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Salmon and Steelhead Studies

by

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Final Report
March 1980 to February 1983

for

City of Seattle, Department of Lighting
Office of Environmental Affairs
Seattle, Washington

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Approved:

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Chapter 1: Evaluation of Salmon Fry Stranding Induced by Fluctuating Hydroelectric Discharge in the Skagit River, Washington

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 2:

LIST OF TABLES

1.0 ABSTRACT

The effects of downramping (reduction in flow to follow declining power demand) rates and timing on salmon fry stranding were studied over a period of four years (1980-1983) on the Skagit River. The tests were conducted in the spring months (March and April) when salmon fry abundance was greatest. A total of 29 test conditions were evaluated during the four-year period which included 91 individual gravel bar observations.

Salmon fry stranding rates were variable, but all conditions tested resulted in some fry stranding. Chinook fry were the dominant species stranded by the hydroelectric flow fluctuations but all species present were found stranded.

The timing of the downramp event was found to have a significant influence on the rate of salmon fry stranding on Skagit River gravel bars. When the downramp event was timed such that most or all of the flow reduction at the test site occurred prior to dawn, the rate of fry stranding was dramatically reduced compared to flow reductions which occurred after dawn. The average differential was to increase the stranding rate by a factor of 10.5 for post-dawn downramping.

The rate of the downramp event; i.e., change in flow over time, appeared to have little influence on fry stranding for pre-dawn downramp events. However, for post-dawn downramp events, there is an apparent positive relationship between downramp rate and fry stranding rate. Considering the rates tested as rounded to the nearest 100 cfs/hr., there were 16 rates tested from 400 cfs/hr. to 2,800 cfs/hr.

Observations on stranding of salmon fry in potholes were also made in conjunction with the gravel bar studies. It was noted that tributary inflow

significantly influenced both gravel bar and pothole fry stranding by moderating the effect of the hydroelectric discharge reductions. A tributary inflow between Newhalem and Marblemount of 1,600 cfs was observed to represent a flow condition which minimized pothole stranding at the Rockport study site. Tributary inflow to Rockport was not measured due to lack of a gaging station at or near this location.

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3.0 Introduction

3.1 Historical Background

The City of Seattle began development of the hydroelectric potential of the Skagit River in the early 1900's. The Lighting Department of the City undertook a staged development of three dams: Gorge, Diablo and Ross, which were begun in 1919, 1927, and 1937, respectively. Plans for development included the multistage construction of Ross Dam, which was completed to an elevation of 1,365 ft. in 1940, to 1,550 ft. in 1946, and to the present elevation of 1,615 ft. in 1949. The presence and operation of these dams has altered the general flow and thermal regimes of the Skagit River downstream of the Skagit Project.

Operational constraints, in addition to those specified by Federal license, were implemented in 1972 by informal agreement between the Washington Department of Fisheries (WDF) and Seattle City Light (SCL). Minimum flows were increased during the period of peak juvenile salmon abundance in an effort to reduce the impact of dam operation on fish survival downstream of the project.

In 1979, relicensing of these existing projects stimulated negotiations to obtain greater resolution of the relationships between regulated discharge and salmon and steelhead production. The City of Seattle, Washington Departments of Fisheries and Game, Skagit System Indian Tribes, U.S. Fish and Wildlife Service, and U.S. National Marine Fisheries Service entered into a two-year interim agreement (FERC Docket No. EL-78-36) regulating the rate and magnitude of flow fluctuation in the Skagit River. The present salmon fry stranding studies were conducted as a portion of a study program required by this agreement to obtain additional data on salmon and steelhead production. For the purposes of this report, stranded fry are those which were completely dewatered and killed not those isolated from flowing water and not killed.

The stranding of salmon fry (Oncorhynchus spp.) on gravel and sand bars and in shallow sloughs and side channels below hydroelectric dams as water levels recede during the downramping phase of the hydropower load following or "peaking" cycle has been well documented in Washington State (Thompson 1970; Graybill et al. 1979; Phinney 1974; Bauersfeld 1977, 1979; Becker et al. 1981). The relationship of hydroelectric power peaking and stranding kills of salmon fry on the Skagit River has been examined periodically in cooperative studies involving Seattle City Light, Washington Department of Fisheries and the University of Washington Fisheries Research Institute since 1969 (Thompson 1970; Phinney 1974; Graybill et al. 1979). The thrust of these studies has been to identify flow regulation procedures which are least detrimental to Skagit River populations of salmon fry. The early studies (Thompson 1970) demonstrated that reduction in flow at Gorge Dam from greater than 5,000 cfs to 1,400 cfs stranded many more fry than did reduction from greater than 5,000 cfs to 2,500 cfs.

During Thompson's study, the reduction in flow was accomplished in a matter of minutes. The thrust of Phinney's study was to determine if reducing the rate of flow reduction to 400 cfs per 6 minutes would significantly reduce the loss of salmon fry due to stranding. The modified downramping rate still resulted in substantial fry mortality particularly when the flow was reduced to about 1,000 cfs at Gorge powerhouse.

3.2 Objectives

The initial objective of the present fry stranding studies was to better define the relationship between downramping rates and the stranding of salmon fry. Through the process of these evaluations, it became apparent that the time period at which the downramping occurred had a significant influence on the resultant fry stranding. Because of this observation, the emphasis shifted in the latter portion of these studies to evaluating the influence of the time of downramping on the stranding of salmon fry.

Associated minor objectives which were identified after the stranding study was initiated are: to determine if fry populations at the study sites were stable; to determine the time differential (lag time) for the occurrence of a downramp event at Gorge Powerhouse and each of the downstream study sites; and to evaluate the assumption that the selected study sites were representative; i.e., that fry stranding was not unique to those locations.

4.0 Materials and Methods

4.1 Experimental Design

The initial study design involved the collection of fry stranding data at three study locations across a range of downramping rates. The fry stranding rate was to be compared to the downramp rate through regression analysis. To aid the regression analysis, the variables of fry abundance, tributary inflow, and time of downramping were monitored throughout the study.

When the variable of time of downramping was recognized as a potential important factor in the stranding of salmon fry, paired tests were conducted to compare downramping during hours of darkness and downramping during hours of daylight. These observations were statistically evaluated with a paired T test.

4.2 Selection of Study Sites

The Skagit River, between Newhalem and the mouth of the Sauk River, was determined to be the area of primary concern relative to downramping and fry stranding. Gravel bars for study sites were selected to represent the graduation in substrate composition, bar slope and tributary inflow between

Newhalem and the mouth of the Sauk River. The average size of gravel bar substrate and bar slope decrease downstream. The average tributary inflow increases downstream.

Three study sites were assumed to adequately represent the area of concern and be logistically practical to work with the crew available. The selected sites were the Thornton Creek site, No. 1 (RM 90.2), Marblemount Bar site, No. 2 (RM 78.2), and Rockport Bar site, No. 3 (RM 67.7) (Figure 1). For the 1982 study year, the upstream site No. 1 was moved to the County Line Bar (RM 89.0). Bar slope measurements for site no. 2 and 3 are presented in Appendix A.

4.3 Survey Techniques

For each study gravel bar, a survey area was established which included the majority of each gravel bar. The length of the survey areas were 720, 720 and 960 feet for sites Nos. 1, 2, and 3, respectively. Parallel transects 20 feet wide were spaced along these bars at one hundred foot intervals, perpendicular to the flow line. During a stranding survey, the areas within the transects were examined followed by the areas between the transects. This practice was discontinued after the second survey because the number of fry within transects was low, and it was more efficient to survey back and forth between the high and low water lines from one end of the gravel bar to the other and back again.

The observation crew initially consisted of two persons per gravel bar but with experience, only one person per bar was required. All observations began at daybreak to prevent loss of fry on the study sites due to scavenging by birds. The observers collected only fry which were available without digging into substrate material. Loose rocks and sticks were moved to locate fry under this material. The goal was to obtain a relative index of stranding

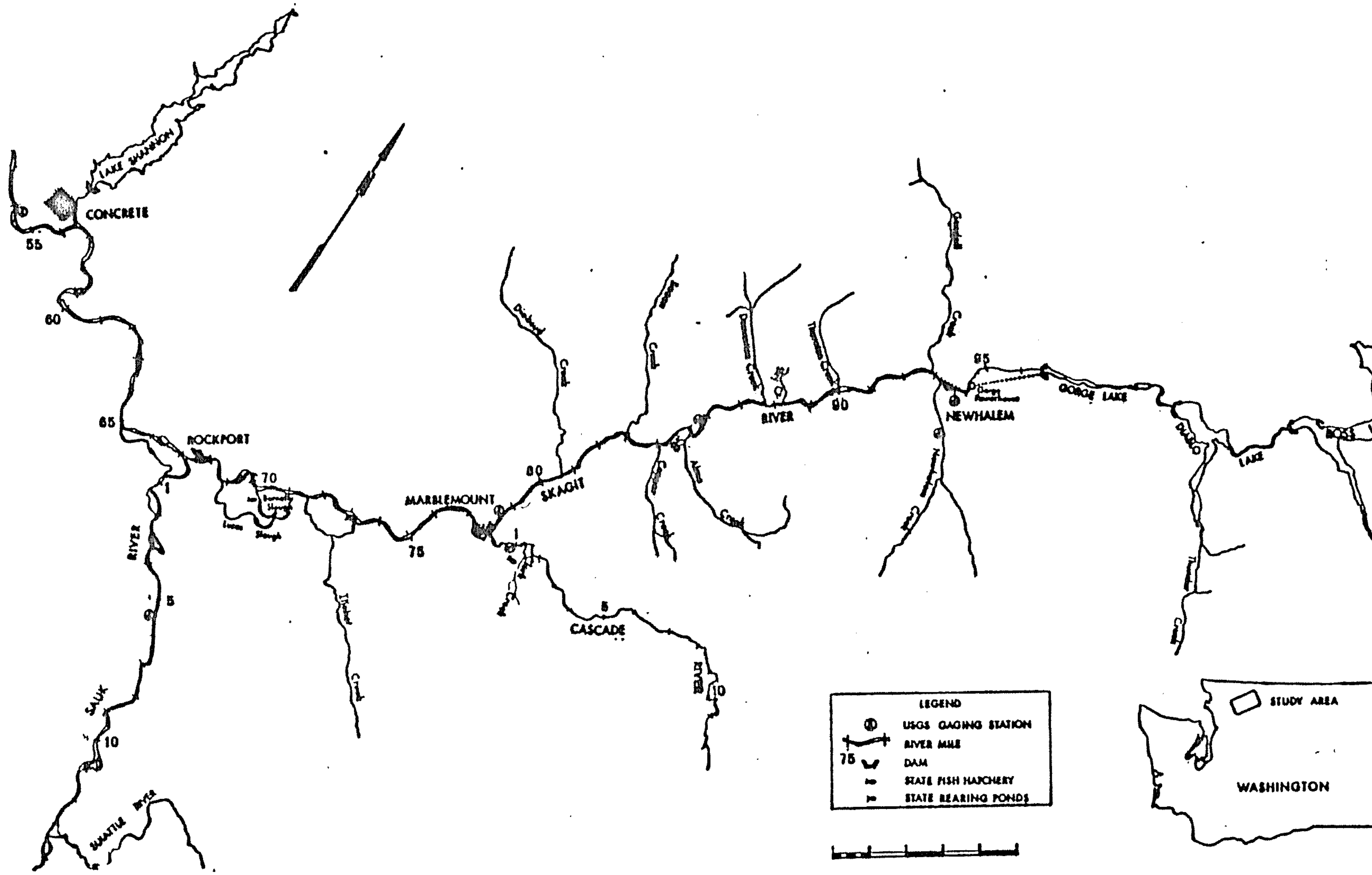

Fig. 1. Skagit Basin study area.

for each observation, not estimates of total number of fry killed. All fry which could be found by systematically searching the entire study area at least twice were removed and enumerated by species.

4.4 Monitoring of Fry Abundance

An electroshocker, Smith Root Type VII, was used to monitor the abundance of fry along the study gravel bars. Electrofishing was conducted the afternoon prior to each downramp test. Two hundred feet of shoreline out to a depth of about 1.5 feet were sampled. During the 1980 sample period, the area electrofished was two one-hundred foot sections separated by about 300 feet of shoreline. During the 1981, 1982, and 1983 sample periods, the area electrofished was a continuous two-hundred foot section of each gravel bar.

This procedure was reasonably successful in establishing the general abundance of salmon fry at the study sites. However, the accuracy of the technique was limited by flow and weather changes between sample periods and the fact that the electrofishing area could not be isolated to prevent fry from being chased out of the sample area as a result of the sampling process. To minimize these complications, caution was exercised to approach and sample the areas consistently. Additionally, the sampling crew always had at least one member who had participated in several previous surveys to help ensure consistency of technique.

4.5 Stream Flow Data

Seattle City Light regulated the discharge at Gorge Powerhouse according to requests to provide prespecified downramp conditions between a high flow of greater than 4,500 cfs and a minimum flow of 2,300 cfs. Comparisons were made between the U.S.G.S. records for the Newhalem (No. 12-1780) and Marblemount (No. 12-1810) gages to determine the level of tributary inflow during the downramp tests. The flow comparison was made during the stable minimum flow period following each downramp cycle.

The timing of the downramp events was determined from SCL records of power production at Gorge Powerhouse. This data source was utilized because the precise hour and minute of the start and end of the downramp event was recorded.

The tributary inflow to Marblemount was also monitored via telephone communications with U.S.G.S personnel in Tacoma. This was done to aid in the decision to send field crews out to conduct tests. Tests were not scheduled if tributary inflow was greater than 1,500 cfs because of the potential for the test to be nullified by a relatively minor sudden increase in tributary inflow.

4.6 Data Analysis

The variables of fry abundance, tributary inflow, and time of downramping were assumed to influence the results of a downramp event independent of downramp rate. These variables were monitored and factored into the regression analysis of downramp rate and fry stranding. The result was an index of stranding for each test. The regression analysis was conducted on the 1980-1982 data and reported in Stober et al. 1982. This form of analysis was not conducted for this report.

For the paired t test evaluation of daylight vs. darkness downramping, the direct count of stranded fry was utilized without factoring for the associated variables of fry abundance and tributary inflow. It was assumed that the process of conducting paired observations on back-to-back days would provide enough stability in the variables of fry abundance and tributary inflow to eliminate the necessity of factoring in these variables.

4.7 Stability of Fry Populations

There was some concern that the electrofishing sampling was not a good indicator of the abundance of fry at the stranding sites. This was evaluated in 1982 by marking groups of fry with fin nips and examining subsequent samples for marked fry.

Fry sampled by electrofishing were anesthetized in MS222 marked with an upper or lower candal nip, allowed to fully recover from the anesthetic, then released into the area from which they were caught. The marking was done at the Marblemount and Rockport study sites. Recapture effort consisted of electrofishing the same locations one and two days after the initial marking.

4.8 Fry Size

When the present study of salmon fry stranding in the Skagit River was initiated, subsamples of the fry captured by electrofishing and all the fry found stranded were segregated by species and their fork length was measured to the nearest millimeter. This data was being collected to test for a size differential between the electrofished sample and the stranded fry.

The systematic collection of fry data was discontinued after the 1980 study season because the sample sizes in the stranded population were small and the lengths essentially indentical to the electrofishing samples. Some random length samples were taken subsequent to 1980. All the length data collected will be reported for general information purposes.

4.9 Associated Observations

4.9.1 Test for Uniqueness of Sample Sites

There was interest expressed in the Skagit Standing Committee, particularly by SCL, when the 1983 study program was being discussed to make additional observations of fry stranding at other sites to give some verification to the WDF contention that fry stranding occurs commonly up and down the Skagit River. It was decided to evaluate this situation with a "blitz" survey which was to include as many sites as we could recruit personnel to survey. We were able to survey ten gravel bars on March 20, 1983.

The ten gravel bars were roughly evenly spaced between Newhalem and Rockport (Figure 1) with three sites above Marblemount. Some additional supplemental surveys were also conducted in the process of training the crew for the "blitz" survey and for additional supporting data on daylight vs. darkness downramping. Bar slope measurements for Hoopers Slough, Eagle Bar and County Line are presented in Appendix A.

4.9.2 Pothole Fry Stranding

Observations of fry being stranded in potholes were made near study site 3 incidental to the gravel bar stranding tests.

Notes were made on the numbers of fry observed and the flow levels which isolated or dewatered potholes inhabited by fry.

5.0 Results

5.1 Fry Abundance

The abundance data for study sites 1, 2, and 3 for the years 1980-1983 are presented in Tables 1, 2, and 3, respectively. The abundance of fry varied between study sites, years, and sample dates within sites and years. The Marblemount site (No. 2) generally had the highest abundance of fry. This may have been due to the physical nature of the site which, at moderate flows, had a pocket area that was separated from the river at its upstream end. It was not uncommon to capture 50 to 100+ fry at the blind end of this pocket of water. The site-specific variances in fry abundance are related to the spawning ground distribution of the adults and the dispersion characteristics of the fry. For example, the area adjacent to and immediately upstream of site 2 is one of the most heavily utilized chinook spawning areas on the

Table 1. Abundance of salmon fry as indicated by electrofishing and numbers stranded by species for the Thorton Creek/County Line study site (No. 1) 1980, 1981, and 1982.

Date	Electrofishing Abundance Estimate					Number of Fry Stranded		
	Total	Chinook	Pink	Chum	Coho	Total	Chinook	Pink
3/23/80	12	11	1	0	0	17	16	1
3/24/80	10	10	0	0	0	3	2	1
3/30/80	25	24	1	0	0	3	1	2
3/31/80	45	44	0	0	1	2	2	0
4/13/80	46	42	0	1	3	3	3	0
4/14/80	42	39	1	1	1	1	1	0
3/24/81	46	44	-	1	1	2	2	-
3/25/81	31	31	-	0	0	1	1	-
3/26/81	37	37	-	0	0	1	1	-
3/27/81	61	59	-	1	1	3	3	-
3/31/81	127	120	-	1	6	0	0	-
3/10/82	192	162	30	0	0	8	5	3
3/11/82	101	87	14	0	0	-	-	-
3/12/82	80	76	3	1	0	3	1	2
3/17/82	94	90	4	0	0	2	1	1
3/18/82	55	48	7	0	0	1	0	1
3/19/82	30	29	1	0	0	0	0	0
3/30/82	134	122	11	0	1	6	4	2
3/31/82	-	-	-	-	-	3	3	0
4/1/82	129	107	16	6	0	1	0	1
4/2/82	76	61	13	2	0	0	0	0

Table 2. Abundance of salmon fry as indicated by electrofishing and numbers stranded by species for the Marblemount study site (No. 2) 1980, 1981, 1982 and 1983.

	Electrofishing Abundance Estimate					Number of Fry Stranded			
Date	Total	Chinook	Pink	Chum	Coho	Total	Chinook	Pink	Chum
3/23/80	61	59	2	0	0	30	29	0	1
3/24/80	19	19	0	0	0	8	8	0	0
3/30/80	158	156	2	0	0	18	18	0	0
3/31/80	171	169	1	1	0	14	14	0	0
4/13/80	171	163	2	2	4	0	0	0	0
4/14/80	298	287	1	8	2	0	0	0	0
3/24/81	218	217	-	1	0	7	7	-	0
3/25/81	109	109	-	0	0	1	0	-	1
3/26/81	70	69	-	1	0	26	26	-	0
3/27/81	122	122	-	0	0	2	2	-	0
3/31/81	162	162	-	0	0	5	5	-	0
3/10/83	86	82	4	0	0	2	2	0	0
3/11/82	92	91	1	0	0	1	1	0	0
3/12/82	134	134	0	0	0	5	5	0	0
3/17/82	104	103	1	0	0	5	5	0	0
3/18/82	105	101	2	1	1	3	3	0	0
3/19/82	62	61	0	1	0	5	5	0	0
3/30/82	163	158	0	4	1	8	7	0	1
3/31/82	87	83	4	0	0	3	3	0	0
4/1/82	58	56	1	1	0	11	11	0	0
4/2/82	97	92	4	1	0	2	2	0	0
4/7/82	117	110	0	7	0	3	3	0	0
4/8/82	122	118	3	1	0	38	-	-	-
3/19/83	45	45	-	0	0	-	-	-	-
3/20/83	65	64	-	1	0	26	-	-	-
3/26/83	53	51	-	2	0	7	6	-	1
3/27/83	83	77	-	6	0	10	10	-	0
4/17/83	497	306	-	191	0	14	6	-	8
4/18/83	210	150	-	60	0	4	4	-	0

Table 3. Abundance of salmon fry as indicated by electrofishing and numbers stranded by species for the Rockport study site (No. 3) 1980, 1981, 1982 and 1983.

	Electrofishing Abundance Estimate					Number of Fry Stranded			
Date	Total	Chinook	Pink	Chum	Coho	Total	Chinook	Pink	Chum
3/23/80	19	15	4	0	0	18	17	1	0
3/24/80	7	7	0	0	0	23	18	5	0
3/30/80	9	9	0	0	0	7	3	2	2
3/31/80	10	9	0	1	0	19	9	8	2
4/13/80	36	13	17	6	0	10	3	2	5
4/14/80	23	7	10	6	0	6	4	2	0
3/24/81	78	71	-	7	0	79	73	-	6
3/25/81	31	28	-	3	0	21	20	-	1
3/26/81	20	19	-	1	0	49	39	-	10
3/27/81	16	15	-	1	0	15	11	-	4
3/31/81	68	63	-	2	3	6	5	-	1
3/10/82	130	120	10	0	0	10	10	0	0
3/11/82	63	55	6	1	1	0	0	0	0
3/12/82	43	41	0	1	1	6	4	2	0
3/17/82	35	30	4	0	1	27	24	2	1
3/18/82	56	51	3	2	0	62	57	4	1
3/19/82	37	36	1	0	0	35	30	1	4
3/30/82	61	40	4	17	0	68	36	5	27
3/31/82	57	45	3	6	3	27	19	2	6
4/1/82	74	66	3	5	0	62	39	4	19
4/2/82	35	30	1	4	0	9	5	1	3
4/7/82	35	21	4	10	0	15	7	6	2
4/8/82	29	21	1	7	0	98	50	8	40
3/19/83	66	66	-	0	0	7	7	-	0
3/20/83	36	36	-	0	0	36	34	-	2
3/26/83	54	49	-	5	0	9	2	-	7
3/27/83	85	68	-	17	0	131	64	-	67
4/17/83	91	15	-	76	0	22	4	-	18
4/18/83	-	-	-	-	-	26	3	-	23

Skagit River, which partially accounts for the consistently high abundance of chinook fry at site 2.

5.2 Stream Flow

The regulated flows which SCL provided for these studies gave a range of downramp rates from 357 to 2,757 cfs per hour. The downramping cycle was completed at the Gorge Powerhouse from an earliest time of 6:45 p.m. to the latest time of 3:10 a.m. during this study. The complete record of test date, downramp rate (cfs/hr), downramp time period, and tributary inflow is presented in Table 4.

During the four-year study period, the tributary inflow was most variable in 1980 and least variable in 1983. During the test conducted by L. Phinney in 1973, the tributary inflow was about one-half that experienced in the present study. This is reflected in the average minimum flows for all tests reached each year at the Marblemount gage (12-1810), with a discharge of 2,300 cfs at the Gorge Powerhouse (1973, 3,000 cfs; 1980, 3,750 cfs; 1981, 3,470 cfs; 1982, 3,418 cfs; 1983, 3,500 cfs).

5.3 Downramp Lagtime

When it became apparent that the relationship of daylight and darkness to stranding might be significant and should be evaluated, it became necessary to more precisely determine the delay or lagtime associated with the reaching of the low point in the downramp cycle at Gorge Powerhouse and the transfer of this flow reduction to the downstream study sites. This information was needed to establish the downramping times for future tests.

The lagtime was measured on two dates, 19 and 30 March 1982, at each of the study sites by monitoring site-specific staff gages which were installed for this purpose. The data for these observations is presented in Tables 5 and 6.

Table 4. Stream flow data during the downramping studies, 1980, 1981, 1982, and 1983.

Date	Ramp Rate cfs/hr	Start Time	End Time	Tributary Inflow, cfs
3/23/80	1,454	1:15 AM	2:45 AM	1,164
3/24/80	603	10:00 PM	2:20 AM	1,092
3/30/80	357	8:30 PM	3:45 AM	1,066
3/31/80	870	12:30 AM	3:10 AM	997
4/13/80	436	8:30 PM	1:30 AM	1,320
4/14/80	714	10:20 PM	1:45 AM	1,973
3/24/81	941	11:00 PM	1:30 AM	1,077
3/25/81	836	9:50 PM	12:40 AM	1,138
3/26/81	966	11:40 PM	2:00 AM	1,066
3/27/81	402	7:00 PM	12:15 AM	1,066
3/31/81	889[a]	9:15 PM	2:30 AM	1,523
3/10/82	384[a]	9:00 PM	2:30 AM	1,509
3/11/82	624[a]	9:00 PM	12:30 AM	1,853
3/12/82	583[a]	9:20 PM	2:30 AM	1,661
3/17/82	715	10:30 PM	2:00 AM	1,317
3/18/82	747	10:30 PM	2:15 AM	1,242
3/19/82	2,100	12:01 AM	1:05 AM	1,231
3/30/82	2,179[b]	12:00 PM	1:00 AM	1,190
3/31/82	560[b]	8:00 PM	1:00 AM	1,120
4/1/82	700[b]	10:00 PM	3:00 AM	1,155
4/2/82	2,757[b]	10:00 PM	11:06 PM	1,083
4/7/82	1,987	10:00 PM	11:15 PM	1,000
4/8/82	2,070	2:00 AM	3:03 AM	1,033
3/19/83	1,784	10:00 PM	11:10 PM	1,425
3/20/83	1,371	1:30 AM	3:10 AM	1,390
3/26/83	1,380	9:20 PM	11:15 PM	1,162
3/27/83	1,541	1:00 AM	2:30 AM	1,138
4/17/83	486	2:45 PM	6:45 PM	1,250
4/18/83	2,278	10:00 PM	11:30 PM	1,431

a/ Variable ramp rate per the Skagit interim flow agreement, number is the average rate.

b/ Variable ramp rate due to ramping at a stage per hour rate, number is the average rate.

Comparison of the downramp end time at Gorge Powerhouse (Tables 4) on March 19 and 30, 1982, with the site-specific data in Tables 5 and 6, indicates that the time lag for completion of a downramp event is 1, 4.5 and up to 7.5 hours for study sites 1, 2, and 3, respectively. Also of interest is the dampening or spread in time of the downramp event as it progresses downstream. For example, a reduction in flow of 2,100 cfs accomplished in one hour at Gorge Powerhouse results in a flow reduction at the Rockport site, which is spread over four hours.

Additional data concerning the relationship of downramp timing at Rockport compared to Gorge Powerhouse was collected incidental to fry stranding observations during 1982. These data are presented in Table 7. Because these data were incidental observations they are not quite as precise for measuring downramp lag time as the March 19 and 30 data. However, the data for March 18, 31, and April 1 are reasonably accurate for measuring lag time of downramping to the Rockport site. Comparison of these data to Table 4 indicates up to 7.75 hour lag time to the Rockport site for completion of a downramp event. It is noteworthy that the drop in water surface elevation is generally less than 0.10 feet during the last hour of flow reduction.

5.4 Fry Stranding

As discussed in the methods section, the emphasis and design of the study shifted from testing variation in rate of downramping to testing the time of occurrence of downramping as field experience and data were accumulated. During the 1982 study period, some directed evaluation of time of downramping was conducted. Based on the tentative relationship observed in these tests, the relationship of downramping to dawn was computed for all the individual tests at each site in 1980, 1981, and 1982.

The regression analysis results and the graphical representation of the

Table 5. Site-specific downramping data for 19 March 1982 (in feet).

USGS Newhalem gage		County line		USGS Marblemount gage		Marblemount		Rockport	
Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.
12:00 M	83.81	12:30 AM	4.60	2:00 AM	3.48	3:10 AM	4.72	4:30 AM	4.16
1:00 AM	82.86	12:45 AM	4.60	3:00 AM	3.39	3:20 AM	4.66	5:00 AM	4.12
2:00 AM	82.50	1:00 AM	4.50	4:00 AM	3.01	3:40 AM	4.50	5:27 AM	4.03
3:00 AM	82.19	1:15 AM	4.36	5:00 AM	2.78	4:00 AM	4.34	5:50 AM	3.92
4:00 AM	82.19	1:30 AM	4.20	6:00 AM	2.74	4:20 AM	4.20	6:00 AM	3.86
		1:50 AM	4.04	7:00 AM	2.72	4:40 AM	4.08	6:55 AM	3.68
		2:00 AM	3.96			4:50 AM	4.06	7:55 AM	3.56
		2:10 AM	3.90			6:00 AM	3.92	8:10 AM	3.54
		2:15 AM	3.89					8:30 AM	3.53

Table 6. Site-specific downramping data for 30 March 1982 (in feet).

USGS Newhalem gage		County line		USGS Marblemount gage		Marblemount		Rockport	
Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.	Time	G.H.
12:00 M	83.75	1:00 AM	4.48	2:00 AM	3.47	2:54 AM	4.74	4:40 AM	3.98
1:00 AM	82.65	1:18 AM	4.24	3:00 AM	3.33	3:00 AM	4.70	5:00 AM	3.94
2:00 AM	82.16	1:30 AM	4.12	4:00 AM	2.94	3:18 AM	4.58	5:15 AM	3.90
3:00 AM	82.16	1:48 AM	3.96	5:00 AM	2.74	3:30 AM	4.50	5:30 AM	3.86
		2:00 AM	3.88	6:00 AM	2.71	3:42 AM	4.38	5:45 AM	3.78
		2:06 AM	3.86	7:00 AM	2.70	4:00 AM	4.26	6:00 AM	3.72
		2:12 AM	3.86			4:18 AM	4.12	6:15 AM	3.64
						4:30 AM	4.06	6:40 AM	3.54
						4:42 AM	4.02	7:00 AM	3.46
						5:00 AM	3.96	7:25 AM	3.42
						5:18 AM	3.91	8:00 AM	3.38
						5:30 AM	3.90	8:30 AM	3.34
								8:45 AM	3.32
								9:00 AM	3.32

Table 7. Downramping data for the Rockport Site by date 1982. Gage heights are in feet.

March 12		March 17		March 18		March 31		April 1		April 2	
Time	GH	Time	GH	Time	GH	Time	GH	Time	GH	Time	GH
7:00 AM	4.46	6:25 AM	3.90	6:15 AM	3.80	5:30 AM	3.65	5:50 AM	4.06	5:25 AM	3.52
8:00 AM	4.42	7:10 AM	3.80	7:10 AM	3.70	6:15 AM	3.58	7:00 AM	3.90	6:25 AM	3.44
8:40 AM	4.40	8:00 AM	3.72	7:40 AM	3.64	7:15 AM	3.50	8:00 AM	3.74	8:00 AM	3.30
		8:50 AM	3.69	8:15 AM	3.62	8:20 AM	3.48	8:30 AM	3.66		
				8:30 AM	3.60	8:50 AM	3.47	9:15 AM	3.56		
				9:10 AM	3.59			10:00 AM	3.50		
								10:30 AM	3.47		
								10:50 AM	3.46		

tentative relationship between time of day and fry stranding were previously reported in Stober et al. 1981 and Stober et al. 1982.

These types of analyses of the data were not continued to include the 1983 data. Instead, the data base 1980-1983 was examined to determine how many of the individual tests could be categorized as paired comparisons of daylight vs. darkness downramping.

Ordering the data in pairs, where applicable, eliminated the necessity of factoring the variables of fry abundance and tributary inflow to compute a "Stranding Index." Use of direct stranding observations was based on the assumptions that paired tests; i.e., tests on back-to-back dates, occurred at times when the uncontrollable variables of fry abundance and tributary inflow were reasonably stable. Another source of variance which is eliminated by using the paired tests is the change in species composition through the several week study period and between years.

The decision to concentrate on evaluating daylight vs. darkness and utilizing data pairs eliminates a significant portion of the early data base from the analysis. This data is still presented in Tables 1, 2, and 3 for completeness of the available record and potential utility to readers.

The most substantial portion of data eliminated from the current analysis was the data for study site 1. This site is located close enough to Gorge Powerhouse, such that all downramping which occurred during our tests was during hours of darkness. This site was not monitored in 1983. The data for this site (Table 1) indicates that the incidence of fry stranding was typically low. Usually less than five fry for the entire study site; range 0-17, mean 3 for 20 observations.

The data for site 2 is presented in Table 2 and indicates a moderate and quite variable incidence of stranding; range 0-38, mean 9.2 for 28 observations. There were five paired observations made at site 2 during the period 1981-1983. Unfortunately, one of the sample days has no data due to a sampler not arriving to conduct the survey. The data omission occurred on March 19, 1983. The paired t test analysis was conducted two ways. First, it was run with the March 19-20, 1983 pair eliminated and secondly, it was run by using the mean of the other darkness downramp observations as the data point for the missed survey on March 19.

The paired observations and the resultant t statistics for site 2 are presented in Table 8. The hypothesis that the incidence of fry stranding at site No. 2 is equal with downramping occurring during darkness or daylight was rejected at the $\alpha = 0.10$ level for the four pair comparison and rejected at the $\alpha = 0.05$ level for the five pair comparison. These results indicate that the presence of daylight did have a significant influence on the incidence of stranding. It should be noted that the tests were keyed to achieving downramping before or after dawn at site 3. The result of this study design feature was that a portion of the downramping for daylight tests occurred prior to dawn at site 2, which is ten miles closer to Gorge Powerhouse. This gives even more weight to the significance of the effect of daylight at site 2.

The data for site 3 is presented in Table 3 and indicates a moderate to high incidence of stranding; range 0-131, mean 30.6 for 29 observations. There were also five paired observations made at site 3 during the period 1981-1983.

The paired observations and the resultant t statistics for site 3 are presented in Table 8. The hypothesis that the incidence of fry stranding at site 3 was equal with downramping occurring during daylight or darkness was rejected at the $\alpha = 0.05$ level. This result indicates that the presence of

Table 8. Data pairs and paired T statistics for daylight and darkness downramping at the Marblemount and Rockport study sites.

Dates	Marblemount Daylight	Marblemount Darkness	Rockport Daylight	Rockport Darkness
3/26-27/81	26	2	49	15
4/1-2/82	11	2	62	9
4/7-8/82	38	3	98	15
3/19-20/83	26	4 1/	36	7
3/26-27/83	10	7	131	9

Marblemount: t calc = 2.45 df = 3
t 0.05(3) = 3.18

1/ t calc = 3.27 df = 4
t 0.05(4) = 2.78

Rockport: t calc = 3.01 df = 4
t 0.05(4) = 2.78

1/ No data due to sampler absence value of 4 inserted (average of other darkness observations) to check effect on t statistic.

daylight did have a significant influence on the rate of fry stranding at site No. 3.

Although regression analysis of the influence of downramping rate on incidence of fry stranding was not conducted in 1983, the data for all observations (1980-1983), which could be categorized as "daylight" or "darkness" downramping, was ordered and plotted vs. downramp rate. This information is presented in Figures 2 and 3 for study sites 2 and 3, respectively.

Examination of these figures suggests there may be a trend of increased stranding with increased downramp rates for the daylight tests. However, downramp tests during darkness are consistently low. The most dramatic example of this lack of effect of downramping rate during hours of darkness occurred on April 17 and 18, 1983 when downramp rates of 500 and 2,300 cfs, respectively, during darkness were compared. The result was nearly equal numbers of fry stranded on both days at site 3 and more fry stranded on April 17, 1983 than April 18, 1983 at site 2.

5.5 Fry Population Stability

The mark recovery at both the Marblemount and Rockport sites resulted in a very low rate of mark recaptures (Table 9). Less than 10 percent of the marked fry were recovered the day following marking, and for the first mark groups, no fry were recovered on the third sample day.

The low rate of mark recovery is an indication that electrofishing in this situation provides a limited estimate of fry abundance. These estimates are only useful for indicating general level of fry population abundance and species composition.

There are several possible explanations for this low mark recovery rate, including:

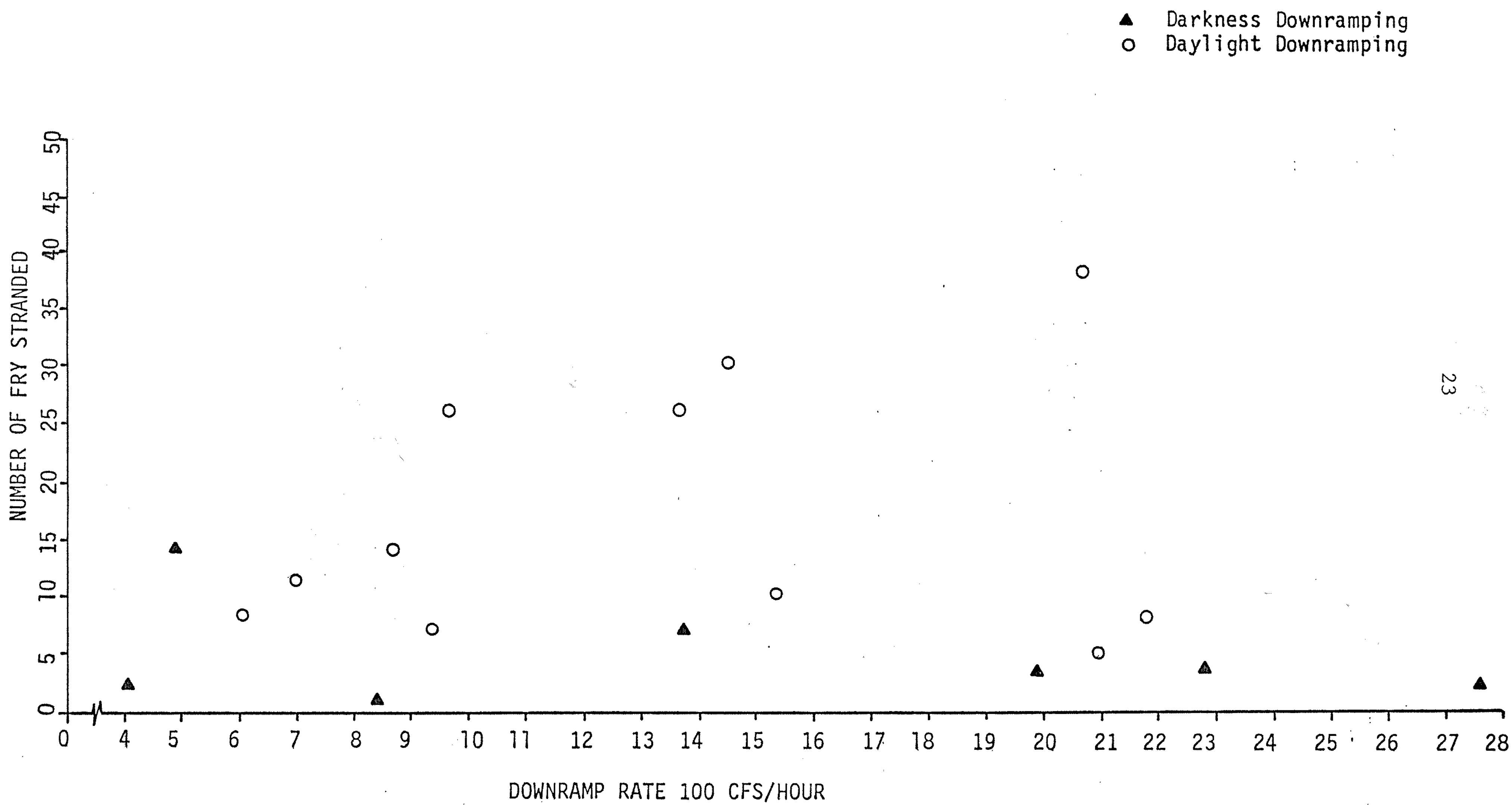

Figure 2. Downramp rate vs fry stranding for daylight and darkness downramping at the Marblemount study site.

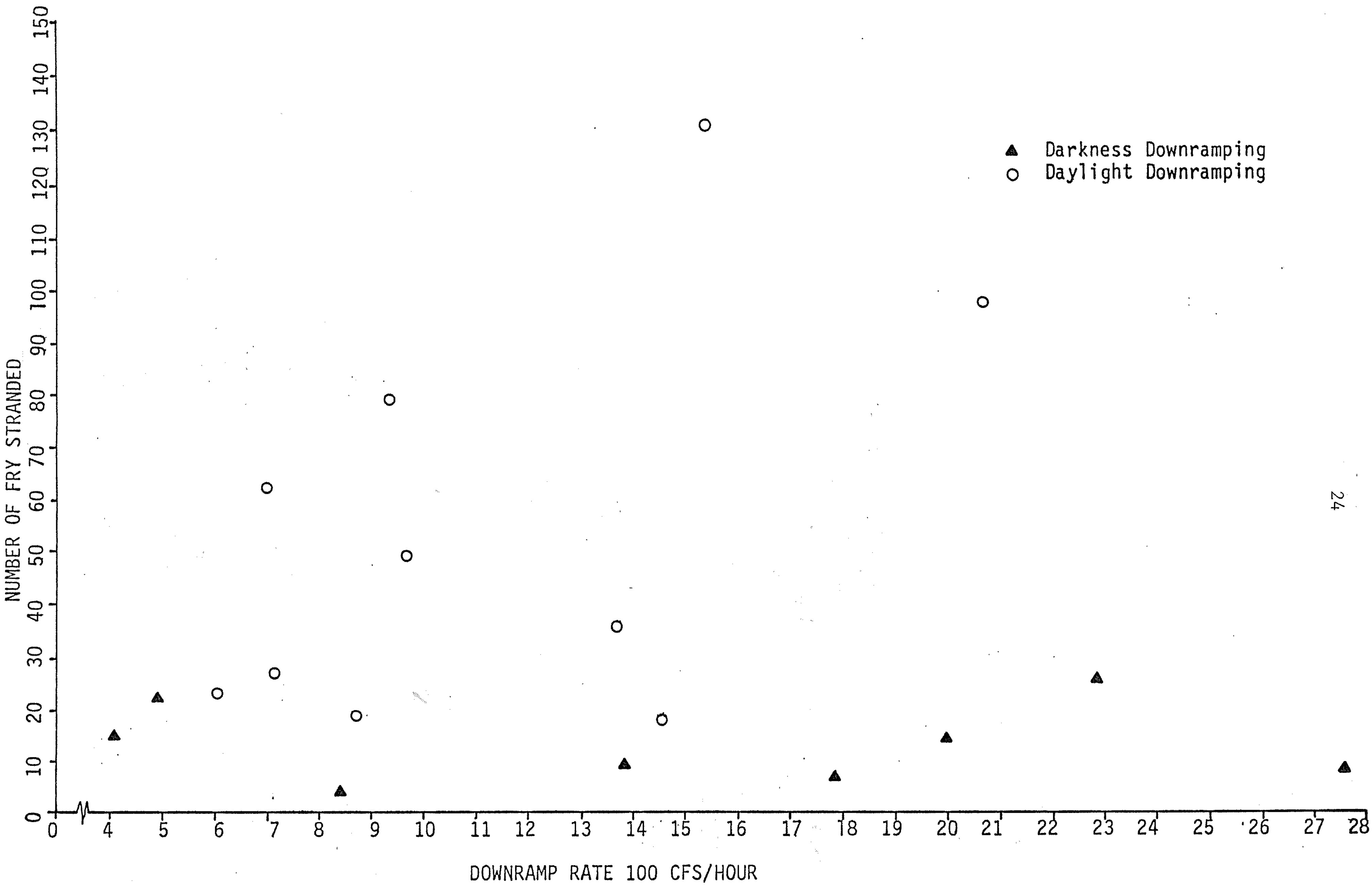

Figure 3. Downramp rate vs fry stranding for daylight and darkness downramping at the Rockport study site.

Table 9. Chinook fry marking and recovery data for the Marblemount and Rockport study sites, 1982.

Date	Marblemount			Rockport		
	No. Marked	No. 1st Recap.	No. 2nd Recap.	No. Marked	No. 1st Recap.	No. 2nd Recap.
3/2/82	75	---	---	94	---	---
3/3/83	162	3	0	119	9	0
3/4/83	---	12	---	---	2	---

1. Low capture efficiency for the gear employed;
2. High mortality for the fry captured and marked;
3. Displacement of the fry captured and marked; and
4. High rate of turnover in the population; i.e., relatively large portion of population either leaving or being recruited to area each day.

5.6 Fry Size

The taking of length data was somewhat sporadic through the course of this study, primarily because it became apparent early in the collection of this data that there was little variance associated with it (Table 10). For a total of 694 chinook fry measured, the fork lengths ranged from 33 mm to 52 mm, with a mean of 41.2 mm.

5.7 Associated Observations

5.7.1 Uniqueness of Sample Sites

The "blitz" survey of ten gravel bars from Newhalem to Rockport was conducted from March 20, 1983. The total number of fry found stranded is presented in Table 11. Stranded fry were found on all gravel bars surveyed with the numbers generally increasing progressing downstream. Additional supplemental surveys of fry stranding were also conducted to gather more data on daylight vs. darkness downramping. The results of these surveys are included in Table 11, which lists the total fry found stranded by site and date for all surveys conducted during 1983. The numbers of fry stranded at all sites inspected was consistently greater with daylight downramping. The rate of stranding increase with daylight downramping varied from 1.43 to 36.00 times the darkness rate, with an average increase by a factor of 10.5 for daylight downramping.

These supplemental surveys support the conclusion that downramping during

Table 10. Length data for chinook fry collected from 1980 - 1982, fork length in millimeters (mm).

Date	Study Site No. 1				Study Site No. 2				Study Site No. 3			
	No.	Min. Length	Max. Length	Mean Length	No.	Min. Length	Max. Length	Mean Length	No.	Min. Length	Max. Length	Mean Length
3/22/80[E]	11	39	43	41.0	14	39	42	40.3	15	38	43	40.5
3/23/80[S]	14	36	45	41.0	17	34	46	40.2	24	33	43	40.4
3/29/80[E]	18	37	44	41.2	25	37	44	40.5	--	--	--	----
3/30/80[S]	--	--	--	----	16	38	42	39.8	5	39	43	40.2
3/30/80[E]	29	38	43	40.3	33	37	46	40.6	9	37	42	39.6
3/31/80[S]	--	--	--	----	12	36	42	40.1	7	38	44	40.4
4/12/80[E]	15	37	52	43.5	16	40	47	42.4	11	35	44	39.7
4/13/80[E]	14	38	51	43.4	--	--	--	----	7	40	43	41.6
3/4/81[E]	20	37	48	42.3	20	41	45	43.0	20	37	45	42.8
3/23/81[E]	19	37	44	42.2	20	40	49	42.4	21	38	44	41.8
3/24/81[E]	--	--	--	----	--	--	--	----	20	40	45	43.0
3/24/81[S]	--	--	--	----	--	--	--	----	17	39	44	41.8
3/26/81[S]	--	--	--	----	20	39	47	42.3	20	40	46	42.6
3/3/82[E]	--	--	--	----	36	34	46	40.8	32	38	43	41.1
3/18/82[E]	29	38	45	40.5	52	38	44	40.4	36	38	50	40.7

[E] Electrofishing sample

[S] Stranding sample

Table 11. Total fry stranded by site and date for all surveys, including the "blitz," during 1983.

	Survey Locations by River Mile									
Date	89.0	82.6	80.7	78.2	77.5	72.6	70.9	70.0	68.5	67.7
3/19[a/]					47			6		7
3/20[b/]	20	14	3	26	68	21	41	69	140	36
3/26[a/]				7	13			2		9
3/27[b/]				10	43			72		131
4/17[b/]				14						22
4/18[b/]				6						26

[a/] Downramping during darkness.

[b/] Downramping during daylight.

daylight results in higher loss of fry than does downramping during darkness. This was most evident at the sites near Rockport.

5.7.2 Pothole Fry Stranding

Stranding of salmon fry was noted in potholes above and below study site 3 at Rockport. Observations of pothole stranding were made incidental to the gravel bar stranding study. Because these observations were incidental and supplemental information and also because the potential severity of this type of stranding was not initially recognized, there were several occasions when the potholes on Rockport gravel bar became dewatered and no data was collected concerning the occurrence of stranded fry. On these occasions, either no fry were present in the potholes to be killed or the dead fry were removed by scavenging birds prior to the time the sites were sampled.

Potholes are formed by depressions in gravel bars and small pools in side channels. They tend to be points of concentration; i.e., preferred habitat, for salmon fry because they have greater depth and lower velocity than surrounding areas at a given flow. Also, they are often associated with instream cover such as logs and stumps.

The potholes are isolated from surrounding flowing water as flows decline and drain dry gradually if the water surface elevation continues to decline below the pothole elevation. It was noted at Rockport that the trapping and/or killing of fry in potholes was strongly influenced by the final water surface elevation at the end of the downramp event. Since the flow level at Gorge Powerhouse was standardized at 2,300 cfs for the end point of each downramp event, variation in tributary inflow levels from test to test determined presence or absence of water in potholes at Rockport.

The incidental pothole stranding observations which were made at Rockport are summarized in Table 12. There is no active flow gage at Rockport so the

Table 12. Observations of fry stranded in potholes near the Rockport study site, 1982 and 1983.

Date	Fry Number and Condition	Water Condition	Marblemount Flow
3/12/82	50 live in each of two potholes	water level adequate	3,961
3/18/82	17 dead in small pothole 300-400 live in large pothole	water level marginal in large pothole	3,542
3/30/82	none observed	potholes dry	3,490
4/2/82	none observed	potholes dry	3,383
3/27/83	50 dead	potholes dry	3,438
4/17/83	152 dead	potholes dry	3,550
4/18/83	live fry present, no count	water level marginal	3,731

tributary inflow level at Marblemount was used as a basis for comparison. The data in Table 12 indicates that the flow levels which occurred at Rockport when there was 1,600 cfs inflow to the Marblemount gage, i.e., 3,900 cfs at Marblemount and 2,300 cfs at Gorge Powerhouse, provided enough water in the critical potholes to keep the fry present alive.

The other important aspect of the pothole stranding observations is the fact that relatively large numbers of salmon fry can be involved. This is due to these sites being preferred habitat under the higher flow conditions present when fry enter these areas. For example, 152 fry were killed in the critical potholes at Rockport on April 17, 1983, whereas there were 22 fry killed on Rockport gravel bar at this time. The potholes are a few hundred square feet in area whereas Rockport Bar had about 65,000 square feet of area exposed.

6.0 Discussion

6.1 Downramp Rate vs. Fry Stranding

The initial emphasis of the present fry stranding studies was to evaluate the potential to reduce the mortality associated with downramping by moderating the rate of downramping. Through the planning process and in conducting the initial study observations, it became apparent that the uncontrollable variables of fry abundance and tributary inflow could have a significant influence on fry stranding observations.

When these variables were measured and utilized to convert the numbers of fry observed to indices, the resulting correlations between downramp rate and fry stranding were positive but not strong (Stober et al. 1982).

Further field observations, particularly at the Rockport site, indicated the probability that time of downramping was a significant factor in the relationship of downramping to fry mortality. The available stranding data was categorized as "daylight" and "darkness" downramping and plotted against downramp rates in Figures 2 and 3. This generalized comparison suggests there may be a trend of increased stranding with increased downramp rate for daylight tests at the Rockport site. Downramp tests during darkness were consistently low for all downramp rates. This trend was not analyzed statistically and if daylight downramping was proposed as a significant operational feature of the Skagit project, further testing of this relationship may be necessary.

6.2 Downramp Time vs. Fry Stranding

The behavior of salmon fry during darkness and daylight is apparently quite different and influences their susceptability to mortality due to hydroelectric downramping. The presence of a strong photo-negative behavior in developing pre-emergent fry is well known and has been evaluated in several experiments. Hatchery incubation facilities maintain fry in darkness or reduced light to prevent mortality due to suffocation which can occur when the developing fry crowd together to avoid light.

Some studies have indicated a progressive weakening of this initial photo-negativity (Stuart 1953; Woodhead 1957; Mason 1976; and Dill 1977). Bams (1969) found that sockeye salmon were negatively phototactic throughout their entire intragravel incubation and that any light inhibited emergence. Early studies by Neave (1955) and Hoar (1968) showed that pink, chum and sockeye fry were negatively phototactic and that these initial responses eventually give way to rapid dramatic changes to neutral or positive photobehavior.

Mason (1976) in studies on coho fry found that the pronounced photo-negative behavior was suddenly lessened at time of emergence but remained photo-negative. Mason refers to this retention of photo-negative response as hiding behavior in which fry use the gravel bed as a refuge.

The utilization of the "gravel bed as a refuge" in response to light is a possible explanation for the higher incidence of fry stranding when downramping occurs during daylight hours. The degree to which post-emergent fry utilize the streambed for refuge is probably variable according to species and amount of stream residence time. When conducting electrofishing sampling, it is rare to visually see pink, chum, or coho fry prior to disturbing them with the electrical field. Chinook fry, on the other hand, are frequently observed swimming openly and feeding in the shallow stream margins and in side channels. When these chinook fry are disturbed, they typically seek cover and hide between the streambed cobbles or under submerged debris. The fry captured when electrofishing are typically "pulled out" of these hiding places.

When making stranding observations on the Rockport gravel bar, it was common to find fry sufacing from under loose surface material (cobbles, sticks, bark, etc.) five to twenty minutes after the surface of these areas was dewatered. These fry sought refuge in very small pockets of water until these dried up, and when they "emerged" from these refuge sites, they were unable to reach the surface water of the river. Salmon fry have very limited mobility when struggling on the substrate surface. It was not uncommon at Rockport to find dead or dying fry a matter of inches from the edge of the river. It should be noted that scavenging birds are keyed into the availability of these fry and the opportunity for a fry to re-enter the river once it has been stranded is further limited by this predatory activity.

6.3 Fry Habitat vs. Fry Stranding

The occurrence of fry stranding is strongly influenced by the extent to which the rearing and/or refuge habitat of the fry is dewatered. The earlier fry stranding studies on the Skagit River (Thompson 1970 and Phinney 1974) identified a dramatic decrease in fry stranding when the minimum flow at Gorge Powerhouse was increased from 1,100 cfs to about 2,300 cfs. These studies also identified a flow level of 5,000 cfs at Gorge Powerhouse as establishing a "bank full" condition in downstream areas and flow fluctuations above this level were presumed to induce little or no stranding mortality. Flow fluctuations above the 5,000 cfs level alter the depth and velocity in fry habitats but do not dewater these habitats.

A substantial portion of the fry stranding observed by Thompson and Phinney was classified as pothole stranding. Both depressions on the gravel bars and in side channels behind; i.e., shoreward of, gravel bars consistently had "the largest numbers of dead fry." Thompson discussed the influence of tributary inflow on fry stranding and concluded that inflow had a dramatic influence on stranding due to the influence on area dewatered. His preliminary conclusion was that a flow level of 2,800 cfs was adequate to substantially reduce fry stranding at Marblemount and that the corresponding flow at Rockport was "roughly 3,900 cfs." These levels were estimated on March 30, 1969 with a tributary inflow to Marblemount of 1,425 cfs.

During the present Skagit fry stranding study, stranding of fry in potholes on or near the Rockport gravel bar was observed and noted to be a source of significant mortality on some occasions. The dewatering of potholes and the resultant fry mortality was associated with periods of low tributary inflow. The specific observations made (Table 12) indicate that with a base flow of 2,300 cfs at Gorge Powerhouse, a tributary inflow condition resulting in 3,700 cfs at Marblemount resulted in marginal water levels in the potholes at Rockport.

It was interesting that the flow level which was necessary to provide protection of pothole habitat at Rockport in 1982-83 was about 1,000 cfs greater than the equivalent estimate in 1969. The most probable cause of this difference is a change in the character of the Rockport gravel bar and associated potholes. This is highly likely over a period of 14 years.

7.0 Conclusions

The recent series of tests provide conclusive evidence that all downramping which results in dewatering of fry rearing and/or refuge habitat will have an associated stranding mortality. These tests and the results of previous studies indicate that there are two methods of significantly reducing the impact of hydroelectric flow fluctuations <u>if they must occur</u> during the period of fry residence and within the habitat zone of salmon fry.

The first technique is to establish flow levels which maintain surface water over the preferred habitat of salmon fry and limit minimum flows to this level during the time period that fry are present. On the Skagit River, a substantial amount of tributary inflow is present between the hydroelectric projects and the areas most vulnerable to fry stranding. Fluctuations in the tributary inflow have dramatic influence on the amount of fry habitat influenced by hydroelectric flow fluctuations. The opportunity exists to monitor tributary inflow and utilize this information to more precisely match the flow requirements of the fish and maintain greater flexibility in the hydroelectric operations.

The second method of reducing fry losses involved controlling the time period for downramping to levels which are dewatering known stranding areas. The level of gravel bar fry stranding observed in these studies was consistently and significantly reduced when downramping at Gorge Powerhouse was timed to allow the full effect of the flow reduction to carry downstream to Rockport by dawn. For the flow conditions tested, about 7.5 hours lagtime was involved in the transefer of the complete downramp event from Gorge Powerhouse to Rockport. The majority of the downramp at Rockport had occurred 6.5 hours after the downramp end time at Gorge Powerhouse.

The reduction in severity of stranding loss when downramping occurs during hours of darkness is apparently due to behavioral characteristics of the fry. The fry appear to have a reduced dependence on the substrate for cover during darkness resulting in a greater tendency for fry to remain in the water column and move as the flow level declines. Conversely, the fry appear to be either actively seeking refuge in the substrate at dawn or reacting to the combined stimulus of light and reduced flow by seeking refuge in the substrate.

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Chapter 2: Skagit River Steelhead Studies - 1983

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SKAGIT RIVER STEELHEAD STUDIES - 1983

Introduction

March 1981, an "Interim Offer of Settlement" was submitted to the Federal Energy Regulatory Commission. It was conditionally approved May 12, 1981. This interim flow agreement spelled out certain modifications to the operation of Seattle's Skagit River projects for the purpose of mitigating and studying effects on downstream fisheries resources. As a party to that agreement, and as specified by its terms, Department of Game was funded by Seattle City Light (SCL) to perform certain studies. In 1983, the Department was contracted to survey steelhead spawning with the objective of defining the "period, exact timing, and general distribution of steelhead spawning activity for redd/depth flow analysis and expected mainstem fry distribution."

Methods

Department of Game personnel scheduled and performed aerial (helicopter) spawning surveys. At least one person from Fisheries Research Institute (FRI) was present during each survey for the purpose of mapping individual mainstem Skagit steelhead redd locations from Rockport to Newhalem. These maps as well as overall spawning timing and intensity/distribution data will be used in conjunction with other ongoing studies by University of Washington, Fisheries Research Institute, the major contractor for Interim Agreement studies.

Spawning surveys were conducted at regular intervals, as weather and river turbidity permitted. Of surveys funded by Seattle City Light, a total of seven were conducted at intervals of 13 to 20 days. Department of Game also performed additional aerial and on-the-ground spawning counts of Skagit Systems tributaries and upper Sauk River. These combined observations allowed calculation of steelhead spawning escapement and total run sizes.

Steelhead fry stranding studies were conducted during August-October using the same methods applied to salmon fry. Nine gravel bars were intermittently surveyed, however, electrofishing was confined to Marblemount, Test Barr and Rockport bars.

Results and Discussion

Steelhead Redd Surveys

Steelhead redd distribution observed with the aerial surveys are shown in Table 1. These data are the combined SCL funded and Supplemental Game Department observations.

For comparison, aerial redd counts for years 1975 through 1983 are summarized in Tables 2 and 3. Table 2 displays mainstem Skagit River counts and Table 3 summarizes counts from Sauk River, the largest Skagit River tributary system. Other aerial surveys date back to 1964, but count interval and area coverage were less consistent.

In 1983, peak instantaneous redd numbers in Skagit and Sauk Rivers were observed in May. This has consistently been the month of most intensive activity throughout the 1975-83 period of record, though fewer data points are available for Sauk River because turbid runoff conditions have precluded late spring counts some years. Wild origin steelhead spawning commences in March and continues well into June. For management purposes, steelhead spawning after March 15 are defined as wild origin and those spawning before as hatchery origin. From scale analysis and known maturation timing of hatchery stock steelhead, March 15 is felt to be approximately the mid-point of overlap between hatchery (Chambers Creek stock) and wild origin spawners.

Table 4 shows sub-basin and total spawning escapements for the Skagit River system by year for the period 1978 through 1983. These escapements were calculated based on aerial surveys in Tables 3 and 4 as well as ground surveys of index areas in tributary streams. Procedures followed in spawner surveys and escapement estimation are essentially as described in WDG (1978) and Phillips et al. (1980). Actual escapement is not necessarily directly proportional to redd count. For example, the highest instantaneous mainstem Skagit redd count of record was observed in 1983, while the highest measured escapement occurred in 1982. This apparent discrepancy is due to differences, between years, in the relationship of redd visibility duration to survey interval. The net result is that a larger number of individual redds were counted more than once in 1983 than in 1982. Conversely, there was a greater turnover between counts in 1982 than in 1983.

The majority of steelhead spawning activity occurs in tributary streams. Over the 1977-78 through 1982-83 period of record, 80 percent of steelhead spawning in mainstem Skagit sub-basin (excluding Cascade and Sauk sub-basins) used tributary streams. Taken by itself, this relationship underestimates the actual production value of mainstem Skagit. In fact, there may be substantial recruitment of presmolt juveniles to the mainstem from tributary areas and that both mainstem and tributary spawning are seeding mainstem rearing areas (Phillips et al. 1981). Additionally, the relationship between tributary and mainstem spawning may be influenced by run strength. For example, during the 1977-78 through 1980-81 cycles, 58 percent of Sauk River sub-basin spawners used small tributaries while during the 1981-82 and 1982-83 cycles, tributary spawning amounted to 23 percent of the total. This occurred because mainstem

Sauk spawner use increased while tributary use remained relatively stable. Skagit system wild steelhead spawning escapements have, in general, been below that necessary to achieve full productive capacity as determined by environmental conditions and habitat quality. Major steps are being taken to secure adequate escapements and, as these runs rebuild, the relative use and importance of mainstem areas could greatly increase.

Over the past several years, Department of Game has been intensively studying wild steelhead stocks. The focus of this effort is to collect information needed for more refined and effective management. Between 1977 and 1981 these studies included specific research on the Skagit River system. Important products of these studies have included identification of needed spawning escapement levels. Based on the work by Phillips et al. (1981), a minimum escapement objective of 8,000 steelhead was set for Skagit River system in the 1981-82 and subsequent seasons. Significant harvest management regulation changes were implemented to secure adequate escapement. And, in 1981-82, the largest measured escapement to date was achieved. While 8,000 remains the minimum escapement objective, an escapement management goal of 9,600 wild steelhead was set for the 1983-84 season (WDG 1983). Total run size, harvest and escapements for the period 1977-78 through 1982-83 are shown in Table 5.

Steelhead Fry Stranding

The number of steelhead fry stranded by gravel bar in 1983 is summarized in Table 6. Ten sites were observed for stranded fry and of these sites three (Rockport, Test Bar and Marblemount) were electrofished prior to observation. The catch of steelhead fry per distance sampled had a high variance from 0.06 to 0.87 steelhead per foot surveyed and chiefly confirmed the presence of fry prior to each survey.

The highest numbers of fry stranded occurred on August 17 during the intial survey with 25, 18 and 29 at Rockport, Eagle Bar and Marblemount, respectively. A total of 76 were stranded on this initial survey suggesting that the fry may be more susceptable to stranding earlier in the emergence period since the numbers stranded declined throughout the study period.

Pothole stranding was observed at Rockport, Tin Shack, Eagle Bar, Hoopers Slough and Marblemount. The largest number (100) stranded in pothole areas occurred at Rockport on August 24, 1983. The total number observed in potholes declined through September 9, 1983.

These data indicate that steelhead fry do become stranded and that the smallest fry may be stranded in larger numbers, however, due to the lack of consistency in the data by site and date it was difficult to draw more specific conclusions. It was unfortunate that length data were not available for August 1983. The 1982 observations indicated that fry became less susceptable to stranding once a length of about 40 mm was reached (Stober et al. 1982). The 1983 length data averaged 40.9 mm on September 15. Following this date very little stranding was observed in one test. Although the 1983 data are not conclusive sampling during 1981 and 1982 suggested that by early October fry appear to achieve sufficient growth to prefer habitat in areas of deeper water at greater distances from shore.

Table 1. 1983 Department of Game/Seattle City Light Aerial Steelhead Spawning Surveys.

Skagit River	3/22	4/6	4/22	5/6	5/19	6/7	6/27	Total
I-5 to Baker River	15	58	108	193	227	46	70	717
Baker R. to Sauk River	7	11	31	47	48	7	20	171
Sauk R. to Cascade River	9	19	58	139	188	103	77	593
Cascade R. to Newhalem	2	1	5	32	35	16	21	112
Total	33	89	202	411	498	172	188	1,593

Sauk River	3/22	4/6	4/22	5/6	5/12	5/19	6/7	6/27	Total
Mouth to Suiattle River	6	16	38	138	NC	117	*	*	315
Suiattle R. to Darrington	10	36	104	NC	289	269	*	*	708
Darrington to Whitechuck R.	3	22	76	NC	121	79	*	*	251
Whitechuck R. to Forks	NC	NC	NC	NC	NC	60	*	*	60
Total	19	74	168	138	410	525			1,334

* Too turbid to survey

Table 2. Summary of Department of Game Aerial Steelhead Spawning Surveys for Skagit River, 1975 through 1983.

1975	Sedro Woolley to Baker R.	Baker R. to Sauk R.	Sauk R. to Cascade R.	Cascade R. to Bacon Cr.	Bacon Cr. to Newhalem	Total
28 March	1	4	7	3	1	16
18 April	38	15	89	35	1	178
9 May	58	18	60	5	2	143
18 June	Too turbid to count below Sauk R.		4	7	0	11
	97	37	160	50	4	348
1976						
30 March	1	0	NC	NC	NC	1
29 April	22	9	12	2	0	45
18 May	8	3	7	11	0	29
3 June	5	4	12	11	6	38
	36	16	31	24	6	113
1977						
1 April	21	8	22	3	1	55
20 April	52	13	38	6	2	111
19 May	66	32	83	45	8	234
	139	53	143	54	11	400

Table 2 (continued)

	Sedro Woolley to Baker R.	Baker R. to Sauk R.	Sauk R. to Cascade R.	Cascade R. to Bacon Cr.	Bacon Cr. to Newhalem	Total
1978						
20 March	60	18	13	3[1/]	4[2/]	98
6 April	37	33	16	7[1/]	3[2/]	96
24 April	53	35	18	4	8	118
18 May	182	54	86	18	1	341
1 June	147	43	86	30	3	309
19 June	27	4	11	1[3/]	NC	43
	506	187	230	63	19	1005
1979						
22 March	21	25	28	2	12	88
19 April	68	34	38	9[1/]	11[2/]	160
	89	59	66	11	23	748
1980						
6 March	NC	0	1	0	0	1
21 March	10	17	3	0	0	30
5 April	9	15	5	0	0	29
21 April	NC	NC	3	2	1	6
7 May	10	6	26	7	2	51
9 June	18	9	17	16	7	67
	47	47	55	75	10	184

1/ Cascade to Alma Creek
2/ Alma Creek to Newhalem
3/ To 1 mile above Cascade R.

Table 2 (continued)

	Sedro Woolley to Baker R.	Baker R. to Sauk R.	Sauk R. to Cascade R.	Cascade R. to Bacon Cr.	Bacon Cr. to Newhalem	Total
1981						
3 March	0	2	2	0	0	4
17 March	4	11	8	1 1/	1 2/	25
2 April	7	15	22	2 1/	1 2/	47
13 April	15	20	23	2 1/	0 2/	60
12 May	68	43	158	23 1/	16 2/	308
22 May	86	37	196	60 1/	48 2/	427
4 June	Too turbid to count below Sauk R.		112	44 1/	23 2/	179
25 June	Too turbid to count below Sauk R.		77	15 1/	2 2/	94
	180	128	598	147	91	1144
1982						
26 February	0	0	10	0	NC	10
16 March	0	2	9	0	0	11
6 April	47	16	21	1 1/	0	85
26 April	80	42	71	3 1/	0	196
13 May	84	62	136	16 1/	1 2/	299
2 June	Too turbid to count below Sauk R.		98	13 1/	4 2/	115
	211	122	345	33	5	716
1983						
22 March	15	7	9	2	0	33
6 April	58	11	19	1	0	89
22 April	108	31	58	3 1/	2 2/	202
6 May	193	47	139	30 1/	2 2/	411
19 May	227	48	188	31 1/	4 2/	498
7 June	46	7	103	13 1/	3 2/	172
27 June	70	20	77	13 1/	8 2/	188
	717	171	593	93	19	1593

1/ Cascade to Alma Creek 2/ Alma Creek to Newhalem 3/ To 1 mile above Cascade R.

Table 3. Summary of Department of Game Aerial Steelhead Spawning Surveys for Sauk River, 1975 through 1983.

	Mouth to Suiattle R.	Suiattle R. to Darrington	Darrington to Whitechuck R.	Whitechuck R. to forks	Total
1975					
28 March	8	6	19	4	37
18 April	26	32	7	6	71
9 May	31	48	21	1	101
18 June	Too turbid to count		-	-	-
	65	86	47	11	209
1976					
29 April	19	33	9	4	65
18 May	17	33	5	NC	55
3 June	14	10	8	NC	32
	50	76	22	4	152
1977					
1 April	5	2	NC	NC	7
20 April	15	23	NC	NC	38
19 May	70	115	NC	NC	185
	90	140	-	-	230
1978					
20 March	10	13	NC	NC	23
6 April	6	22	NC	NC	28
24 April	11	50	NC	NC	61
18 May	74	70	NC	NC	144
1 June	38	61	NC	NC	99
	139	216	-	-	355
1979					
22 March	7 2/	3 3/	0 1/	NC	10
19 April	16 2/	36 3/	3 1/	NC	55
	23	39	3	-	65
1980					
6 March	0	0	NC	NC	0
21 March	3	3	NC	NC	6
5 April	15	5	NC	NC	20
21 April	Too turbid to count				-
7 May	Too turbid to count				-
9 June	4	19	0 1/	NC	23
	22	27	0	-	49

1/ Darrington to Clear Creek

2/ Mouth to Government Bridge

3/ Government Bridge to Darrington

4/ Whitechuck R. to Elliott Creek

Table 3 (continued)

	Mouth to Suiattle R.	Suiattle R. to Darrington	Darrington to Whitechuck R.	Whitechuck R. to forks	Total
1981					
3 March	0	0	NC	NC	0
17 March	1 2/	3 3/	1 1/	NC	5
2 April	8	0	1 1/	NC	9
13 April	5	1	0 1/	NC	6
12 May	Too turbid to count				
22 May	28	40	5 1/	NC	73
4 June	Too turbid to count below Whitechuck R.			5 4/	5
	42	44	7	5	98
1982					
26 February	0	0	NC	NC	0
16 March	0	0	0 1/	NC	0
6 April	8	12	2 1/	NC	22
26 April	20	61	19	15 4/	115
13 May	71	88	37	13	209
	99	161	58	28	346
1983					
22 March	6	10	3	NC	19
6 April	16	36	22	NC	74
22 April	38	104	26	NC	168
6 May	138	NC	NC	NC	138
12 May	NC	289	121	NC	410
19 May	117	269	79	60	525
	315	708	251	60	1334

1/ Darrington to Clear Creek

2/ Mouth to Government Bridge

3/ Government Bridge to Darrington

4/ Whitechuck R. to Elliott Creek

Table 4. Estimated escapement of winter-run steelhead to Skagit River System by subbasin, 1977-78 through 1982-83 run cycles.

	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83
Mainstems						
Skagit	736	474	648	1259	1530	1172
Sauk	264	167	228	294	1114	1203
Suiattle	266	170	233	196	550	688
Cascade	159	102	139	148	168	412
Total	1425	913	1248	1897	3362	3475
Tributaries						
Skagit	5358	2595	3954	2824	5631	2237
Sauk	302	214	441	378	435	245
Suiattle	207	161	265	220	308	98
Cascade	2	60	110	116	48	81
Total	5869	3030	4716	3538	6422	2661
Grand Total	7294	3943	6009	5435	9784 1/	6136 2/

1/ Includes only part of estimated hatchery origin steelhead spawning escapement (see Table 5).

2/ Does not include estimated hatchery origin steelhead spawning escapement; surveys started after March 15.

Table 5. Skagit System Winter Steelhead Total Run Size Data 1977-78 through 1982-83 (WDG 1983).

Season	Sports Catch[a/]			Commercial Catch[b/]			Escapement[c/]			Run Size		
	H	W	T	H	W	T	H	W	T	H	W	T
77-78	3,057	347	3,404	3,533	719	4,252	1,537	5,757	7,294	8,127	6,823	14,950
78-79	4,626	252	4,878	3,874	1,013	4,887	961	2,982	3,943	9,460	4,247	13,707
79-80	2,666	812	3,478	3,990	209	4,199	721	5,288	6,009	7,377	6,309	13,686
80-81	1,219	1,117	2,336	2,390	597	2,987	1,127	4,308	5,435	4,736	6,022	10,758
81-82	1,571	1,083	2,658	2,346	351	2,697	724	9,609	10,333	4,641	11,043	15,135
82-83	627	671	1,298	1,299	682	1,981	355	6,136	6,491	2,281	7,489	9,415

a/ Hatchery and wild from sport creel census scale analysis.

b/ Hatchery and wild from commercial scale analysis when available, sport scale analysis when not.

c/ 1981-82 and 1982-83 escapements estimated using the average exploitation from 1977-78 through 1980-81 for hatchery fish.

Table 6. Summary of the number of steelhead fry stranded per gravel bar, abundance determined by electrofishing, average length, ramp rate and timing for 1983.

					Number Stranded/Gravel Bar Location										
Date	Ramp rate cfs/hr	Ramp end time	Electro-fishing (catch/feet)	Average length (in mm)	Rock-port	Tin Shack	Eagle Bar	Sutter Creek	Test Bar	Hoopers Slough	Big Eddy	Marble-mount	Bacon Creek	County line	Total
8/16/83	820	24:00	99/114=.87									x			
8/16/83	820	24:00	138/540=.26		x										
8/17/83	803	24:00	85/114=.75									x			
8/17/83	803	24:00	49/540=.09		x										
8/17/83	803	23:30			25	-	18	-		-	4	29	-	-	76
8/18/83	591	02:00			6	-	1	-		-	5	5	-	-	17
8/24/83	495	02:00	20/100=.20						x						
8/24/83	495	02:00			0(100-L)*	8	8(5-L)	0		3	0	4(6-L)	0	0	23(111)
8/25/83	949	23:00			5	8(5-L)	1	5		1(10-L)	1	7(3-L)	1	1	30(18)
8/31/83	880	02:00			6(1-L)	8(2-L)	1	-		-	-	3(11-L)	-	-	18(14)
9/1/83	791	23:00			0	2	8	-		-	-	1	-	-	11
9/8/83	511	23:00			0	0	0	-		-	-	2(2-D)	-	-	2(2)
9/9/83	736	02:00			2	0	6	-		-	-	1(1-D)	-	-	9(1)
9/15/83	892	01:00	96/114=.84	40.9								x			
9/15/83	892	01:00	22/100=.22	50.0					x						
9/15/83	892	01:00	33/540=.06	43.8	x										
10/1/83	739	23:30	37/114=.32	46.2								x			
10/1/83	739	23:30	51/100=.51	55.3					x						
10/1/83	739	23:30	98/110=.89	49.5	x										
10/5/83	927	23:00			0	2	0	-		-	-	3	-	-	5

* Numbers in parentheses indicate additional fish stranded in pothole areas (L = live, D = dead).
x = Site where electrofishing was conducted.

REFERENCES

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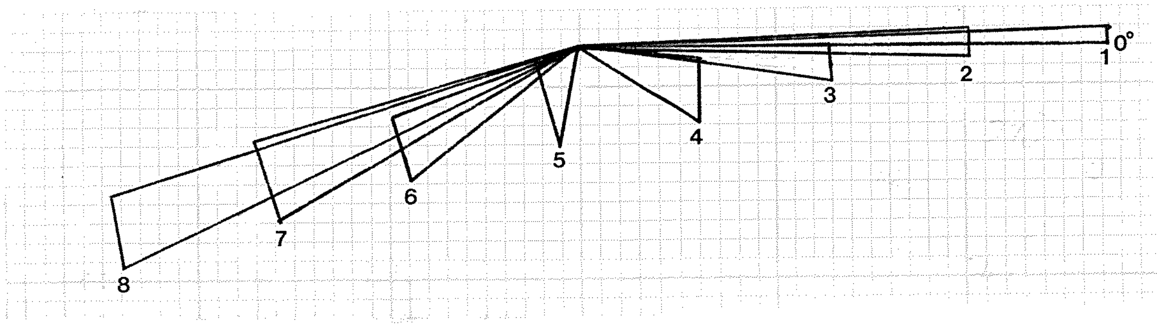
APPENDIX A

Survey Reach Bar Slopes

Representative transect points were identified in the field, relative elevations determined and located according to their distance and angle from a central point (Tables 1 and 2). The initial location line was assigned the 0^{o} designation with all other lines assigned a value based on the 360^{o} circle read in a clockwise fashion. This procedure was used for the two endpoints of each transect as well as an additional one to four points along each transect. The slope was calculated by graphically plotting each point, determining the distance between the points and dividing into the change in elevation between those points. Therefore, the slopes are not exact but do provide an idea of the average slope and the differences in slope within a single transect. Greater accuracy would occur with exact distance mesurements between points taken in the field but that information was not available.

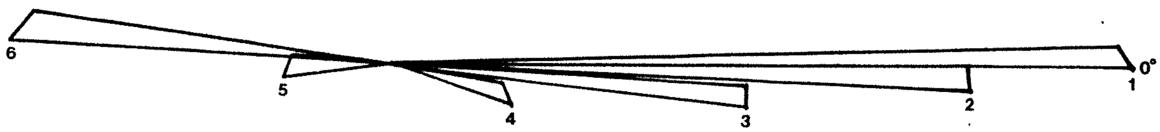
Contour lines were to be determined and graphically illustrated for these sites based on the field data collected and listed in Tables 3, 4 and 5 and the stage and duration information illustrated in Figure 1. However, not enough information is available to do so. A similar analysis as was done for Hoopers Slough and Eagle Bar is possible but the degree of accuracy was suspect and the benefits questionable.



Transect	Elev.	Distance (ft. x 10)	Angle	Slope
1	-1.972	270.7	0	
	-1.224	271.0	358.18	.0086
	- .440	271.3	356.52	.0090
	.131	271.4	355.07	.0036
	Substrate 6-9" on sand			
2	-2.087	201.0	1.09	
	-1.106	200.3	358.39	.0113
	- .722	199.7	356.36	.0044
	.190	200.6	354.32	.0061
	Substrate 6-9" on sand			
3	-2.221	129.9	8.39	
	-1.985	128.0	5.09	.0037
	-1.342	128.0	1.11	.0102
	-0.741	128.7	357.56	.0095
	Substrate 3-6" on sand			
4	-2.533	72.8	34.07	
	-2.051	66.8	29.03	.0060
	-1.467	63.1	22.39	.0073
	-1.047	61.2	15.59	.0053
	- .938	60.1	8.29	.0014
	Substrate 2-4" loose			
5	-2.592	52.1	101.45	
	-2.129	44.5	106.06	.0055
	-1.637	37.7	112.28	.0059
	-1.171	32.1	121.30	.0056
	- .753	27.1	134.35	.0050
	- .253	23.9	153.33	.0060
	Substrate 2-4" loose			
6	-3.018	111.4	142.1	
	-2.549	108.13	145.55	.0055
	-1.995	105.48	150.42	.0065
	-1.378	103.960	155.39	.0073
	-1.040	103.569	160.41	.0040
	Substrate 2-4" loose			
7	-3.278	180.8	150.38	
	-2.398	179.4	153.38	.0102
	-1.998	179.2	156.04	.0047
	-1.752	177.6	158.51	.0029
	-1.236	177.5	161.26	.0060
	- .853	178.1	164.04	.0045
	Substrate 4-6"			
8	-3.655	261.44	154.33	
	-2.631	260.059	156.15	.0108
	-2.047	258.753	158.03	.0062
	-1.644	257.969	160.09	.0042
	-1.486	257.073	162.07	.0017
	Substrate 4-6"			

Table 1. Bar-slope calculations for Hoopers Slough on 3/26/83. The angles are expressed as degrees. Minutes.

Table 2. Bar-slope calculations for Eagle Bar on 3/26/83. The angles are expressed as degrees. Minutes.



Transect	Elev.	Distance (ft. x 10)	Angle	Slope
1	-1.191	749.585	0	.0205
	- .607	740.865	358.27	.0412
	.568	737.6	356.44	
	Substrate 2-4"			
2	-1.276	575.3	5.12	.0318
	- .322	575.5	2.11	.0300
	.577	570.9	359.38	
	Substrate 2-4"			
3	-1.378	367.1	13.24	.0320
	- .443	362.5	9.27	.0152
	0	360.1	6.48	
	Substrate 2-4"			
4	-1.480	129.6	38.14	.0302
	- .587	120.2	27.41	.0181
	- .069	117.7	19.13	
	Substrate 2-3" imbedded			
5	-1.493	111.3	166.39	.0212
	- .873	100.6	179.08	.0378
	.236	96.7	192.44	
6	-2.005	384.2	187.22	.0247
	-1.227	377.9	191.34	.0145
	- .771	368.4	197.13	
	Substrate 3-6"			

Table 3. Bar-slope measurements for Marblemount (Site No. 2) site on 4/21/82. (WE = wetted edge)

Transect	Elev.	Distance		Angle	
1	5.49	402 -	692 =	0	
	5.50	405	695	1.55	
	5.91	446	734	4.12	
	6.32	487	775	6.08	WE
	6.68	525	813	8.25	
2	5.88	487	692	.47	
	6.14	512	717	4.03	
	5.70	468	674	7.15	
	6.27	528	730	10.10	
	6.40	537	743	11.22	WE
	6.68	565	772	13.39	
3	5.62	482	642	.04	
	6.62	581	742	4.56	
	6.05	523	685	8.28	
	6.45	563	725	12.34	
	6.71	589	752	16.40	
4	5.86	534	640	355.10	
	5.59	516	622	1.11	
	6.49	596	702	4.58	WE
	7.39	684	794	11.12	
	6.57	600	714	16.21	
	6.64	606	721	20.43	
	6.92	632	752	26.20	
5	5.95	570	619	353.09	
	6.32	607	656	9.04	
	7.46	720	771	19.35	
	6.64	634	694	37.04	WE
	7.02	670	732	45.40	
	7.20	687	755	53.00	
6	5.92	569	615	192.10	
	6.76	654	700	173.02	WE
	7.03	679	728	160.40	
	7.38	712	765	147.22	
7	6.06	553	660	189.20	
	6.83	629	736	180.40	WE
	7.02	648	756	174.08	
	7.28	678	782	167.30	
8	6.32	546	718	187.05	
	7.00	612	785	181.15	WE
	7.20	635	808	176.28	
	7.37	650	826	172.25	
9	7.00	564	834	184.24	
	7.38	600	870	181.03	WE
	7.55	620	890	177.10	
	7.78	642	910	175.12	

Table 4. Bar-slope measurements for County Line site on 4/21/82. (WE = wetted edge)

Transect	Elev.	Distance		Angle	
1	5.78	527	627	0	
	5.89	539	640	5.33	
	6.67	614	716	11.06	
	7.22	670	774	12.09	WE
	7.76	724	731	22.58	
	8.70	812	925	29.16	
2	5.42	518	568	.28	
	5.81	556	607	13.04	
	6.18	591	643	24.00	
	7.16	688	746	36.40	WE
	7.86	754	819	46.00	
	8.76	840	915	52.06	
3	5.50	0	0	0	
	5.74			91.02	
	6.27	615	639	92.44	
	6.64	645	680	91.25	
	7.21	699	743	89.43	WE
	8.53	825	883	89.45	
	9.13	882	944	89.46	
4	5.46	520	570	177.27	
	5.63	539	589	164.51	
	6.15	588	644	152.04	
	7.20	589	753	140.10	WE
	8.21	784	859	139.00	
	8.95	853	935	129.54	
5	5.39	489	589	177.18	
	5.63	512	613	170.12	
	6.43	590	693	164.10	
	7.20	668	775	158.14	WE
	8.16	760	873	153.03	
	8.93	832	952	148.20	

Table 5. Bar-slope measurements for Rockport site on 4/21/82. Angles expressed as Degrees. Minutes.

Transect	Elev.	Distance	Angle
1	6.15	280	0
	6.34	285	1.24
	6.58	282	3.00
	6.84	282	4.02
2	6.10	190	4.40
	6.33	193	6.12
	6.85	199	9.50
3	6.18	154	10.24
	6.40	157	12.11
	6.65	158	14.13
	6.90	160	16.37
4	6.18	76	29.00
	6.43	80	31.41
	6.66	84	34.46
	6.93	86	37.29
5	6.32	73	139.10
	6.49	77	135.47
	6.83	80	132.10
	7.02	86	128.27
6	6.36	140	156.48
	6.58	142	154.29
	6.85	145	152.20
	7.00	148	149.00
7	6.38	192	162.12
	6.62	196	160.10
	6.88	193	158.50
	7.12	198	156.04
8	6.44	240	164.02
	6.65	240	162.25
	6.90	243	160.20
	7.08	239	158.35
9	6.44	304	165.03
	6.77	305	162.24
	7.08	305	161.06
	7.23	305	160.28

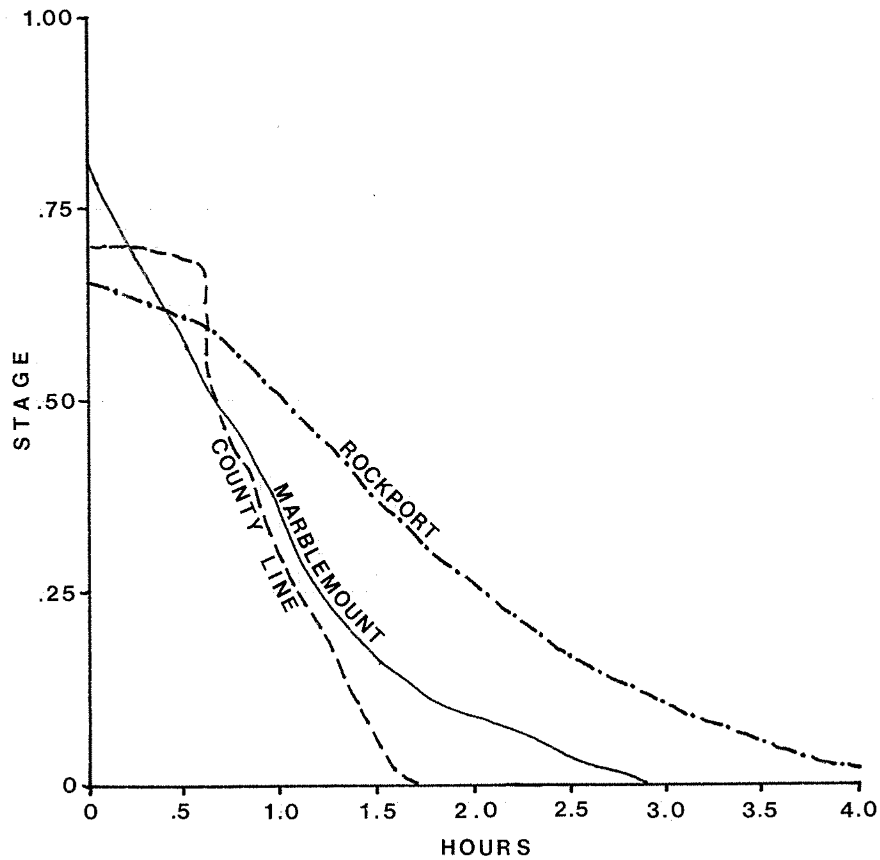


Figure 1. Stage and duration for County Line, Marblemount, and Rockport site bar-slope measurements.