream stability surveys were performed annually near Plumbago Creek (RM 19.8-20.0) by the Lummi Tribe from 1983-1986. Consistently unstable ratings have been obtained. Scores have fluctuated with the severity of winter storms. The score at this site increased from 112 to 122 following major storms in the winter of 1983-84. The score dropped to 105 following the calm winter of 1984-85, and rose back to 112 in 1986.

Streambed cross-sections were measured during low flow conditions at riffles at RM 19.9 and 14.5. The riffle cross-section at RM 19.9 showed only slight changes of less than a foot between 1983 and 1986. The elevations for the riffle at RM 14.5 remained relatively constant between 1985 and 1986. Platts et al. (1983) noted that measurement of stream cross-sections during subsequent low flow periods may not detect erosion and deposition occurring temporarily during high flows. Although the cross-section measurements were not taken frequently enough to determine the degree of scouring and deposition during the incubation period, they did verify the relative stability of the streambed level from year to year. The measurements indicate that serious aggradation did not occur during the study period. There appears to be a tendency toward slight degradation or flushing of bedload at these two riffle sites, in contrast with the adjacent pool at RM 19.9 which filled in dramatically between 1983 and 1986.

Another indicator of channel stability and intragravel survival are the results of scour monitoring studies done on the South Fork between RM 14.4-15.5 during the winter of 1984-85 (see Appendix XIV). Scour, deposition and channel changes were documented at eight spring chinook redd locations through the use of scour chains placed in the vicinity of the redds. Three of eight of the apparent redd locations did not appear to survive winter high flows due to channel scouring and deposition, although flow conditions were moderate compared to the winter floods of 1981, 1982, 1983 and 1985.

Based on this information, considerable mortality to eggs incubating in the gravel appears to be occurring. The loss of 37% of the redds in a moderately unstable reach during a winter without severe flooding indicates that significant mortality is probably occurring on a regular basis. The widespread occurrence of moderately unstable to unstable channel conditions documented in the stream stability indices indicates that the problem is occurring throughout the South Fork. Higher mortality would be expected in reaches which are more unstable and in years when winter storms and high flows are more severe.

Spawning Habitat as a Limiting Factor

We do not consider availability of suitable spawning habitat to limit the current size of the spring chinook run in the South Fork. However, at some increased run size we suspect that spawning habitat would become limiting. This would be particularly true for the river upstream of RM 25 (Table 11). The next reach where we could anticipate a limited rate of spawning success is RM 10 to 20. This reach would continue to be used by a large proportion of returning hatchery stock fish. Limited spawning habitat availability, combined with an increased number of spawners would result in use of less suitable habitat, reduced spawning success per redd, and redd encroachment and destruction by competing fish.

We showed that about 4% of the total potential area of suitable spawning habitat was rendered unsuitable by 50 to 100% embeddedness in 1986. We then determined what would be at risk if the total river area of spawning habitat that was 25 to 50% embedded was further degraded to then exceed 50% embeddedness. This loss from the total area of suitable spawning would be an additional 37% (Table 11). If embeddedness should increase due to increased sedimentation, then the spring chinook run would be in serious jeopardy due to much reduced area of suitable spawning habitat.

It appears that survival to emergence is limited by redd disturbance and dewatering associated with stream channel instability. Losses are probably most severe in the most unstable areas during winters having major storm events.

The reduced level of spawning in the South Fork downstream of RM 10 may be more directly a problem of excessively high water temperature during the holding stage. However, this impact potentially extends into the spawning stage and thus causes spawning to be limiting during some years. Only restoration of the South Fork's historic mean depth throughout the river can be expected to correct this temperature problem.

INNER GORGE LANDSLIDE AND STREAM-BANK EROSION INVENTORY

Due to concern over the effect of sedimentation on fish habitat, information on sediment sources such as inner gorge (streamside) landslides and stream-bank erosion was collected during the course of the fish habitat inventory. The stream channel from RM 0.0 to 33.56 was surveyed except for 1.25 miles between RM 30.9 and 32.15.

Additional information on sediment sources affecting the South Fork Nooksack was documented during a separate, concurrent study of mass wasting in the Howard Creek watershed, by PEAK Northwest (1986).

METHODS

Information on inner gorge landslides and eroding or riprapped stream banks was collected by walking the stream. Locations were recorded on 1984 DNR 1/4 Township orthophoto maps. Due to the recent photography and good resolution (1:12,000 scale) many of the larger landslides could be seen on the photomaps and features could usually be accurately located and recorded.

Height and length were measured with rangefinders or estimated where access to the base of the slide was restricted. Visual estimates were made of the particle size composition of exposed materials, the activity level of erosion processes, the degree of undercutting by the river at various flows, and the amount of sediment input directly into the stream.

Photographs were taken of most of the inner gorge landslides and some of the most significant areas of bank erosion. Many of these features were also recorded on a video tape of the stream channel. The tape was made by the Nooksack Tribe from a helicopter in the fall of 1986.

RESULTS

Inner Gorge Landslides

Appendix XV gives the complete survey data for each of the 37 landslides documented in the study area, and the location of each is shown in Figure 14. Many of the landslides were observed to be actively eroding and putting large amounts of sediment directly into the stream. Table 12 presents information on the relative location and numbers of the most significant sediment sources.

Landslide density (number of landslides per mile) steadily increases in an upstream direction, ranging from 0.0 landslides per mile near the mouth to 2.6 landslides per mile at the upper end of the survey area. This appears to be due to the effect of the terrain on channel geomorphology. The channel is more confined in narrow, incised gorges in the upper reaches and the

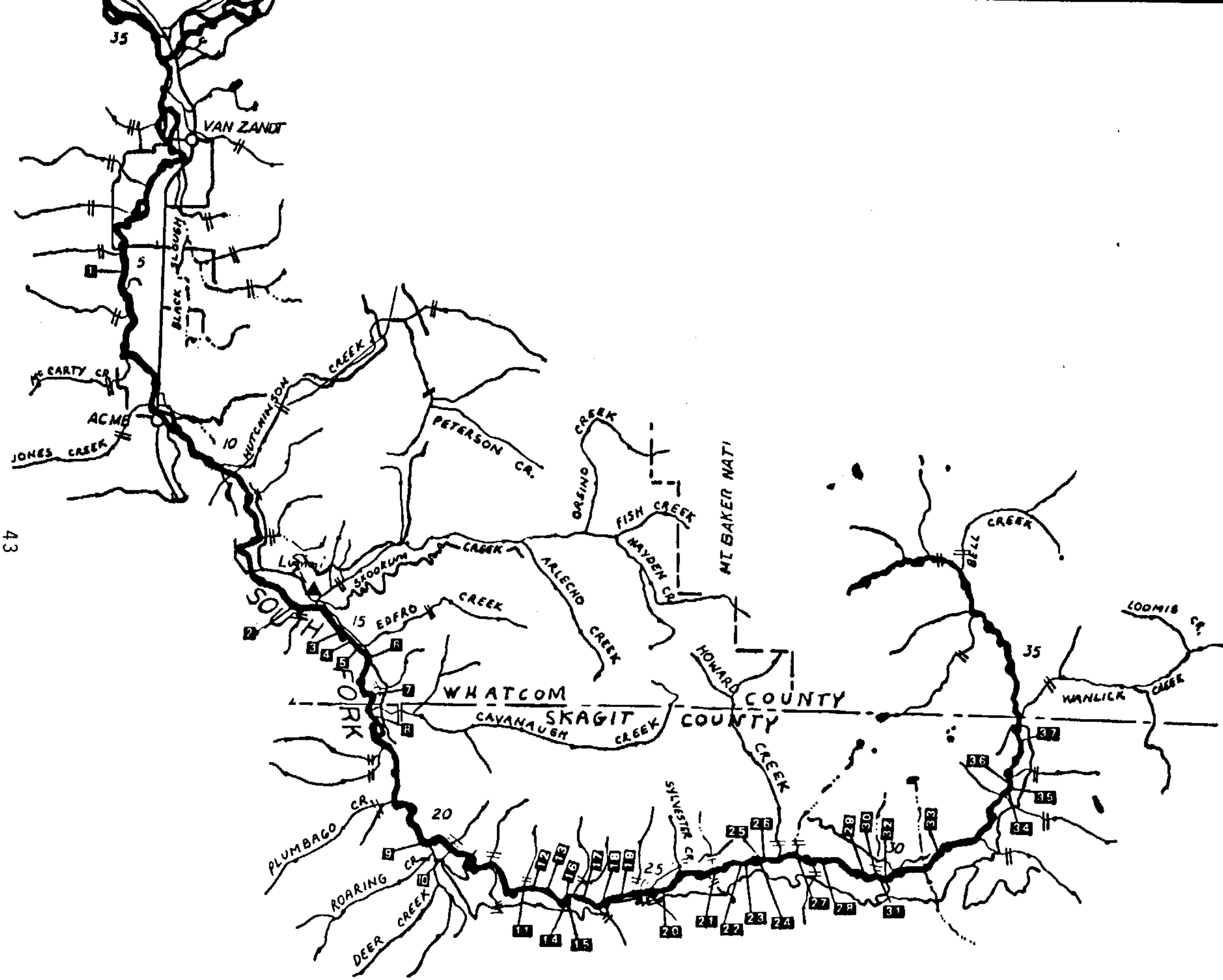


Figure 14. Location of inner gorge landslides adjacent to the channel of the South Fork Nooksack River.

river often undercuts unstable slopes. Further downstream the valley widens and the stream channel comes into contact with the valley walls much less frequently.

Table 12. The location and significance of South Fork Nooksack inner gorge landslides.

		Number of Landslides					
River mile Location	Miles Surveyed	Total	Per Mile	Erosion Active	W/Large Sed. Input	>50% Clay Content	Area >10,000 Sq Ft
0 - 5	5	0	0	0	0	0	0
5 - 10	5	1	0.2	1	1	1	1
10 - 15	5	2	0.4	0	0	0	0
15 - 20	5	6	1.2	1	1	1	1
20 - 25	5	10	2.0	6	4	9	7
25 - 30	5	12	2.4	7	8	9	7 @
30 - 33.6	2.3 *	6	2.6	6	4	5	6
	32.3	37	1.1 &	21	18	25	22 @

* - 1.25 miles (RM 30.9-32.15) not surveyed due to rough terrain.
& - Average number of landslides per mile.
@ - Data unavailable for three landslides.

Most large, actively eroding landslides were located in the upper part of the study area. Only two actively eroding landslides were found below RM 20, while 19 actively eroding landslides were found between RM 20 and 33.56. The same pattern was true for landslides putting large amounts of sediment directly into the stream; 16 landslides in that category were observed above RM 20, while only two were found below. Likewise, 22 landslides above RM 20 had surface areas greater than 10,000 sq ft, as compared with only two below RM 20.

Twenty-three (82%) of the landslides located above RM 20 had a clay content of greater than 50%. Many of these landslides were predominately made up of blue clay which was capped by glacial till of varying depth. Large blocks of clay were observed at the base of many of the actively eroding landslides. Apparently they fell as a result of the river undercutting the nearly vertical clay walls.

Undercutting of the landslide by the stream appeared to be one of the major factors in activation of the slides and delivery of sediment to the stream channel. Thirty-four (92%) of the slides were judged to be undercut by high flows, 25 (68%) had undercutting at moderate flows, and 14 (38%) had undercutting even at low flows. Several landslides appeared to be the result of slow but massive downslope movement of material, possibly a result of deep-seated earth flows.

Stream-bank Erosion

Figure 15 shows the results of the stream-bank erosion inventory. Extensive areas of raw, eroding stream banks and formerly eroding stream banks armored with rock riprap are present along the channel of the South Fork. The greatest total bank erosion was observed in the reach between RM 5-10, with about 3.5 lineal miles of eroding stream bank. Over two miles of eroding stream bank was present in the reach from RM 0-5 and RM 25-30. The majority of eroding banks below RM 15 were ripraped to protect farmland and improvements from erosion.

DISCUSSION

Inner Gorge Landslides and Stream-bank Erosion

Actively eroding inner gorge landslides and stream-bank erosion appear to be significant sources of sediment input to the channel of the South Fork. A large number of inner gorge landslides and eroding stream banks were identified along the channel of the South Fork. Sediment production from 21 actively eroding inner gorge landslides representing over 800,000 sq ft of surface area was documented. In addition, over eight linear miles of eroding stream bank and four miles of riprapped stream bank were documented. Fourteen landslides showed evidence of more limited current erosion due to partial revegetation. These, and the two completely revegetated features provide an indication of past sediment production.

Estimation of the actual volume of sediment produced from these sources is not possible at this time because the rate of erosion from the surface of the landslides and stream banks is not known. Observation of large blocks of clay and gravel deposits at the base of raw, actively eroding landslides indicates that the rate of erosion is rapid in some cases.

Inner gorge landslides and stream-bank erosion are significant sources of sediment due to their proximity to the stream channel. Nearly all the sediment produced goes directly into the stream channel where it is mobilized and transported downstream during subsequent high flows. Consequently the effect on downstream resources is rapid and direct.

The composition of the material in the slides is also important. Many of the 37 inner gorge landslides had some clay content, 25 contained over 50% clay material. Most landslides with high clay content were located above RM 20 and were associated with lacustrine (ancient lakebed) deposits of blue clay capped with glacial till deposited as the glaciers retreated. Eroding stream banks in this vicinity often were similar in composition.

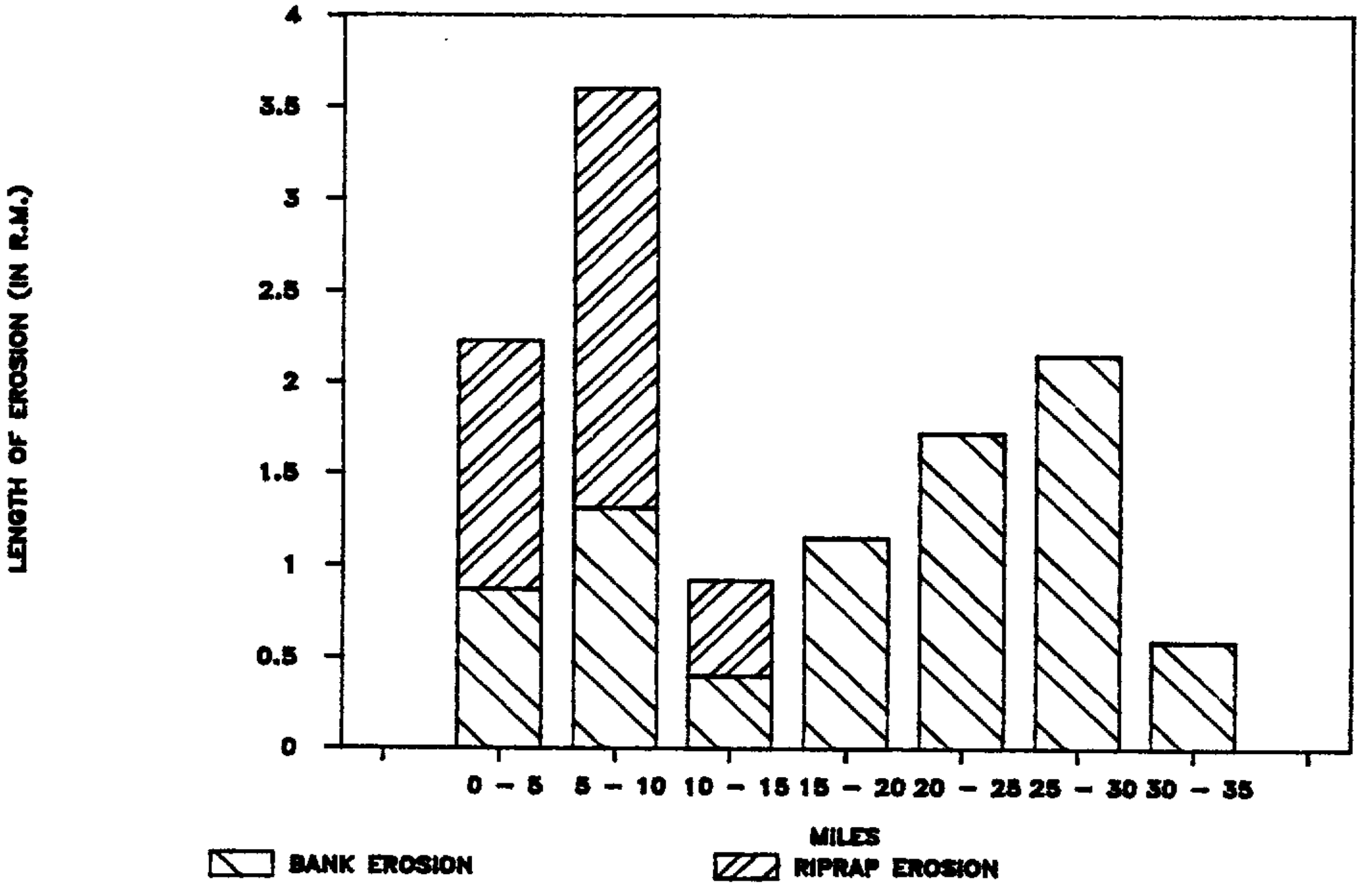


Figure 15. South Fork Nooksack bank erosion.

Inner gorge landslides and stream-bank erosion in the reach from RM 20 to 33 (as well as along lower Howard Creek) appear to be the major source of blue clay into the South Fork. Large blocks of blue clay material were observed which had sloughed off into the South Fork from these sources and were in the process of breaking up and being transported downstream.

Effects of the blue clay on downstream habitat and water quality appeared to be extensive. Riffles in the vicinity of blue clay landslides often were contaminated with cobble to gravel-sized pieces of blue clay which were in the process of disintegrating into fine sediments. Although no gravel composition samples were taken in the vicinity of the landslides, increased levels of fine sediments would be expected to occur in these situations. Gravel substrates were observed to be embedded and blanketed with a layer of fine, blue clay particles in the vicinity of sources of blue clay, particularly in areas of low gradient and low velocity. These conditions would be expected to reduce invertebrate production and the intragravel survival of salmonids.

The blue clay landslides also appear to be a major cause of turbidity. After only several days of rain in September, visibility in the vicinity of RM 30 deteriorated rapidly. The increase in turbidity was associated with a small increase in stream flow which caused erosion and mobilization of clay deposits at the base of actively eroding landslides. Besides the degradation of water quality associated with increased turbidity, a detrimental effect on the survival of newly emergent salmonid fry during high runoff periods in the spring has been observed in hatchery fish. Turbidity interferes with feeding behavior of young fry, resulting in stunted growth and mortality. A similar effect on the natural fry in the South Fork would be expected during spring storms.

In addition to their role as major sources of blue clay fine sediment, inner gorge landslides appear to be significant sources of larger bedload material such as cobbles, gravels and sand. These materials, together with bedload from other sources discussed below, contribute to downstream conditions such as filling of pools and destabilization of the channel. Trees falling into the stream from the faces of actively eroding landslides and stream banks also contribute to the amount and distribution of large organic debris in the stream channel.

Sources of Sediment from the Upland Areas of Tributary Watersheds

Results of a study of sediment production in Howard Creek indicate that large amounts of sediment are being contributed to the South Fork by at least one tributary in the forested, mountainous portion of the upper watershed. The study (PEAK Northwest 1986) documented sources of sediment in the Howard Creek watershed through the use of aerial photography and site visits.

Howard Creek is a major tributary of the South Fork which enters at RM 27.5. Its 7.62 sq mi watershed drains the east side of Bald

Mountain and the rugged west flank of the Twin Sisters Mountains. A combination of steep side slopes, a major fault line, unstable soils and an over-steepened inner gorge area has created conditions conducive to mass wasting and sediment production. These conditions have been aggravated by past activities such as road building and timber harvest which have caused an increase in the already high natural rates of erosion in the watershed.

The PEAK Northwest study identified 74 active landslides in the Howard Creek watershed between 1940 and 1983. These landslides contributed an estimated initial failure volume of 4,256,300 cubic yards of sediment to the stream channel. According to aerial photo analysis, 30% of the landslides occurred on unmanaged (natural) sites and contributed 23% of the total volume; 50% of the landslides occurred on harvested sites and contributed 75% of the volume; while 20% of the landslides were associated with roads and produced 2% of the volume.

The PEAK Northwest study also documented progressive bank erosion and aggradation (buildup and widening) in the stream channel from 1968-1983. This was indicative of increased rates of sediment input which exceeded the capacity of the channel to transport it. The large debris fan at the mouth of Howard Creek also indicates the large contribution of sediment from Howard Creek to the channel of the South Fork.

The results of this study indicate that steep, unstable portions of the upper South Fork basin, such as Howard Creek, are contributing large amounts of sediment to the South Fork. Other streams exhibiting conditions which indicate high rates of sediment transport include Plumbago Creek, Cavanaugh Creek, an unnamed left-bank tributary (WRI# 01-0318), and the tributaries draining the east flank of the Twin Sisters Mountains.

Sediment input from the Howard Creek watershed was estimated to have increased to four times the natural or unmanaged rate as a result of past logging and road building activities. This has contributed to an increase in bank erosion and aggradation of the channel. If a similar rate of sediment production has occurred in other parts of the upper watershed, this would represent a large increase in the bedload sediment load transported by the South Fork. Widening of the channel due to aggradation of sediment has apparently resulted in increased lateral stream cutting which increased bank erosion and the activation of debris slides in constricted inner gorge areas.

The increased bedload from the upper watershed, together with sediment contributed by bank erosion and inner gorge landslides, is all contributing to conditions observed in downstream reaches such as filling of holding pools, loss of channel stability, fine sediment embeddedness and temperature increases.

WATER TEMPERATURE STUDY

Water temperatures were continuously monitored in the South Fork Nooksack River and most major tributaries between RM 32.8 and 12.45 during July and August, 1986. Riparian features affecting temperature, including canopy cover and channel dimensions, were also inventoried. Data analysis in this report is limited to water temperatures within the South Fork only.

METHODS

Continuously recording thermographs were anchored underwater within the main current away from possible bank seeps at nine locations (Figure 16) in the South Fork between RM 32.8 and 12.45. Many of the sites were within or immediately adjacent to holding areas utilized by spring chinook during the monitoring period. Twenty-one additional monitoring sites were located in tributaries. Instrumentation used included Ryan Model G and D, Fisher Porter panel type and Partlow recording thermographs. All instruments were calibrated to a standardized thermometer prior to the study. Installation of instrumentation began July 8, with all instruments in place and operating by July 31. Instruments were removed during the first week in September. It would have been desirable to monitor temperatures through September, however risk of damage to instruments from high flows increases with the onset of autumn storms. Instruments were field-checked biweekly. Other data collected but not reported here include channel depth, width, slope, percent canopy cover and discharge. Instrumentation to collect air temperatures was also installed but did not operate properly.

Instantaneous afternoon water temperatures were taken within holding areas and randomly throughout the study reach in an effort to identify the existence of cool water refuges.

Information on the effect of water temperature on spring chinook eggs was needed to assess potential temperature impacts on production. Eggs from adult fish holding in the river were collected as part of the normal broodstock operations at Skookum Hatchery. Eggs from hatchery rack broodstock and those from the river broodstock were incubated under the same hatchery conditions in order to determine if higher water temperatures in the river during holding affected egg viability or survival.

RESULTS

Daily maximum and minimum temperatures at monitoring stations are reported in Appendix XVI. The highest recorded water temperature was 72.68 degrees F on August 9 at RM 16.4. Temperatures of 70 degrees F or greater were recorded at multiple stations between Larson's Bridge and Skookum Creek on seven different dates. The extreme minimum between July 31 and September 4 was 51.98 degrees F at RM 25.0. Diurnal fluctuations were approximately sinusoidal.

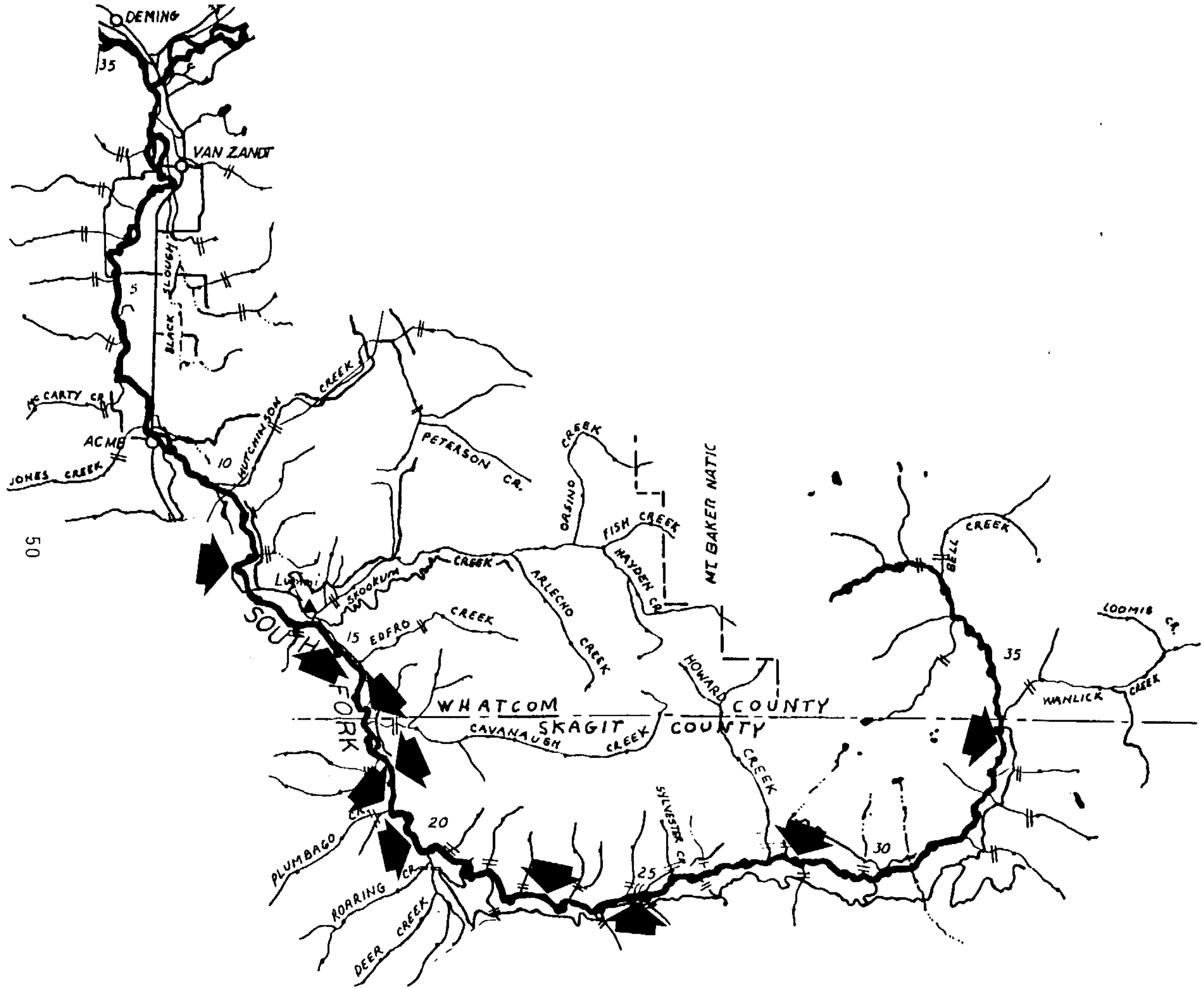


Figure 16. Location of continuously recording thermographs.

Hourly temperatures are not reported here. A lag period of varying length was observed for the Ryan instruments with plastic casing and internal probes. This was likely due to equilibration time of the instrument body with the surrounding stream environment. This problem has been corrected in newer models of this instrument. This may have resulted in a slight damping effect in the recorded daily range at some stations. However, instruments generally recorded within one degree F throughout the record. Instruments with accurate hourly sequencing (Fisher Portor) and field observations showed maximum daily temperatures to occur between 2 PM and 7 PM, with a daily duration of two to four hours. Minimum temperatures occurred between 4 AM and 8 AM with a similar duration. Maximum temperatures, at or exceeding 65 degrees F, occurred at multiple stations for all but six days of the study period. Although sublethal, provided acclimation occurs, these temperatures are considered to be in the danger zone for adult spring chinook (Bell 1984).

A trend of increasing temperatures between RM 32.8 and 23.5 was observed. Maximum daily temperatures between RM 23.5 and 16.4 (above Larson's Bridge to Cavanaugh Hole) stayed more or less constant (Figure 17). Minimum daily temperatures at RM 16.4 averaged 1.08 degrees F cooler than the average of three adjacent upstream stations.

A comparison of changes in daily maximum and minimum temperatures between adjacent stations was made. Given an instrument precision of +/- 1 degree F, RM 25 and 23.5 were the only adjacent stations with significant differences in maximum daily water temperatures when averaged over the entire study period. Significant differences did occur between other adjacent stations on individual days.

Differences in minimum daily temperatures between adjacent stations were most pronounced for the reach from RM 32.8 to 27.7 (Figure 18). Minimum temperatures at Lunchstop (RM 17.96) and Saxon Hole (RM 12.45) were significantly warmer than at adjacent stations by a small margin. Generally, there was less change in the daily minimum than the daily maximum over the course of the study period.

Significant reductions in the amplitude of both minimum and maximum temperatures were recorded at RM 12.45 (Saxon Hole). The largest recorded daily fluctuations were at RM 32.8 with a mean amplitude of 9.15 degrees F.

Instantaneous temperature sampling identified few cool water seeps. The South Fork received water from several tributaries which were substantially cooler, however holding habitat was not available in the immediate vicinity of the confluences of these tributaries. A spring was located at RM 19.7. Daily continuous temperature recordings were taken for larger tributaries but are not reported here.

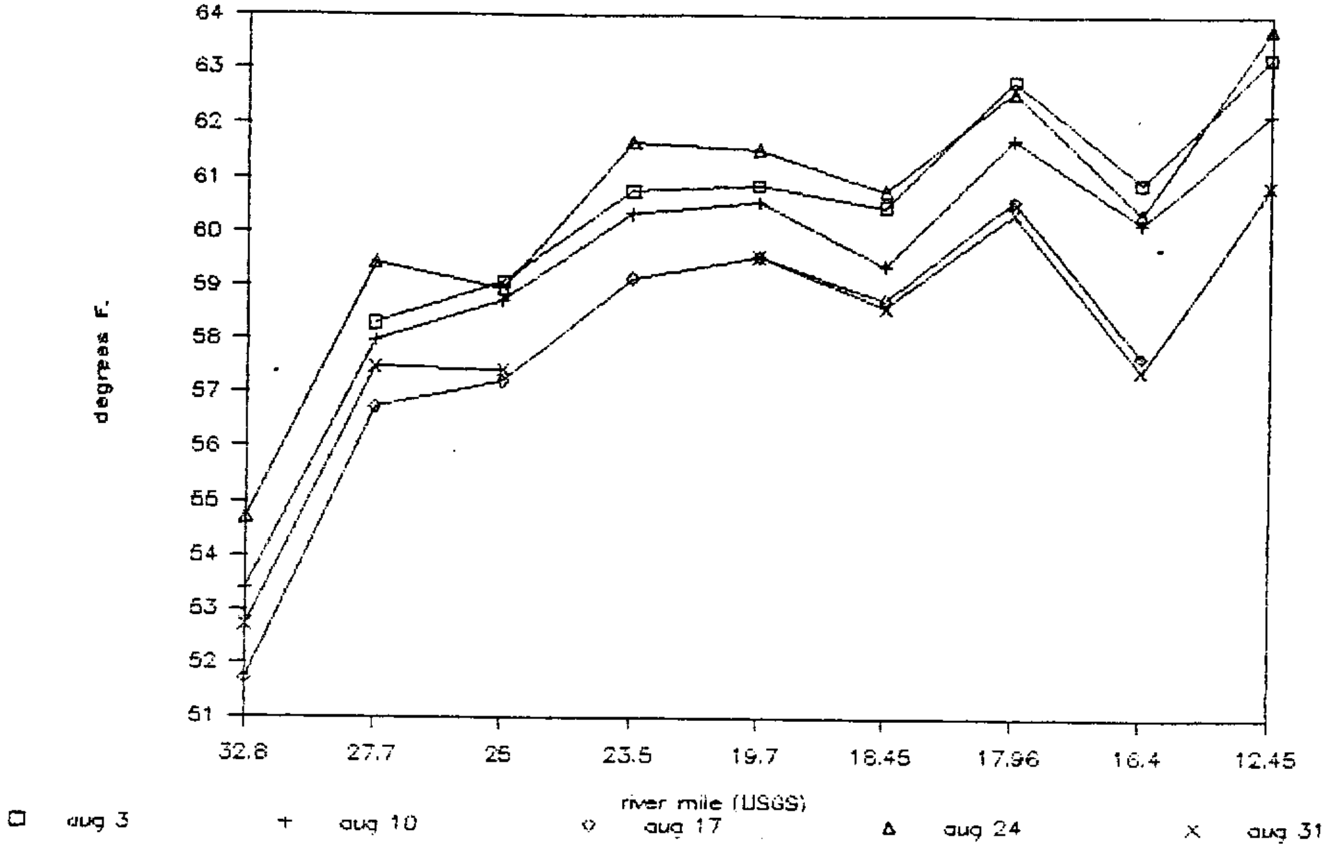


Figure 17. Seven-day average maximum daily water temperature.

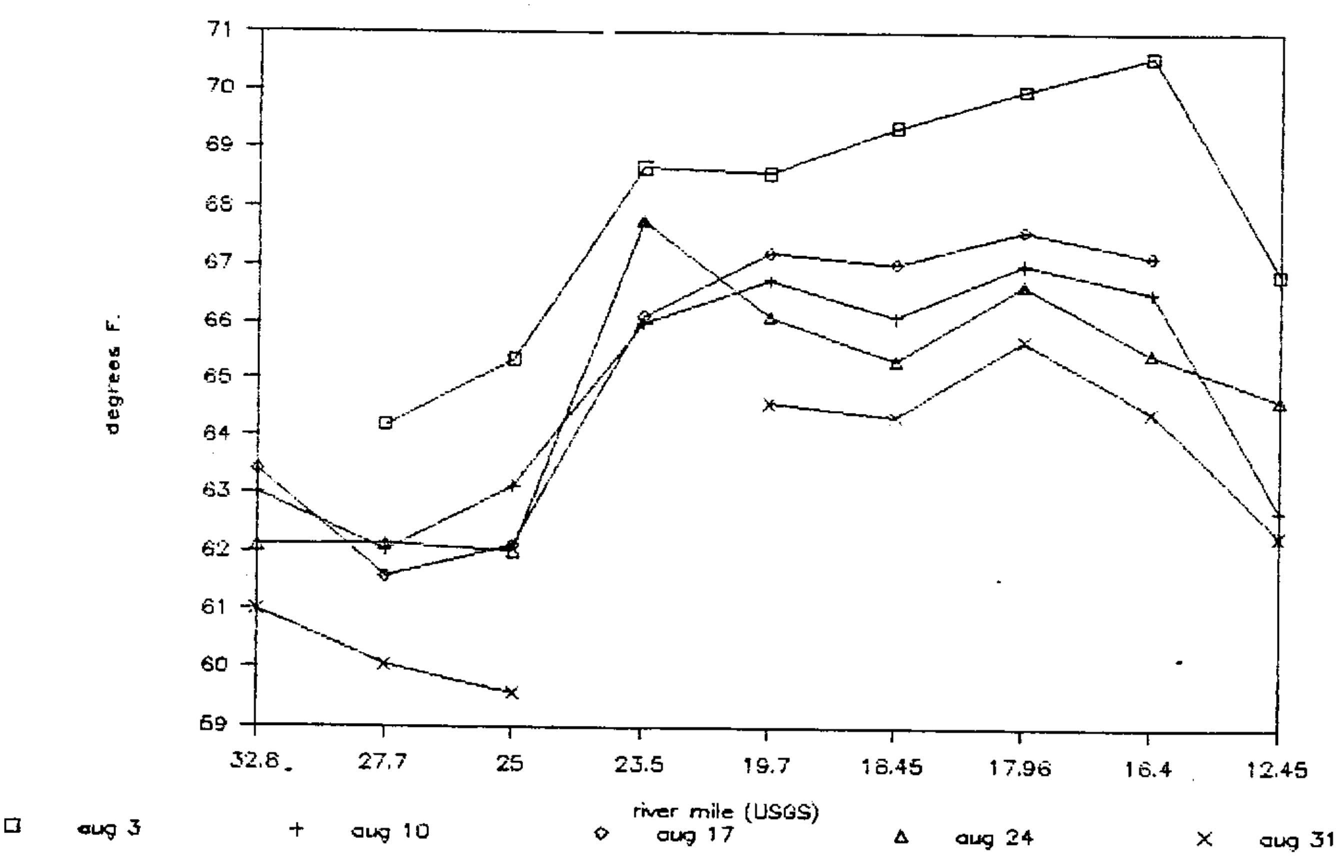


Figure 18. Seven-day average minimum daily water temperature.

DISCUSSION

Stream temperature is regulated by the net energy balance of heat gains and losses acting on a given volume of water (Theurer et al. 1984), as schematically shown in Figure 19. The formula is:

$$q\ net = q\ solar + q\ sky + q\ conv + q\ evap + q\ soil$$

where:

q net = net heat flux
q solar = solar insolation
q sky = radiation exchange with the sky
q veg = long wave radiation exchange with vegetation
q conv = convective heat transfer
q evap = evaporative heat transfer
q soil = conduction to the soil

Solar radiation is the primary source of heat to the stream (Tennessee Valley Authority 1972). The energy available for a given day is governed by the relative position of the sun to the stream, a clearness factor for the sky and the percent of canopy opening allowing direct solar radiative input (Quigley 1981).

Longwave radiative heat transfer, i.e., solar radiation stored as heat in objects of the surrounding environment and then released back, is a lesser source of heat to the stream. Radiative heat losses of the stream include radiation back to the surrounding environment, convection, evaporation and conduction of heat to the stream bed. Radiative heat exchange with the sky is a function of stream temperature relative to the surrounding air temperature. Canopy cover can modify the exchange process in much the same way as it does on a clear, cold night when frost occurs on the windshield of a car parked in the open but not on one under a carport.

The stream temperature is constantly seeking to come to equilibrium with the surrounding air temperature. The greater the difference between stream and air temperature, the more rapidly the heat exchange processes of radiation, evaporation and convection occur. An examination of the thermodynamic equation for these processes shows that air temperature regulates the maximum temperature a stream can reach in the summer (Tennessee Valley Authority 1972). Furthermore, the temperature change for a parcel of water in a stream is a product of the net heat exchange multiplied by the stream surface area divided by its volume (Theurer and Voos 1982). Dimensional analysis proves stream depth to be the determining factor for how quickly a stream comes to equilibrium with air temperature. Large, deep rivers will take longer to reach equilibrium but will have very little amplitude in daily water temperature fluctuations. Theoretical and field evidence (Kate Sullivan, Weyerhaueser Co., personal communication) shows that streams greater than approximately one meter in depth remain at the mean daily air temperature (or weekly/monthly for very large rivers). Heat exchange processes in shallow streams will occur rapidly with hourly stream temperatures closely tracking hourly air temperatures.

Ground water adds cooler water (49.5 degrees F or mean annual air temperature) to summer stream flows. The resulting downstream water temperature equals the sum of the temperatures of incoming water and the stream prior to influx weighted by their respective flow rates (Brown 1972).

Downstream warming trends in daily maximum stream temperature is a result of distance from cool water inputs, i.e., ground water dominated tributaries and snow melt. Below RM 23.5 the South Fork has come to equilibrium with existing air temperature. Maximum daily water temperature still remains slightly below maximum air temperature due to the lag time required by water having moderate depth to come to equilibrium with instantaneous air temperatures.

The slight reduction in amplitude of daily stream temperatures at RM 12.45 may be a result of increased average depth. Inflow of Skookum Creek and hatchery water may also be the cause. The large daily fluctuations in stream temperature at RM 32.8 is congruent with the concept of the quick response of shallow streams to air temperature fluctuations. This station is above major tributaries to the South Fork, most notably Howard Creek. Cool water inflow above RM 32.8 is larger in proportion to in-channel flow than for reaches lower on the South Fork. Ground water and snow melt dominate the minimum temperature, yet the shallowness of the channel results in the stream temperature rapidly approaching equilibrium with rising daily air temperatures. However, the mean daily temperatures were closer to those preferred by holding adult spring chinook than those temperatures further downstream (Figure 20).

Problems developed with meteorological instrumentation used in the study stream. Therefore temperatures were compared with air temperatures at a nearby NOAA station in Sedro Woolley (Figures 21-24). Mean stream temperatures below RM 23.5 closely tracked mean air temperature (Figure 21). Higher in the system water temperatures still patterned air temperature trends but remained cooler (Figure 21). In addition to incoming groundwater being proportionately greater for upper reaches, nighttime air temperatures might be significantly lower. Nearby NOAA stations (NOAA 1986) showed a much stronger orthographic effect for minimum daily temperatures than for maximum daily temperatures. For upper river reaches, cold nighttime air sinks from the adjacent Twin Sisters range and Mt. Baker would lower minimum air temperatures.

Temperature effects on fish in the wild are poorly understood. Temperature does effect metabolic and rate blood chemistry (Thomas et al. 1986) which in turn influences development, growth and activity. Synergistic effects such as increased susceptibility to disease also occur (Figure 25).

Laboratory and hatchery evidence shows that salmonid survival is very poor above 70 degrees F. Preferred temperatures for most salmonids at various life stages generally are in the low 40's to a maximum of 58 degrees F (Bell 1984; Brett 1952; Lance 1971).

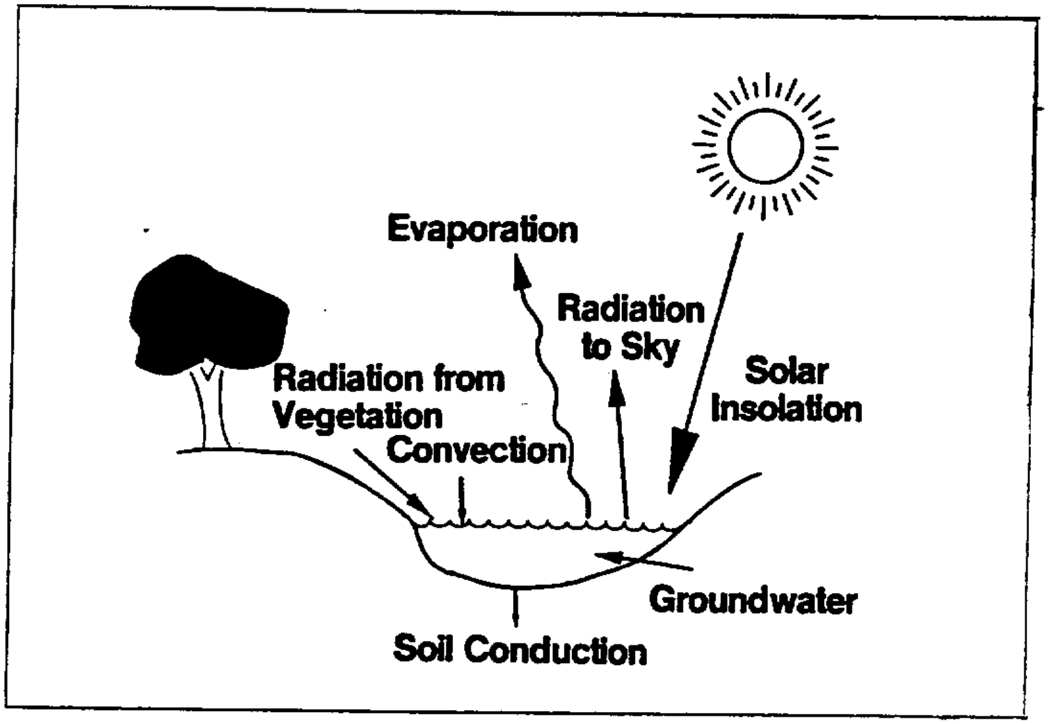


Figure 19. Radiative heat transfer.

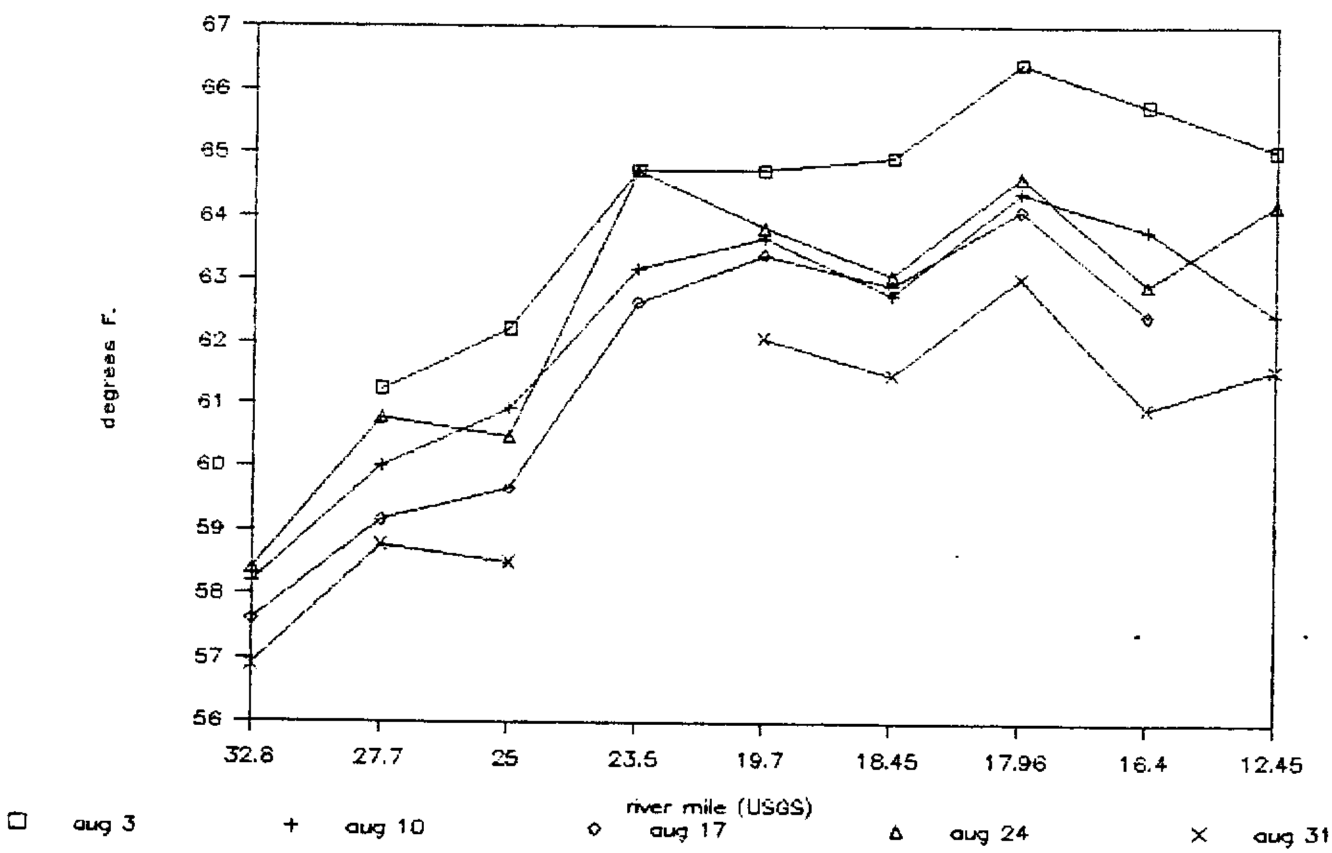


Figure 20. Seven-day average for mean daily water temperature.

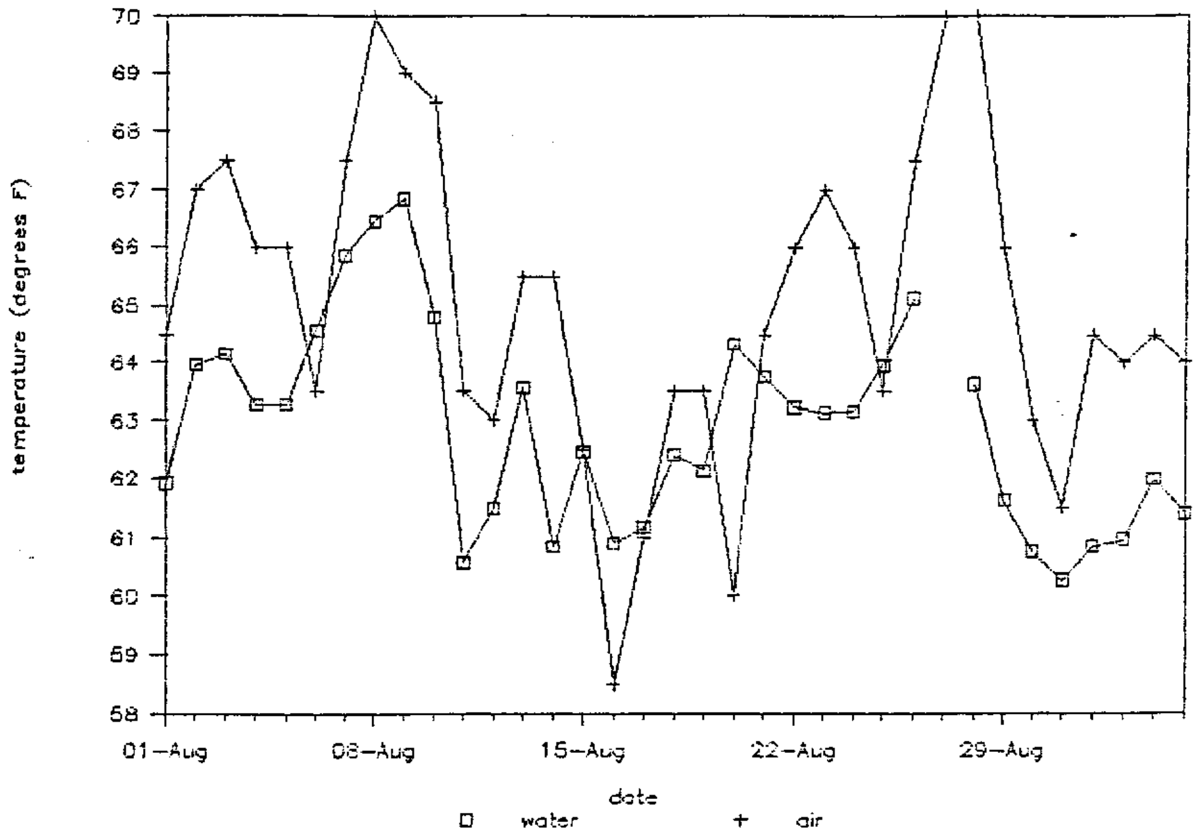


Figure 21. Mean daily temperatures for South Fork RM 18.45.

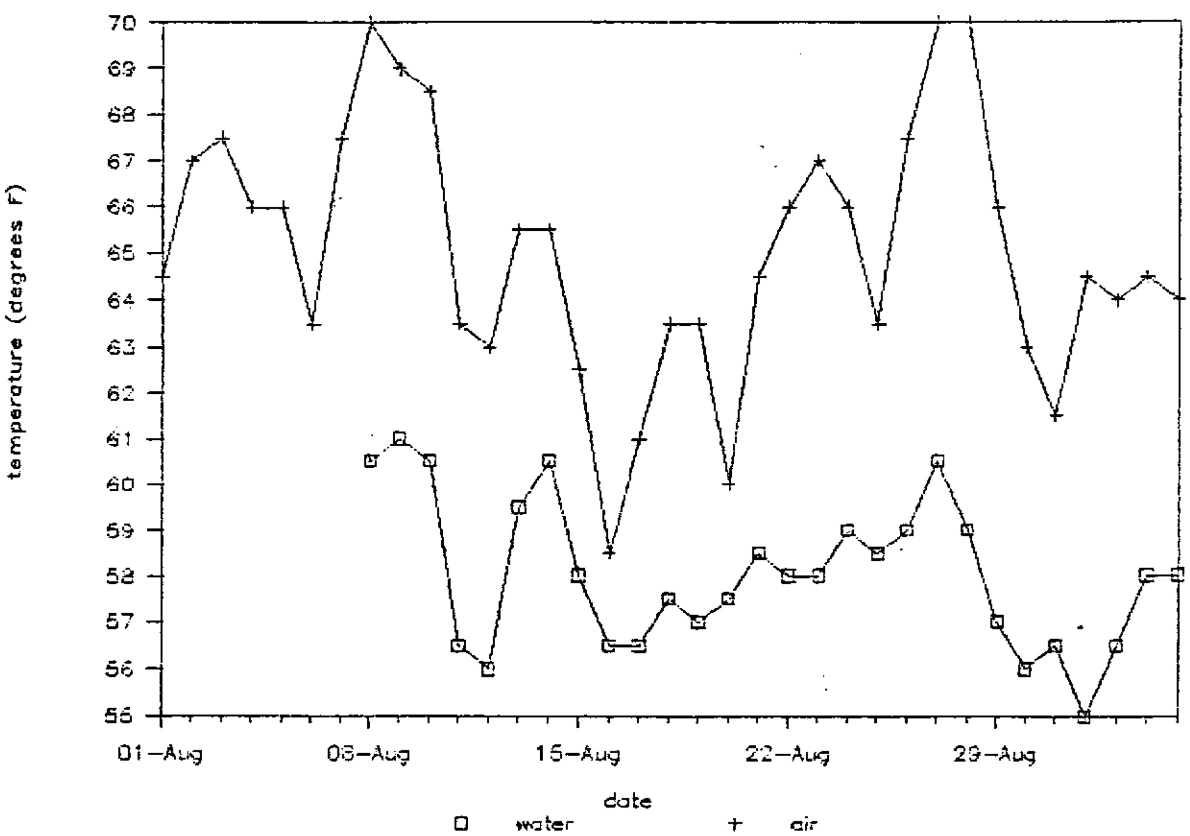


Figure 22. Mean daily temperatures for South Fork RM 32.8.

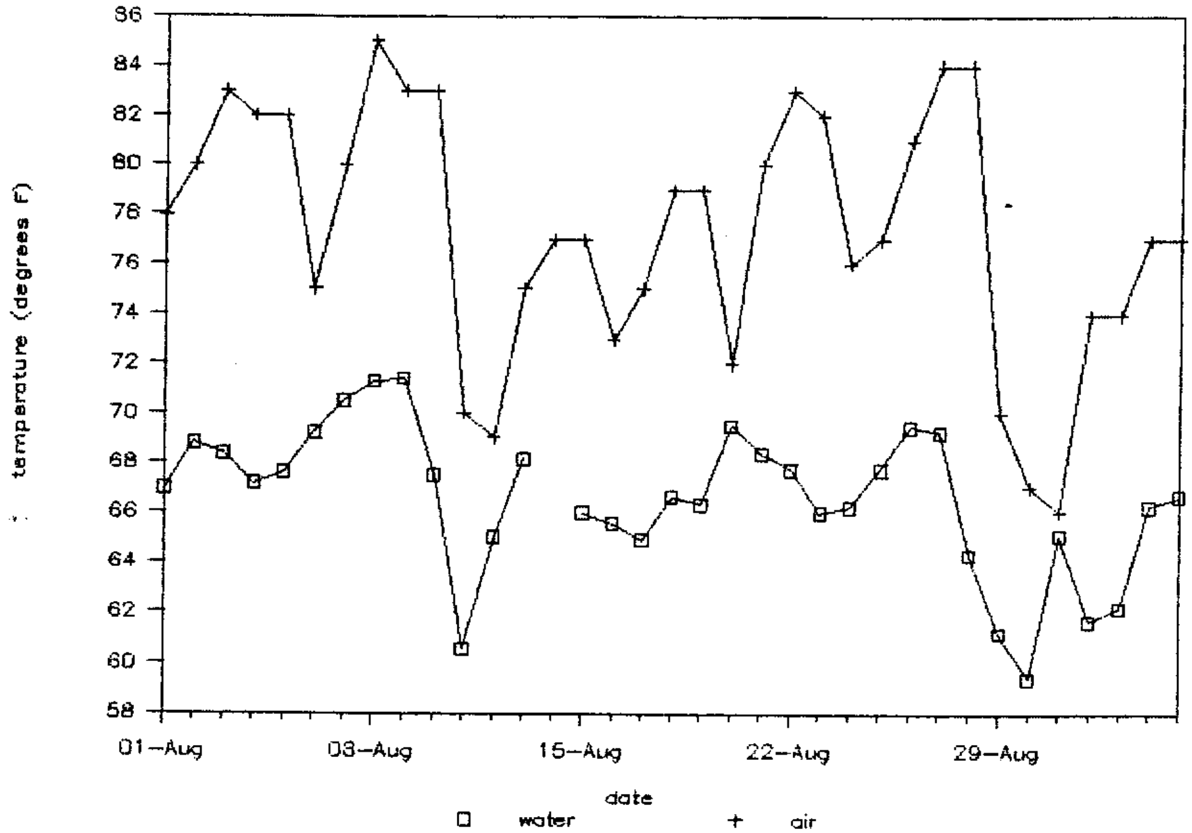


Figure 23. Maximum daily temperatures for South Fork RM 18.45.

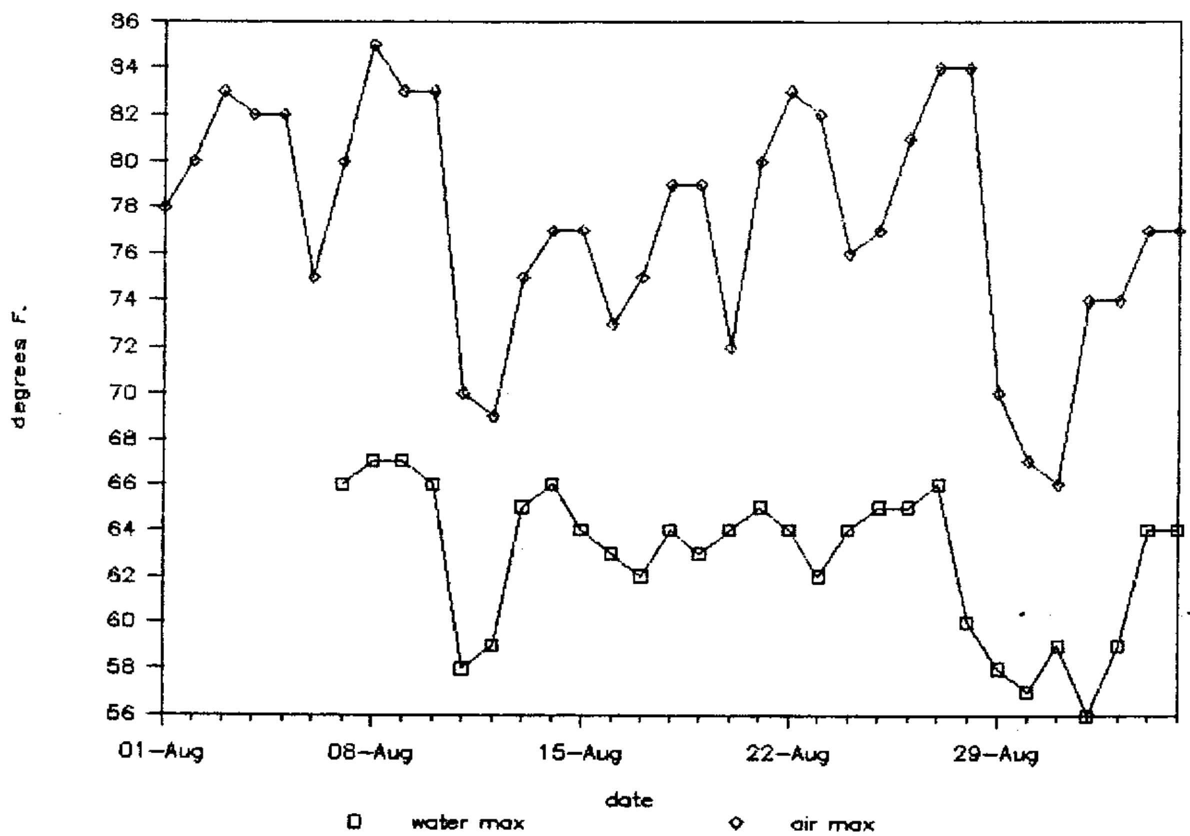


Figure 24. Maximum daily temperatures for South Fork RM 32.8.

Increasing complexity of acquisition and use

Physiology	Behavior	Periodicity	Water Quality
Survival	Habitat utilization	Incubation duration	Solubility of dissolved gases
Growth rate	Activity	Onset of spawning	Deoxygenation rate
Embryonic development	Distribution	Onset of migration	Photosynthesis/ Respiration
Susceptibility to parasites and disease	Species interaction	Gonadal maturation	Synergistic toxicity

Figure 25. Biological effects of temperature.

Adult chinook are thought to be particularly prone to ill effects of elevated temperatures. There is a broad range of temperatures between preferred and lethal for which effects are not well documented. Sublethal temperatures likely affect reproduction, disease resistance, energetics, metabolic rates, spatial and temporal distribution and competition. Sluggish adult chinook holding in elevated temperatures are also much more susceptible to poaching (personal observation). Elevated temperatures during spawning activities have been shown to detrimentally affect the viability and survival of eggs (Smith et al. 1983). Although no differences in total survival of eggs to emergence between river broodstock and hatchery broodstock were noted, other subtle effects are possible and should be further evaluated. Investigation is required on the effects of temperature on number of eggs per holding female, size of eggs and condition of resulting juveniles. Once eggs have been deposited in the gravel there is little problem with ambient temperature. Random sampling within known spawning reaches showed intragraval temperatures to be in the low 50's, even when surface water temperatures exceeded 70 degrees F.

Few studies to date have looked at the effect of fluctuating temperatures on salmonids (Tom Quinn, personal communication). This knowledge could greatly help in evaluating habitat preferences. For example, if holding adults can tolerate elevated temperatures provided they can reduce their body temperature and net metabolic rate for at least part of each day, then upstream river reaches at RM 32.8 would be preferable. Conversely, if fish can tolerate temperatures in the upper 60's and low 70's provided acclimation time occurs but do not tolerate daily fluctuations in excess of 5-6 degrees F, then downstream reaches where the average depth is greater would be preferable.

Air temperatures near the mouth of the South Fork are likely higher than those further up the valley at higher elevations. The equilibrium temperatures of the water near the mouth would thus be higher also. This could be a factor in limiting useable holding habitat near the mouth.

High sediment loading rates (PEAK Northwest 1986) have aggravated temperature problems in the South Fork. Deposition occurs when sediment delivery rates exceed the stream power available to transport the material downstream. A wide, shallow channel results. Additionally, increased sediment has had the effect of decreasing channel stability. Channel shifts leave wide, unvegetated gravel bars making riparian shading ineffective during summer months. The width to depth ratio for the South Fork is high for a river of its size. Reduced overall depth allows the water to approach equilibrium with air temperature much more rapidly. Maximum water temperature only slightly below daily maximum air temperature results.

Sediment has also filled in pools. Historical anecdotal information cites past pool depths of approximately 30 ft. It is very likely such deep pools would intercept significant amounts of ground water, thereby locally reducing temperatures in the pools.

Such pools may have provided cool water refuges for holding adults. Pool filling with sediment has evidently reduced the value of many pools as holding habitat for spring chinook.

Continued efforts to reduce sediment inputs is one of the most effective ways to manage for temperature problems in the South Fork. Reducing sediment input would allow the channel to downcut its thalweg, increasing maximum water depth. Increased depth would lead to smaller fluctuations in water temperature and reduced daily maximums. Research efforts are underway as part of the Timber/Fish/Wildlife (TFW) agreement to identify those stream reaches characteristically temperature sensitive to canopy removal. Guidelines for riparian management to address temperature concerns on the South Fork should be developed to reflect findings of the TFW study.

Providing fish passage above the barrier at RM 30.5 would increase access to holding sites with cooler minimum temperatures. Also, providing for other habitat requirements of holding fish near cool water tributaries of sufficient volume (7-8 cfs) could create temperature refuges.

Further field and laboratory investigations on tolerance and effects of elevated water temperatures for spring chinook should be performed. Comparisons of river broodstock fish, captured from pools where temperature has been monitored, with hatchery fish held at different temperatures may provide valuable insight on effects of temperature on South Fork spring chinook.

SUMMARY AND CONCLUSIONS

Spring Chinook Habitat Utilization

Spring chinook were documented holding in pools between RM 2.0 and RM 30.7. This was the first documented sighting in recent years of spring chinook above the falls at RM 25 and confirms that the falls is currently passable for spring chinook.

South Fork spring chinook demonstrated a holding preference for pools deeper than 5.0 ft. They also demonstrated a holding preference for habitats with cover, particularly woody debris, although other cover types such as turbulence and boulders were used when woody debris cover was unavailable. It was concluded that spring chinook need instream cover to successfully hold in the South Fork until spawning.

Measurements were taken on 150 spring chinook redds. Redds were observed between RM 0.5 and 30.7, with the greatest concentration of spawning activity observed between RM 10 and 20. Utilization curves developed from redd measurements indicated that South Fork spring chinook spawning habitat preferences were similar to those recorded for spring chinook in the literature, with minor differences in depth and velocity.

Current Habitat Conditions

A total of 282 small and 147 multi-celled holding sites were identified from RM 33.6 to the mouth of the South Fork. These sites contained over 2,000,000 cu ft of holding pool habitat. The largest amount of holding habitat was found in the reaches between RM 10-15, 15-20, and 25-30.

A shortage of the type of habitat preferred by holding spring chinook was observed. Lack of cover, especially woody debris was noted. Much of the woody debris was deposited on the upper banks by flood events where it was unavailable as instream cover during low flows. The mean maximum pool depth was only 5.0 ft, well below the depth preferred by spring chinook. Filling of pools with sediment is occurring. Six ft of pool filling was documented at the Tether Hole (RM 19.9) between 1985 and 1986, and this process has been observed at other locations. Depths of many pools appear to be far less than historic depths. Lack of pool depth and instream cover contribute to the problems of high temperatures, poaching, and predation that appear to be causes of stress and mortality during the holding period.

Almost 3 million sq ft of available useable spawning habitat was inventoried betweem RM 0.0 and 30. Spawning gravel was most abundant below RM 20, and became increasingly scarce further upstream. Available spawning habitat appeared to be more than adequate for current depressed populations.

Over 4% of otherwise suitable spawning habitat was over 50%

embedded with fine sediments, rendering it unuseable for spawning. Another 37% had between 25% and 50% embeddedness. This spawning habitat could be rendered unuseable if sedimentation increases. Fine sediment levels at four locations ranged from 9.76% near Acme in 1986 to 13.31% at the Skookum/Edfro site in 1985. Significant intragravel mortality is not indicated at these levels. Levels at the Larson's Bridge site have been increasing and could cause low survival to emergence in the future if they rise above 15%.

Redd disturbance due to stream channel instability (scour, deposition and dewatering due to channel shifting) appears to be reducing intragravel survival in the South Fork. Stream channel stability indices performed at six locations ranged from moderately unstable to unstable. The most unstable locations apeared to be downstream of major sources of sediment input such as Howard Creek. Cross-sections measurements at two riffles showed no signifcant aggradation. A redd survival study on spring chinook redds documented that 3 of 8 redds were lost due to scour, deposition and channel shifting during the relatively moderate winter of 1984-85. Redd loss due to channel instability is likely higher in years with major storm events.

Temperatures of 70 degrees Fahrenheit or greater were recorded at multiple stations between Larson's Bridge and Skookum Creek on seven different dates. Maximum temperatures, at or exceeding 65 degrees Fahrenheit, occurred at multiple stations for all but six days of the study period. Although sublethal, provided acclimation occurs, these temperatures are considered to be in the danger zone for adult spring chinook (Bell 1984).

Potential Escapement Levels Based on Available Habitat

In recent years management biologists have estimated spring chinook escapement into the Nooksack River, knowing that the run was depressed below the river's carrying capacity (Nooksack Spring Chinook Technical Group 1987). One purpose of this study was to use a different approach, i.e., to estimate the potential spring chinook escapement that could be supported by suitable spawning habitat presently available in the South Fork. Spawner escapement is normally estimated by one or more techniques that rely on counts of fish or redds in the stream of interest (Cousens et al. 1982). But, these techniques do not yield an estimate of the total potential escapement. One way to derive such an estimate is to apply a factor for surface area of spawning habitat required per spawning pair. Bell (1984), citing work by Burner (1951), recommended that 16 sq yd (2304 sq ft) was an appropriate area for spawning spring chinook. This area consisted of the area of the redd plus adjacent interredd space. Burner found that when enough chinook spawners were present to utilize virtually all useable gravel, the interredd space amounted to nearly three times the area occupied by the redd. The average area needed for a pair was about four times that of the average redd. Burner's average redd area, 3.9 sq yd, was based on observations of spring chinook in two Columbia River tributaries in Washington.

We used a ratio of 1.34 males to each female to calculate potential escapement. This ratio was developed from eight years of data collected during South Fork brood stock capture. The total potential escapement, 2889, appears large compared to recent estimates of actual escapement for the Nooksack drainage (Nooksack Spring Chinook Technical Group 1987). Graybill et al. (1979) observed that in the Skagit River system, potential spawning area available to chinook greatly exceeded that needed to support rational spawning escapements. They concluded that it was unreasonable to derive an escapement estimate by taking potential spawnable area and dividing by a factor for average area required by a spawning pair. It is uncertain how reasonable our total estimate of 2889 spawners may be. It is certain that there are usually limiting factors present in most regional streams that restrict number of spawners to less than the potential based on suitable habitat area. The estimate of 2889 spawners represents a relative run size goal that may be achievable if all limiting factors are corrected, e.g., restoring South Fork water temperatures during low flow to an acceptable range. The estimate, 2889, would be even higher if the effect of substrate embeddedness was reduced.

Potential Limiting Factors

Amount of holding habitat appears adequate overall in the system but may become limiting in certain reaches at higher population levels, i.e., above RM 30. The poor quality of holding habitat due to lack of adequate cover and pool depth and above-optimal temperatures appears to be a more serious limiting factor during the holding period. These factors appear to aggravate stress and increase mortality due to poaching and predation. Mortality due to these factors is probably significant throughout the anadromous zone, and the extremely limited utilization by spring chinook of the habitat below RM 10 may be related to these factors.

Spawning habitat is limited above RM 20 and may become limiting in this reach as the population increases. The abundant spawning habitat below RM 10 is hardly utilized at present despite anecdoctal accounts of heavy use in the past (Mark Schuller, WDF, personal communication). This may be due to unfavorable holding conditions. Fine sediment accumulation does not appear to be a serious limiting factor as levels of fines were below the threshold where significant mortality would be anticipated. Only 4% of the available spawning habitat was embedded with fine sediments to the point that it was considered unuseable. However, substantially more (37%) could be rendered unuseable if sedimentation increases.

Redd disturbance due to stream channel instability appears to be the most significant cause of mortality in the intragravel stage of development. Most reaches rated moderately unstable or unstable, and significant redd loss was documented during a winter having only moderately high flows. During winters with high peak flows, high mortality is probable.

Rearing habitat was not studied. It is considered unlikely to be a limiting factor since past studies indicate most juveniles outmigrate to salt water during the spring of their first year.

Coded wire tag data indicates that harvest of Nooksack spring chinook in Canadian waters has a major effect on the numbers of adults returning to the system. Higher interception rates may exist for yearling smolts than for subyearling releases.

In conclusion, neither the amount of available holding or spawning habitat appear to be limiting factors. The major freshwater limiting factors for South Fork spring chinook appear to be: adult mortality from poaching; predation and stress during holding due to lack of woody cover; lack of cool water temperatures and inadequate pool depth; and loss of eggs due to stream channel instability.

Effects of Watershed Conditions on Spring Chinook Production

Inner gorge landslides appear to be a major source of fine sediment to the South Fork. Thirty-seven inner gorge landslides were documented between the mouth and RM 33.6. Of these, 21 landslides with a surface area of over 800,000 sq ft were judged to be actively eroding. Eighteen landslides were putting large amounts of sediment into the stream, and 25 had over 50% clay content. Most of the large, actively eroding landslides were located above RM 20. Large blocks of blue clay were observed in the river at the base of a number of these landslides.

Over eight lineal miles of eroding stream banks and over four miles of stream banks which had been riprapped to control erosion were documented.

Sediment production from tributary watersheds in the upper portion of the South Fork basin appears to be the greatest source of sediment to the channel of the South Fork. Results of a previous study documented 74 active landslides in the 7.6 sq mi tributary watershed of Howard Creek between 1940 and 1983. Activities such as timber harvest and logging road construction increased the already high natural rate of sediment production by an estimated 400%. If sediment production in other watersheds has also increased as a result of timber management activity, the combined sediment input from tributary watersheds would represent a large increase in the sediment load to the main channel of the South Fork.

The combined sediment input from all sources would contribute to a number of habitat conditions which were observed, including filling of pools, fine sediment embeddedness, redd loss due to instability of the stream channel, and higher stream temperatures.

Sedimentation has aggravated temperature problems in the South Fork. Increased sediment deposition has decreased channel stability, causing channel shifts and creating wide, unvegetated gravel bars which make riparian shading ineffective during summer months. It has also caused the development of a wide, shallow channel. Reduced overall depth allows the water temperature to approach equilibrium with air temperature much more rapidly. Maximum water temperature only slightly below daily maximum air temperature has resulted.

Sediment has also filled in pools. Historical anecdotal information cites past pool depths exceeding 25 feet. It is very likely such deep pools would intercept significant amounts of ground water, thereby locally reducing temperatures in the pools. Such pools may have provided cool water refuges for holding adults.

Continued efforts to reduce sediment inputs is one of the most effective ways to manage for temperature problems in the South Fork. This would allow the channel to downcut its thalweg. Increased depth would lead to smaller water temerature fluctuations and reduced daily maximums. Reducing sediment input would also promote restabilization of the stream channel, reduction in fine sediment embeddedness, increased holding pool depth, and greater stream channel depth thus reducing temperatures.

Recommendations

1. Monitor South Fork spring chinook spawning and rearing habitat at regular intervals to determine trends in habitat quantity and quality over time using the results of this study as a baseline.

2. Enhance holding habitat by improving holding cover through addition of woody debris such as root wads, particularly between RM 20 and 25. Investigate the potential for developing coldwater holding refuges.

3. Develop and implement a cooperative strategy to reduce sediment input to the South Fork through the Nooksack Watershed Coop Group or TFW. Examples of erosion control measures which have been used locally include inner gorge landslide stabilization, use of proper abandonment techniques on logging roads (culvert and fill removal, waterbarring and sidecast stabilization), and stabilization of in-channel woody debris. PEAK Northwest (1986) identifies other potential erosion control measures, including some site specific suggestions for the Howard Creek watershed.

4. Document the rate of redd loss and changes in fine sediment levels, particularly in the vicinity of Larson's Bridge.

5. Undertake an examination of cumulative effects of timber harvest activity in the South Fork watershed with emphasis on the effects of changes in sediment delivery and hydrology on the stream channel.

6. Guidelines for riparian management to address temperature concern

on the South Fork should be developed to reflect findings of the TFW Cooperative Monitoring, Evaluation and Research Committee's temperature study.

7. Providing fish passage above the barrier at RM 30.5 would increas access to holding sites with cooler minimum temperatures. Also, providing for other habitat requirements of holding fish near cool water tributaries of sufficient volume (7-8 cfs) could create temperature refuges.

8. Further field and laboratory investigations on the effects of elevated water temperatures for spring chinook should be performed.

9. Evaluate the effectiveness of enforcement activities in preventin poaching of South Fork spring chinook, and consider additional options such as road closures and sportfishing closures during the spring chinook holding period to reduce poaching.

10. Investigate the effects of sedimentation on productivity and utilization of juvenile rearing habitat and invertebrate production.

REFERENCES

Bell, M.C. 1984. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps Engineers. North Pacific Div. Fish Passage Development and Evaluation Program. Portland, OR.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish Wildl. Serv. Biol. Rep. 86 (7). 235p.

Brett, J. 1952. Temperature tolerances of young pacific salmon. J. of Fish Res. Board of Canada. 9:265-323.

Brown, G.W. 1972. An improved temperature prediction model for small streams. Water Resources Research Institute. Pub. No. 16. Oregon State Univ. Corvallis, OR.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish Wildl. Serv. Fish. Bull. 611: 7-110.

Cederholm, C.J. and K.V. Koski. 1977. Effects of stream channelization on the salmonid habitat and populations of lower Big Beef Creek, Kitsap County, Washington 1969-73. Coop. Fish. Res. Unit., Coll. of Fish. Univ. of Wash., Seattle, WA. 33p.

Cederholm, C.J., L.M. Reid, B.G. Edie and E.O. Salo. 1982. Effects of forest road erosion on salmonid spawning gravel composition and populations of the Clearwater River, Washington. Pages 1-17 IN: Hashagen, K.A. (ed.). Habitat Disturbance and Recovery: Proceedings of a Symposium. Calif. Trout Inc. San Francisco, CA. 90p.

Cederholm, C.J., L.M. Reid, and E.O. Salo. 1980. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, WA. Contribution No. 543. Coll. of Fish. Univ. of Wash. Seattle, WA. 35p.

Cederholm, C.J. and E.O. Salo. 1979. The effects of logging road landslide siltation on the salmon and trout spawning gravels of Stequaleho Creek and the Clearwater River basin, Jefferson County, WA 1972-1978; final report part III. FRI-UW-7915. Fish. Res. Inst. Univ. of Wash. Seattle, WA. 99p.

Chambers, J.S., G.H. Allen, and R.T. Pressey. 1955. Research relating to study of spawning grounds in natural areas -- Annual Rep. Washington Department of Fisheries. Olympia, WA. 175p.

Cousens, N.B., G.A. Thomas, C.G. Swann, and M.C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Tech. Rep. of Fish. and Aquatic Sciences. No. 1108. Dept. of Fisheries and Oceans. Nanaimo, B.C. 122p.

Graybill, J.P., R.L. Burgner, J.C. Gislason, P.E. Huffman, K.H. Wyman, R.G. Gibbons, K.W. Kurko, Q.J. Stober, T.W. Fagnan, A.P. Stayman, and D.M. Eggers. 1979. Assessment of the reservoir-related effects of the Skagit Project on downstream fishery resources of the Skagit River, Washington. Final Rep. for City of Seattle, Dept. Lighting. Univ. of Wash. and Dept. of Lighting. Seattle, WA. 601p.

Hamilton, K. and E.P. Bergersen. 1984. Methods to estimate aquatic habitat variables. Colorado Cooperative Fishery Research Unit. Colorado State Univ. Ft. Collins, CO.

Karanka, E.J., R.S. Hawthorn and T.W. Chamberlin. 1981. The application of British Columbia aquatic data to channel stability evaluation. Pages 47-53 IN: N.B. Armantrout (ed.). Symposium on acquisition and utilization of aquatic habitat inventory information. West. Div. Amer. Fish. Soc. Portland, OR.

Koski, K.V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis. Oregon State Univ. Corvallis, OR. 77p.

Lance, R.L. 1971. Influence of water temperature on fish survival, growth and behavior. Pages 182-193 IN: J. Krieger and J.D. Hall (eds.). Forest Land Uses and Stream Environment. Oregon State Univ. Corvallis, OR.

McNeil, W.J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. Manuscript Rep. No. 1. U.S. Fish Wildl. Serv. Fish. Bull. Vol. 65(2): 495-523.

National Oceanographic and Atmospheric Administration. 1986. Climatological data, Washington. Volume 90: 7-9. Ashville, NC.

Newman, K. 1986. Letter to M. MacKay, dated Sept. 28. Subject: Analysis of Nooksack spring chinook holding pools. From: Northwest Indian Fisheries Commission, Lacey, WA.

Nooksack Spring Chinook Technical Group. 1987. Nooksack spring chinook technical report. Final Draft Report. Nooksack Tribal Fisheries Department. Deming, WA. 86p.

PEAK Northwest. 1986. Nooksack River basin erosion and fisheries study. Lummi Tribal Fisheries Department. Bellingham, WA. 110p.

Platts, W.S., W.F. Megahan and G.W. Minshall. 1983. Methods for evaluating stream, riparian and biotic conditions. Gen. Tech. Rep. INT-138. USDA Forest Service. Intermountain Forest and Range Exp. Stat. Ogden UT.

Quigley, T.M. 1981. Estimating contributions of overstory vegetation to stream surface shade. Wildl. Soc. Bull. 9(1): 22-27.

Rickert, D.A., G.L. Beach, J.E. Jackson, D.M. Anderson, H.H. Hazen and E. Suwijn. 1978. Oregon's procedure for assessing the impacts of land management activities on erosion related nonpoint source problems. Oregon 208 Nonpoint Source Assessment Project. Oregon St. Dept. of Env. Quality. Portland, OR. 219p.

Royal, L.A. 1972. An examination of the anadromous front program of the Washington Department of Game. Report to Washington Dept. of Game. Olympia, WA. 176p.

Schuett-Hames, J.P. and D.E. Schuett-Hames. 1984. Spawning gravel fine sediment levels and stream channel stability ratings for salmonid streams in the Nooksack Basin, Washington, 1982 and 1983. Lummi Tribal Fisheries Department. Bellingham, WA. 26p.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation-An emphasis on spawning habitat for salmonids. U.S. Env. Prot. Agency. Env. Res. Lab. EPA-600/3-79-109. Corvallis, OR.

Smith, C.E., W.P. Dwyer, and R.G. Piper. 1983. Effect of water temperature on egg quality of cutthroat trout. Prog. Fish. Cult. 43:176-178.

Stempel, M.J. 1984. Development of fish preference curves for spring chinook and rainbow trout in the Yakima River Basin. U.S. Fish Wildl. Serv. Ecological Services. Moses Lake, WA.

Sullivan, K., T.E. Lisle, C.A. Dolloff, G.E. Grant, and L.M. Reid. 1987. Stream channels: the link between forests and fishes. Pages 39-97 IN: E. Salo and T. Cundy (eds.). Streamside management: forestry and fishery interactions. College of Forest Resources and Institute of Forest Resources. Univ. of Washington. Seattle, WA.

Tennessee Valley Authority. 1972. Heat and mass transfer between a water surface and the atmosphere. Water Resour. Res. Lab Rep. 14. Norris, TN. 166p.

Theurer, F.D. and K.A. Voos. 1982. IFG's instream water temperature model validation. Pages 513-518 IN: F. Kilpatrick and D. Matchett (eds.). Proceedings of the conference on water and energy technical and policy issues. Am. Soc. of Civil Engineers.

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish Wildl. Serv. FWS/OBS-84/15.

Thomas, R.E., J.A. Gharret, M.G. Carls, S.D. Rice, A. Moles, and S. Korn. 1986. Effects of fluctuation of temperature on mortality, stress and energy reserves of juvenile coho salmon. Trans. Am. Fish Soc. 115: 52-59.

U.S. Forest Service. 1978. Stream reach inventory and channel stability evaluation; a watershed management procedure. USDA Forest Service. Northern Region. 26p.

Wampler, P.L. 1986. Development of habitat preference criteria for holding adult spring chinook salmon. U.S. Fish and Wildl. Serv. Fisheries Assistance Office. Olympia, WA.

Washington Department of Conservation. 1960. Water resources of the Nooksack River basin and certain adjacent streams. Washington Div. of Water Resources. Water Supply Bull. No. 12. Olympia, WA. 187p.

Washington Department of Fisheries and Game. 1928. Letter to Tom Nesset, Fire Warden and Forest Ranger, concerning fish passage improvement work on the falls at Sylvester Canyon on the South Fork Nooksack (Appendix III).

Young, W. 1983. Letter from Washington Department of Fisheries to prospective IFIM investigators recommending substrate particle size codes for IFIM applications. July 12, 1983.