USING TIME SERIES STREAMFLOW DATA TO DETERMINE PROJECT EFFECTS ON PHYSICAL HABITAT FOR SPAWNING AND INCUBATING PINK SALMON[1]

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Abstract.--The incremental method of instream flow assessment was applied to identify effects of a proposed hydroelectric project on pink salmon in the Terror River, Kodiak, Alaska. Time series streamflow data are used to compare spawning and incubation conditions for 27 years of simulated pre- and postproject streamflows. This paper demonstrates that an evaluation of project effects based only on a comparison of long-term average monthly streamflows overlooks the dynamic nature of riverine habitat and is likely to have lead the analysts to erroneous conclusions regarding effects of the proposed project streamflows on spawning and incubating pink salmon.

INTRODUCTION

Traditionally, instream flow assessments have arrived at a single valued streamflow requirement to protect the fishery resource -- "a minimum flow." Such an instream flow recommendation, often determined solely from cursory review of streamflow records, overlooks the seasonal and annual variability of instream habitat conditions and provides limited opportunity for negotiation. Furthermore, such an approach promotes the mistaken assumption that only streamflows below this "minimum" are detrimental to instream use and/or resources.

As a result of the inflexibility and fallacies associated with such traditional approaches, a new methodology is emerging, capable of displaying the dynamic response of instream habitat conditions to seasonal and annual changes in streamflow, yet also compatible with the decision-making processes of water planners and managers. This methodology utilizes time series streamflow data in association with physical habitat simulation modeling. The U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group (IFG), Fort Collins, Colorado was instrumental in pioneering and promoting the Incremental Methodology (Bovee and Milhous 1978, Stalnaker 1978, Trihey 1979).

The incremental methodology is based on the theory that the availability and relative value of riverine habitat conditions can be estimated by evaluating the behavioral response of a species/life stage to such streamflow-dependent variables as depth, velocity, water temperature, and channel structure. Thus, this methodology is intended for use in situations where the streamflow regime and channel structure are the principal factors controlling the fishery resource and where field conditions are compatible with the underpinning theories and assumptions of the methodology. This methodology is particularly well suited for displaying effects of proposed water developments or streamflow alterations on riverine fish habitat.

The primary purpose for using hydraulic simulation modeling is to make the most efficient use of limited field data to describe the occurrence of depths and velocities with respect to stream temperature and substrate conditions over a broad range of unobserved streamflows. The availability and quality of fish habitat are reflected as changes in a habitat index value called weighted usable area (WUA). Calculation of WUA does not totally describe the actual quantity or quality of available fish habitat. It does, however, provide a structured analytical approach for using streamflow-dependent variables to

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describe selected physical aspects of fish habitat in riverine environments. Thus, a change in the WUA index can generally be accepted as a good indicator of the effect a change in streamflow would have on the availability of riverine habitat for the species/life stage being evaluated.

This modeling process, utilizing the incremental method, was applied by the Arctic Environmental Information and Data Center (AEIDC) to quantify effects of the proposed Terror Lake Hydroelectric Project on existing fishery resources in the Terror and Kizhuyak Rivers, Kodiak Island, Alaska (Wilson, et al. 1981). For the purposes of this paper, the discussion will be limited to the "Terror Gage" study reach.

This 560-ft study reach was established to characterize project effects on pink salmon spawning habitat in the lower Terror River. Transects 1 through 3 crossed a relatively deep, high-velocity run, and transects 4 through 7 were placed across an upstream pool area. Depth, velocity, and substrate measurements were made approximately every 2 feet along each transect at three streamflow levels (94, 251, and 425 cfs). Both right- and left-bank water surface elevations were surveyed at each transect for each of the three streamflows. Water surface elevation and depth-velocity data were used to calibrate hydraulic models, which were then used to predict depth and velocity values for discharges between 50 and 120 cfs.

A comparison between total surface area and weighted usable area for pink salmon spawning habitat was developed for a range of streamflows from 50 to 1200 cfs (Figure 1). This plot

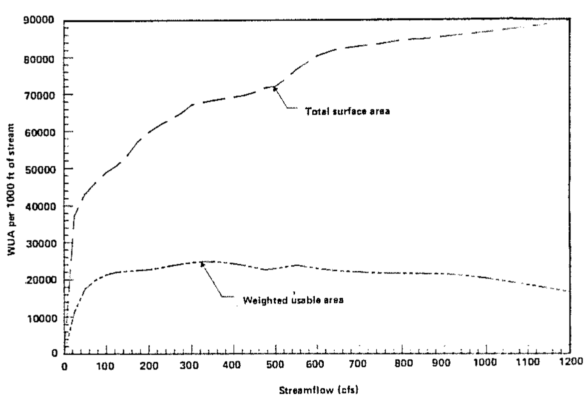

Figure 1.--Total surface area and weighted usable area as a function of streamflow at the Terror Gage study site.

illustrates the reach specific response of total surface area and WUA to incremental changes in streamflow. These curves were used throughout the remainder of the analysis as the primary description of the availability of pink salmon spawning habitat in the lower Terror River as a function of streamflow.

A comparison was made between WUA indices for simulated long-term average monthly pre- and postproject streamflows for the pink salmon spawning period (Table 1). From late July through early September, streamflows would be decreased by approximately 30%. WUA for spawning pink salmon would increase approximately 7% in July while decreasing 3 to 4% during August and September. Overall this represents less than a 5% net change in WUA for the pink salmon spawning period.

Table 1.--Comparison of long-term average monthly pre- and postproject streamflows and corresponding WUA indices throughout the pink salmon spawning period.

Month	Preproject		Postproject	
	cfs	WUA	cfs	WUA
July	579	23,280	346	24,800
August	374	24,610	261	23,850
September	375	24,610	245	23,530
Average	--	24,610	--	24,060

The project sponsor proposed to stabilize Terror River winter flows near 60 cfs. Thus, the simulated long-term average monthly December streamflow would decrease from 80 to 66 cfs, while March flows would increase from 50 to 62 cfs. Changes of this magnitude imply that the proposed postproject streamflows would have a negligible effect on altering preproject levels of redd dewatering and the associated overwinter survival of incubating eggs and alevins.

Solely by comparing simulated long-term average monthly streamflows and corresponding WUA indices, one would conclude that project effects on the availability of spawning habitat for adult pink salmon and the dewatering of incubating eggs and alevins are inconsequential. However, extremes in seasonal and annual streamflow conditions resulting from regional weather patterns cause notable fluctuations in Terror River fish stocks. Fall storms cause high streamflows, which scour eggs and alevins from streambed gravels. Low streamflows during August and September concentrate spawners into confined areas and cause redd superimposition. Low streamflows during winter months often dewater redds and contribute to the freezing of exposed streambed gravels and the developing embryos buried therein.

Therefore, a more rigorous examination would be required of project effects on the annual and seasonal variability of streamflow and the associated WUA indices before project effects on spawning pink salmon could be objectively discussed with any degree of confidence.

STREAMFLOW ANALYSIS

A flow frequency analysis was undertaken to determine the validity of using average monthly streamflow values as a basis for evaluating project effects on fish habitat. These analyses were based on 6 years of average daily streamflow record at the Terror Lake outlet gage (USGS No. 15295600) and 4 years of average daily data at the Terror River gage (USGS No. 15295700).

The 1-, 7- and 30-day high and low flows were determined for each year of record. The ratios of the 1-day to 30-day and 7-day to 30-day flows were also determined to provide an indication of how well monthly streamflow values might represent extremes in seasonal and annual habitat conditions. It was determined that the 30-day low flow closely approximates the average daily low flow (Table 2) while the high-flow statistics indicate that peak daily flows are often two to three times greater than the 30-day high flow (Table 3).

Low-flow statistics (Table 2) indicate that the 1-, 7-, and 30-day low flows are relatively constant. Thus, a reasonably accurate evaluation of project effects on overwintering habitat would result from a comparison of 30-day (monthly) streamflow values. A comparison of 7-day pre- and postproject streamflow values would provide a better portrayal of project effects on the natural stress to which incubating eggs and alevins are being subjected. However, in the case of the Terror River project, insufficient data were available on 7-day pre- or postproject streamflows to justify using anything shorter than a 30-day time step in the analysis, particularly when it was evident that 7-day low flows of record did not differ appreciably from the monthly values.

Midwinter streamflow records were also reviewed to determine months that are most critical to incubation success. Low streamflows occur between January and March but are most prevalent during late February and early March. During this 4- to 5-week period, the mean monthly streamflow was found to be a reasonable indicator of natur-

Table 2.--Low-flow statistics for the Terror River drainage.

TERROR LAKE OUTLET
USGS Gage 15295600

Water Year	Annual low flow in cfs 1-DAY	7-DAY	30-DAY	Min. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1963	18.	19.3	23.4	23.4	.77	.82
1964	11.	11.7	12.4	12.5	.89	.94
1965	10.	10.1	11.1	11.3	.90	.91
1966	8.	8.	9.1	9.2	.88	.88
1967	9.	9.	11.5	11.7	.78	.78
1968	14.	14.6	19.5	26.2	.72	.75
MEAN	11.7	12.1	14.5	15.7	.81	.83

TERROR RIVER GAGE
USGS Gage 15295700

Water Year	Annual low flow in cfs 1-DAY	7-DAY	30-DAY	Min. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1965	28.0	29.1	32.5	33.6	.86	.90
1966	23.0	23.0	26.9	27.4	.86	.86
1967	19.0	20.4	26.6	27.1	.71	.77
1968	38.0	40.3	54.8	75.7	.69	.74
MEAN	25.2	28.2	35.2	41.0	.72	.80

Table 3.--High-flow statistics for the Terror River drainage.

TERROR LAKE OUTLET
USGS Gage 15295600

Water Year	Annual high flow in cfs 1-DAY	7-DAY	30-DAY	Max. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1963	3250	1168	452	270	7.2	2.6
1964	904	554	454	449	2.0	1.2
1965	1490	681	389	362	3.8	1.8
1966	1800	693	564	533	3.2	1.2
1967	1130	587	378	349	3.0	1.6
1968	1560	666	418	371	3.7	1.6
MEAN	1689	725	442	389	3.8	1.6

TERROR RIVER GAGE
USGS Gage 15295700

Water Year	Annual high flow in cfs 1-DAY	7-DAY	30-DAY	Max. Month for Year	Ratio 1-DAY/30-DAY	7-DAY/30-DAY
1965	1490	806	692	625	2.2	1.2
1966	2600	1416	1090	1066	2.4	1.3
1967	1780	1232	708	708	2.5	1.7
1968	2000	968	797	660	2.5	1.2
MEAN	1968	1105	822	765	2.4	1.3

ally occurring low-flow conditions in two of three winters for which continuous streamflow data were available. However, simulated preproject monthly midwinter flows were found to differ markedly from observed monthly streamflows. It was also determined that naturally occurring monthly low flows throughout the 3-year period of record were considerably less than the simulated long-term average monthly streamflows. Therefore, it is reasonable to assume that incubating eggs and alevins are subjected to a greater amount of dewatering and subsequent desiccation and freezing than the simulated long-term average monthly preproject streamflows indicate.

High-flow statistics (Table 3) indicate peak daily streamflows for the year often exceed the 30-day high flow by a factor of 2.5. Thus evaluation of project effects on pink salmon spawning habitat based only on monthly streamflows would cause the potentially detrimental effects of these naturally occurring peak streamflows on spawning success to be overlooked.

Further review of the U.S. Geological Survey (USGS) streamflow records for the Terror River gage indicates that maximum mean monthly streamflows are normally associated with the June-July snowmelt period, while maximum daily streamflows occur between late August and early October as the result of intense rainstorms. Considerable variation was observed among the monthly streamflow values of record. It was also determined that peak daily flows range from 4.75 to 9.45 times greater than the long-term average monthly streamflow for the months in which they occur. Hence pink salmon that spawn in the Terror River are subjected to a wide range of naturally occurring streamflow conditions which, at times, can be detrimental.

SPAWNING

Monthly Streamflows

To visualize the effects that the proposed project flows might have on the natural variability of habitat conditions on the lower Terror River during the pink salmon spawning period, WUA indices were determined utilizing time series streamflow data. The 27 years of simulated monthly pre- and postproject streamflows used by the engineering firm to determine reservoir operational characteristics formed the basis for this analysis. WUA indices were determined for corresponding monthly streamflow values during the pink salmon spawning period for the 27 years of simulated streamflows (Figures 2a and b).

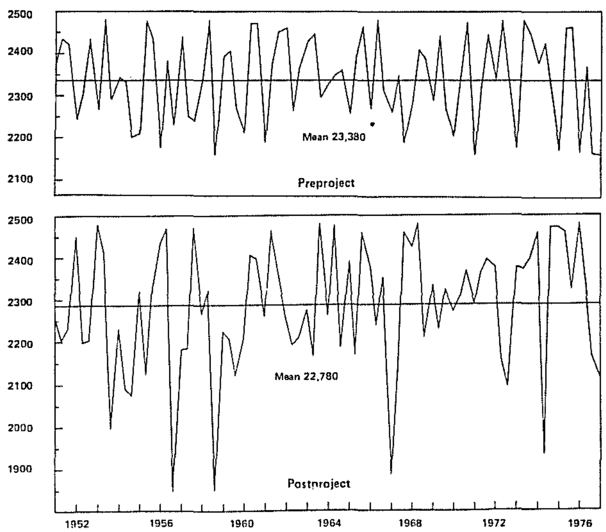

Figure 2.--Composition of time series WUA indices for spawning pink salmon in the lower Terror River for average monthly pre- and post-project streamflows during the spawning season.

The long-term pre- and postproject average WUA indices for the 27 years of simulated values are 23,380 and 22,780, respectively. A comparison between these two averages indicates a net reduction in WUA of 2.6 percent, a relatively insignificant project impact. However, it is quite apparent from a comparison of the time series analyses that the proposed postproject streamflows would notably reduce the WUA index in 8 of the 27 years. This is attributable to the proposed withdrawal of water from the Terror River for power production during naturally occurring low-flow periods without regard for spawning requirements. Such a practice, if allowed, would amplify an already stressed situation and probably cause losses beyond those that would have occurred under natural conditions.

Daily Streamflows

Figures 3a and 3b illustrate the relationship between average daily streamflows and their respective WUA indices for spawning pink salmon. August 1968 was chosen for this analysis because the range of daily streamflows that occurred during that month encompass a broad spectrum of flow conditions that spawning pink salmon are likely to encounter. The average monthly streamflow of 407 cfs is within 10% of the simulated long-term average monthly flow of 374 cfs. Daily flows vary between 129 and 2,000 cfs.

Peak flow events, which occurred on August 10 and 13, were associated with intense rainstorms which frequent Kodiak Island during late summer and fall. The 1,060 cfs streamflow which occurred on August 13 reduced the WUA index for that day, but only about one-eighth as much as the 2,000 cfs event that occurred 3 days earlier. WUA values peaked out between August 19 and 21, when streamflows were in the range of 300 cfs.

Construction of the proposed Terror Lake reservoir is expected to reduce peak daily streamflows at the mouth of the Terror River during August by approximately one-third. Thus, for purposes of illustrating the general effect of the project on the availability of spawning habitat on a daily basis, it was assumed that daily streamflows for August 1968 would have been reduced by 30 percent and the corresponding daily WUA indices plotted (Figure 3c). WUA indices during the

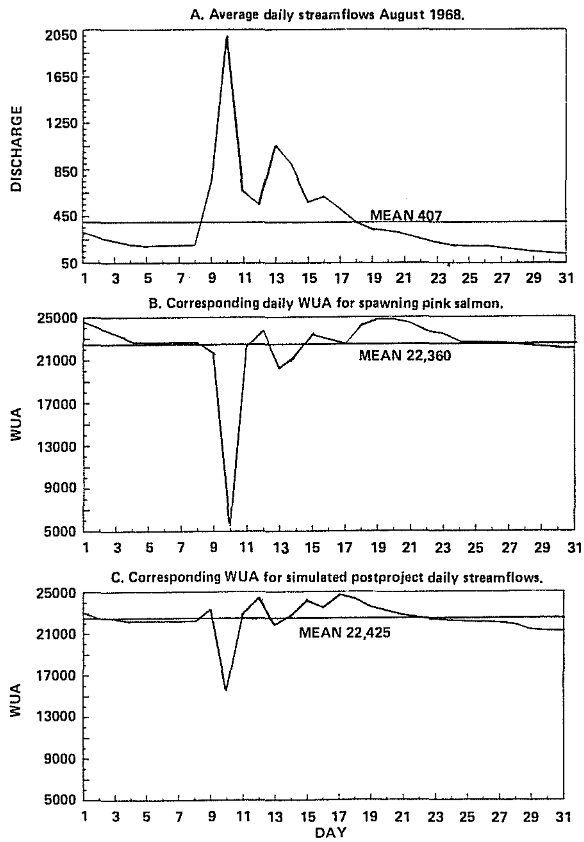

Figure 3.--Average daily streamflows and corresponding pre- and postproject WUA indices for spawning pink salmon in the lower Terror River.

latter part of the month are depressed as a result of the proposed streamflow withdrawals during the low-flow period. The severity of adverse effects from the peak daily flows are greatly diminished. Such a change in daily WUA indices must be interpreted within the proper context. A marked 1- or 2-day change in the WUA index such as discussed here is far more important in alerting the analyst to the biological (reduction of scour), rather than the arithmetic significance of the change in the monthly WUA index.

INCUBATION

In the Terror River, fertilized pink salmon eggs incubate among streambed gravels from their time of deposition through early April. High streamflows during the August-October period are a recurrent cause of streambed scour and associated mortalities. Another major cause of incubation mortality, redd dewatering, persistently occurs during the January-March period. Therefore, to adequately evaluate the effects of postproject streamflows on the existing pink salmon resource of the lower Terror River, a comparison must also be made between the "survivability" of eggs under pre- and postproject streamflow conditions.[3]

Streambed Scour

The following discussion is not intended to serve as an analysis of stream channel stability, but simply to provide a general understanding of the probable effects that postproject streamflows are likely to have on the potential for scouring spawning areas in the lower mainstem of the Terror River.

Streambed scour is principally a function of channel gradient, discharge, and substrate particle size. Particle size is also an important influence on the suitability of streambed materials for spawning. Hence, to evaluate the potential for spawning areas to be scoured, it is necessary to know both the predominant sizes of particles used by spawners and at what discharge rate specific particle sizes are likely to begin moving.

Particles used by spawning pink salmon in the lower Terror River range from medium gravels to cobbles (1 to 8 in). But the predominant particles found in most spawning areas are coarse gravels and small cobbles (2 to 4 in). Threshold velocities required to move the various sized substrate particles found in the lower Terror River were determined through hydraulic analyses. Mean column velocities in the range of 7 to 8 feet per second were required before spawning areas in the lower Terror River were likely to be scoured (Simons et al. 1980).

Simulated mean column velocities at selected transects within the Terror Gage study reach were obtained for a range of streamflows between 400 and 1200 cfs directly from the hydraulic model (Tables 4 and 5). Comparisons between these simulated mean column velocities and the threshold velocity required to move the predominant substrate material at the Terror Gage study reach

Table 4.--Simulated mean column velocities for selected streamflows at designated points along transect 2 (within a riffle/run) at the Terror Gage study reach.

Horiz.	Velocity (fps)			
Dist.	Q=400cfs	Q=600cfs	Q=800cfs	Q=1200cfs
3.5	*	0.00	0.00	0.00
5.0	0.00	.23	.38	.57
6.0	.16	.19	.21	.24
7.4	.34	.48	.60	.83
7.5	.34	.48	.60	.83
8.0	.50	.65	.77	.99
10.0	1.82	2.87	3.96	6.21
12.0	2.46	3.51	4.51	6.40
14.0	3.71	5.10	6.39	8.74**
16.0	3.84	4.99	6.01	7.78**
18.0	4.17	5.25	6.18	7.74**
20.0	4.51	5.52	6.35	7.71**
22.0	4.99	6.27	7.37**	9.23**
24.0	4.85	5.88	6.72	8.11**
26.0	4.78	6.09	7.22**	9.15**
28.0	4.64	5.92	7.03**	8.94**
30.0	4.40	5.65	6.73	8.60**
32.0	3.45	4.15	4.72	5.63
34.0	3.34	4.14	4.80	5.91
36.0	3.16	3.94	4.60	5.70
38.0	3.18	4.19	5.09	6.67
40.0	3.16	4.20	5.12	6.77
42.0	2.87	3.35	3.74	4.34
44.0	2.35	2.73	3.03	3.51
47.0	2.14	2.60	2.58	3.60
50.0	1.68	2.59	3.52	5.41
52.0	1.48	2.10	2.53	3.16
55.4	.99	1.56	1.96	2.51
58.0	0.00	.34	.57	.86
69.0	0.00	0.00	0.00	0.00
90.0	0.00	0.00	0.00	0.00
97.0	0.00	0.00	0.00	0.00
107.5	.19	.33	.42	.54
113.5	.11	.27	.37	.50
119.8	0.00	.14	.23	.34
120.0	*	0.00	0.00	0.00

* No Flow
** Scour Likely

[3]Thermal effects associated with the altered flow regime are also recognized as an essential component of incubation and were evaluated in the Terror Lake study. However, presentation of that assessment is outside of the scope of this paper.

Table 5.--Simulated mean column velocities for selected streamflows at designated points along transect 5 (within a pool) at the Terror Gage study reach.

Horiz. Dist.	Velocity (fps) Q=400cfs	Q=600cfs	Q=800cfs	Q=1200cfs
8.0	0.00	0.00	0.00	0.00
10.5	.43	.68	.85	1.11
12.0	1.06	1.29	1.48	1.76
12.5	1.55	1.81	2.04	2.41
15.0	2.18	2.38	2.54	2.79
18.0	2.43	2.66	2.84	3.13
21.0	2.46	2.65	2.80	3.04
24.0	2.53	2.69	2.82	3.03
28.0	2.41	2.55	2.66	2.84
31.0	2.94	3.29	3.56	4.01
34.0	2.96	3.31	3.58	4.03
37.0	2.77	2.92	3.04	3.23
40.0	3.16	3.59	3.94	4.52
43.0	3.06	3.36	3.60	3.98
46.0	2.88	3.06	3.21	3.45
50.0	3.23	3.71	4.10	4.74
53.0	2.94	3.43	3.84	4.53
56.0	2.89	3.52	4.07	5.02
59.0	2.83	3.25	3.59	4.15
62.0	2.49	3.29	4.02	5.36
65.0	2.47	3.36	4.19	5.76
67.0	1.99	2.81	3.61	5.16
70.0	1.75	1.93	2.07	2.29
73.0	1.83	2.08	2.29	2.63
76.0	1.62	1.98	2.28	2.81
78.0	1.45	1.72	1.96	2.34
82.0	1.63	2.19	2.60	3.21
85.0	1.50	2.01	2.39	2.96
88.0	1.27	1.75	2.11	2.63
91.0	1.37	1.84	2.18	2.70
94.0	1.17	1.67	2.03	2.57
97.0	.95	1.50	1.88	2.43
100.0	.83	1.41	1.80	2.36
103.0	.71	1.32	1.72	2.30
107.5	.59	1.10	1.43	1.91
108.0	0.00	.37	.78	1.27
112.0	*	0.00	0.00	.16
115.5	*	*	*	0.00

* No Flow

indicate that streambed scour is unlikely to occur in pool areas, but local scour probably would occur in runs and riffles when streamflows approach 1,000 cfs. Scour probably would occur in spawning areas throughout the lower mainstem whenever streamflows exceed 1,500 cfs.

Knowledge of the seasonal occurrence and frequency of such flows is of particular importance for evaluating the survivability of deposited eggs. During 1965-1968 period of record at the USGS Terror River gage (15295700), 12 daily streamflows greater than 1,500 cfs and 47 greater than 1,000 cfs were recorded. Ten flows greater than the former and 20 above the latter discharge occurred between mid-July and early October. Annual peak daily flows of record have always occurred in association with rainstorms during late summer and early fall. These peak streamflows are normally of short duration and represent relatively small volumes of water. For example, the September 10, 1965 discharge of 1,490 cfs was preceded by more than a week of average daily streamflows of between 150 and 250 cfs. The September 18-19 and September 26-29, 1966, peak flow periods of 1,000 to 2,200 cfs occurred within a 15-day period when ambient streamflows were between 200 and 450 cfs (USGS 1965 and 1966).

As a result of the project, the storage capacity of Terror Lake would increase from 16,000 to 94,000 acre-feet, providing 78,000 acre-feet of active storage (R.W. Retherford and International Engineering Company, Inc. 1978, 1979). The September 26-29, 1966, runoff (13,500 acre-feet) is the largest volume of water attributable to a fall storm during the 1965-1968 period of record. The Terror Lake drainage area comprises 15.1 mi^2 of the 46 mi^2 upstream of the Terror River gage. If the rainstorm that caused this 4-day peak flow event had been uniformly distributed over the Terror River basin, approximately one-third of the 13,500 acre-feet of runoff or 4,400 acre-feet would have originated above the proposed Terror Lake dam. Seldom would the proposed reservoir with 850 surface acres and 78,000 acre-feet of active storage be so full that it could not temporarily store all the upper basin runoff from such a storm.

Were peak daily streamflows in the lower Terror River reduced by 30% as might result from the proposed dam, only two streamflow events above 1,500 cfs and 11 above 1,000 cfs would have occurred between the mid-July and early October period. This contrasts with 10 flows above 1,500 cfs and 20 above 1,000 cfs for the 1965-68 period of record. Thus, it may be concluded that the frequency at which lower mainstem spawning areas are scoured would be notably reduced but not eliminated as a result of the project.

Dewatering of Redds

Another major factor influencing the survival of fertilized pink salmon eggs is the potential of low winter streamflows to dewater redds. Streamflows during the spawning season provide salmon easy access to spawning habitat along the streambed margins and in riffle areas. However, midwinter water surface elevations often drop appreciably below those present in these areas during the spawning season. As a result, spawning habitat along the stream margins and in riffle areas can become dewatered, and flow through the streambed gravels may be substantially reduced.

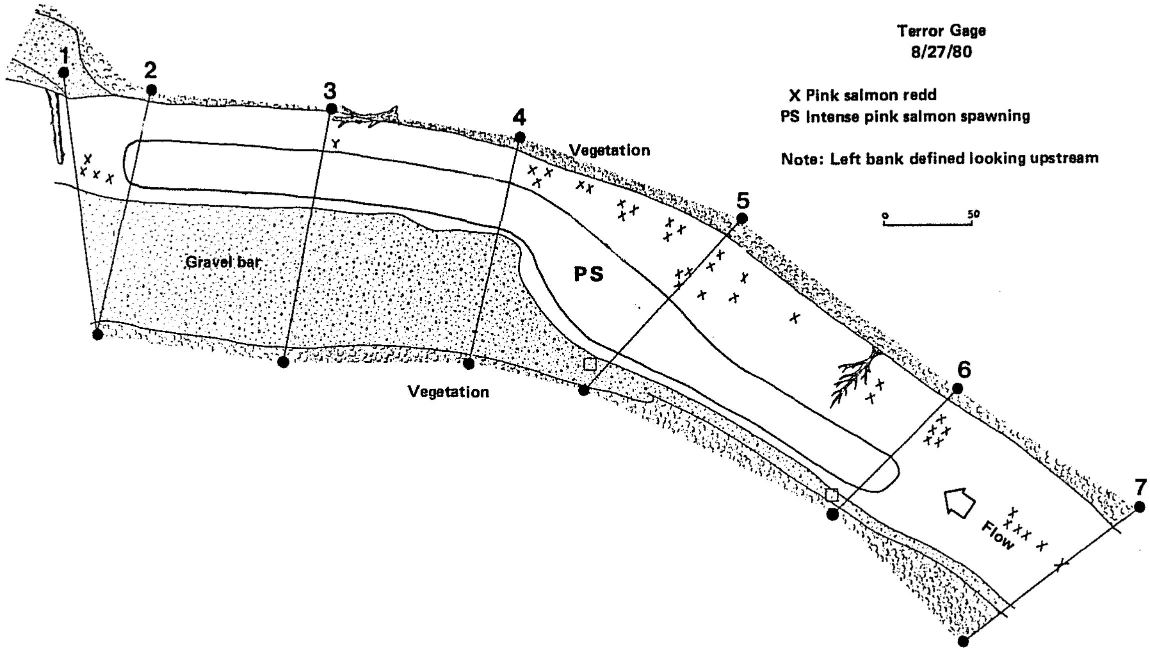

Figure 4.--Redd map of the Terror Gage study reach, August 1980.

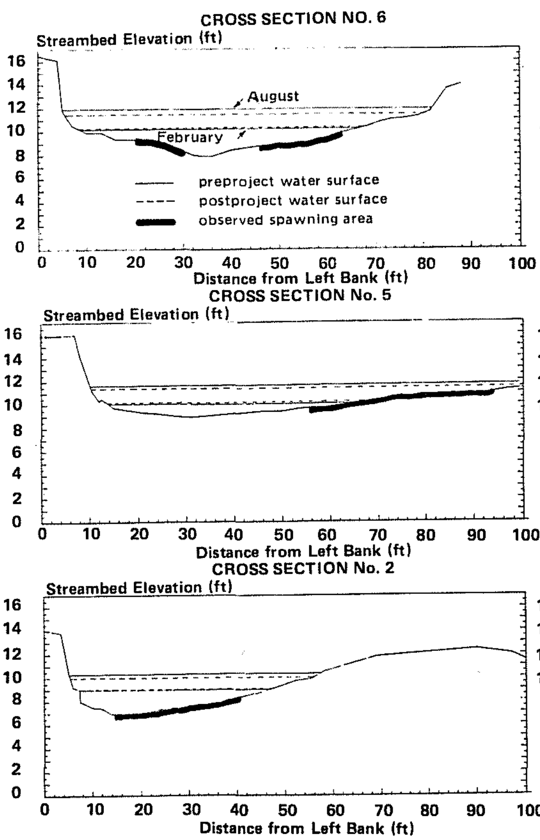

Figure 5.--Comparison of long-term average monthly water surface elevations during August and February in the lower Terror River.

Figures 4 and 5 present a redd map (field sketch) and scale drawing of respective cross sections denoting the locations of pink salmon redds observed during August 1980. Transects 2, 5, and 6 collectively represent typical stream channel cross sections for the study reach, hence the remainder of the transects were deleted from the analysis. To expedite analysis of project effects on redd dewatering, August and February were selected as index months. Figure 5 provides a comparison between pre- and postproject water surface elevations for long-term average August and February streamflows. Postproject streamflows would reduce the magnitude of the change between average monthly water surface elevations for the index months by approximately 0.5 ft. The long-term average postproject winter water surface elevation would be approximately 0.1 ft higher, while during the spawning season it would be approximately 0.4 ft lower.

The 27 years of simulated monthly streamflows during the midwinter incubation period were reviewed and the lowest monthly flow and corresponding water surface elevation for each winter identified. A comparison was then made between these water surface elevations and the water surface elevation associated with a controlled winter release of 60 cfs (Figure 6).

The low-flow statistics obtained in the flow variability analysis indicate that the simulated monthly midwinter streamflows are substantially greater than the lowest daily flows. Therefore, it must be remembered that incubating eggs and alevins are being stressed to a greater extent than the simulated monthly streamflows would

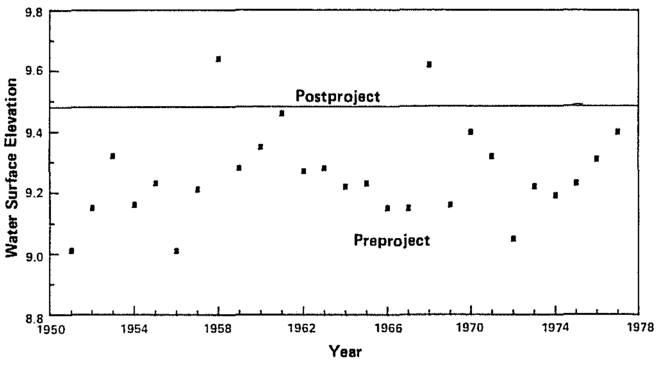

Figure 6.--Comparison of average monthly pre- and postproject water surface elevations for 27 years of simulated streamflows during the incubation season.

imply. Hence, postproject flow regulation near 60 cfs throughout the winter months should do more to protect incubating redds from dewatering than this comparison of average monthly pre- and postproject water surface elevations indicates.

Natural mortality would continue to occur in the lower Terror River as a result of redd dewatering but losses would not be as severe or as frequent as under preproject conditions. Reduction of water surface elevations during the spawning period should encourage adults to spawn closer to midchannel where their redds are not as vulnerable to dewatering. With reference to scour, the proposed project would reduce the magnitude and frequency of flood peaks, thereby improving the potential survival of incubating salmonid eggs in the lower Terror River.

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LITERATURE CITED

Bovee, K.D., and R. Milhous. 1978. Hydraulic simulation in instream flow studies theory and techniques. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, CO. Instream Flow Information Paper No. 5. 130 pp.

Robert W. Retherford Associates and International Engineering Company, Inc. 1978. Terror Lake hydroelectric project, Kodiak Island, Alaska. Definite project report. Report for Kodiak Electric Association, Inc. International Engineering Company, Inc. San Francisco, California. 1 vol.

______. 1979. Terror Lake hydroelectric project, Kodiak Island, Alaska. Application for license. Supplemental Information Report No. 1. Report for Kodiak Electric Association, Inc. International Engineering Company, Inc. San Francisco, California. 1 vol.

Simons, D.B., et al. 1980. Analysis of hydraulic, sedimentation and morphological changes in the Kizhuyak and Terror rivers associated with the Terror Lake hydroelectric project. Report for Kodiak Electric Association. Simons, Li and Associates, Fort Collins, Colorado. 1 vol.

Stalnaker, C.B. 1978. Methodologies for Preserving Instream Flows, The Incremental Method. Pages 1-9 in Instream Flow Management - State of the Art Proceedings. Upper Mississippi River Basin Commission. Fort Snelling, Minnesota.

Trihey, E.W. 1979. The IFG incremental methodology. Pages 24-44 in G.L. Smith, ed. Workshop in instream flow habitat criteria and modeling. Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO. Information Series No. 40.

U.S. Geological Survey. 1965. Water Resources Data for Alaska U.S. Govt. Printing Off., Washington, D.C.

______. 1966. Water Resources Data for Alaska U.S. Govt. Printing Off., Washington, D.C.

Wilson, W.J., E.W. Trihey, J.E. Baldrige, C.D. Evans, J.G. Thiele, and D.E. Trudgen. 1981. An assessment of environmental effects of construction and operation of the proposed Terror Lake Hydroelectric facility, Kodiak, Alaska. Instream flow studies. Final Report. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska 419 pp.

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