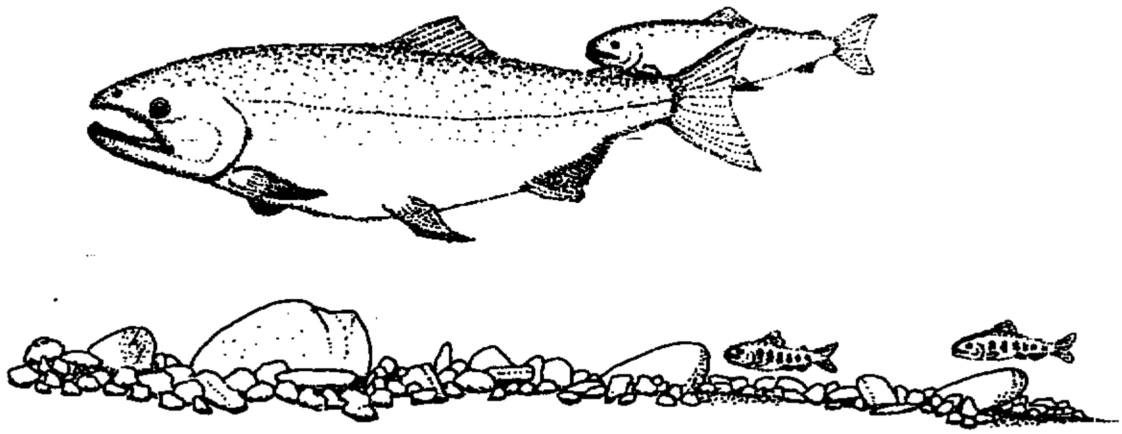
U.S. FISH AND WILDLIFE SERVICE

RECOMMENDED INSTREAM FLOWS FOR THE LOWER DUNGENESS RIVER



WESTERN WASHINGTON FISHERY RESOURCE OFFICE

OLYMPIA, WASHINGTON

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MEMBERS OF DUNGENESS INSTREAM FLOW GROUP

The following persons, almost all of whom helped design and implement the Dungeness Instream Flow Study, also met in late 1992 and early 1993 to definitively interpret the study results.

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ABSTRACT

The Dungeness Instream Flow Group evaluated the data from the Dungeness River Instream Flow Study (Wampler and Hiss 1991) and recommended the following monthly flows for maximum fish habitat in the lower Dungeness River immediately downstream of the irrigation diversions, in cubic feet per second (cfs):

November through March	575 cfs;
April through July	475 cfs; and
August through October	180 cfs.

At times, these flows may exceed the total natural flow in the river, for the flows are not based on hydrologic statistics. Rather, they are based on providing full fish habitat protection by achieving the depths and velocities desired by fish given the channel shape at the time of measurement. These flows provide, for the first time, a benchmark against which lower flows can be evaluated in terms of percent fish habitat gained or lost for key species and life stages, when instream flow is increased or decreased by changes in diversion.

RECOMMENDED INSTREAM FLOWS FOR THE LOWER DUNGENESS RIVER

PREPARED FOR THE DUNGENESS-QUILCENE REGIONAL PLANNING GROUP

by

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INTRODUCTION

In December 1992, the Dungeness Instream Flow Group was reconvened to complete the evaluation and interpretation of the Dungeness Instream Flow Study (Wampler and Hiss 1991). The Dungeness Instream Flow Group includes all agencies responsible for the design and execution of the original study: the U.S. Fish and Wildlife Service, the Jamestown S'Klallam Tribe, the National Marine Fisheries Service, and the Washington Departments of Fisheries (WDF), Ecology (WDE), and Wildlife (WDW). A list of all participants appears on the previous page; their individual professional opinions or observations are cited in this report as personal communications.

The Dungeness-Quilcene Regional Planning Group (RPG) was more recently formed to recommend surface and ground water allocation policy for the Dungeness, Quilcene, and adjacent watersheds, for adoption by the Jamestown S'Klallam Tribe and the WDE. The key disagreement within this organization regarding use of available water has centered around the amount needed for irrigation diversion as opposed to the amount needed for fishery resources in the Dungeness River. The RPG established a Technical Committee to review past water resource research and recommend water conservation projects and additional investigation as needed.

The purpose of this paper is to condense the voluminous Instream Flow Study results into one recommended monthly flow representing maximum fish habitat representing a balance of key combinations of species and life stages. This will allow all parties to the RPG, particularly irrigation and fishery interests, to (1) evaluate the flows left in the river after irrigation, in terms of percent of maximum, and (2) determine how much habitat can be gained for any given increase in instream flow remaining in the river immediately downstream of the irrigation diversions.

ORIGINAL IFIM REPORT

The Instream Flow Incremental Methodology (IFIM) is the generally accepted method of quantitatively relating instream flow in a certain reach of stream to fish or wildlife habitat area. Basically, the IFIM combines (1) curves describing the suitability of certain current velocities and water depths for selected fish species and life stages, with (2) measurements of current, depth, and wetted channel width repeated over a few widely differing flows in stream reaches selected for typical substrate and cover type, to produce (3) a table relating usable habitat area to instream flow for any flow likely to be encountered in the respective reach.

The Dungeness IFIM Study was performed to calculate flows required for salmonid habitat downstream of the irrigation diversions (Wampler and Hiss 1991), based on field work conducted in 1988 and 1989. The report predicted usable habitat area for two stream reaches (Figure 1) representing unconfined channel and diked channels, respectively. The lower reach habitat was measured at River Mile (RM) 2.3, with results applicable between RM 1.8 and 2.5. The upper reach habitat was measured at RM 4.2, with results applicable between RM 3.3 and 6.4. Tables of habitat area versus flow were developed separately for each site and for each side channel at the upper site (Wampler and Hiss 1991). This paper summarizes that report by citing the flow required for maximum habitat area for each reach according to fish species, life stage, and number of wetted channels (Table 1).

The IFIM study did not take into account the monthly pattern of fish use in the Dungeness, nor did it attempt to prioritize the many differing and sometimes conflicting maximum habitat flows for each combination of species, life stage, reach, and seasonal side channel flow.

IFIM EXECUTIVE SUMMARY

The "Executive Summary of the Dungeness River IFIM Study" (Hiss and Lichatowich 1990) brought the IFIM results closer to definitive interpretation by tentatively selecting priority months (August and September) and species-life stage combinations (chinook migration, spawning and rearing; pink spawning; and steelhead rearing). It presented graphs of habitat area for each reach and priority life stage, and graphically compared maximum fish habitat flows to mean monthly flows over the year.

However, the summary did not prioritize the upper versus lower reaches, or the upper reach side channels versus the upper reach main channel. Nor did it select a single key species and life stage. Thus, it did not achieve the goal of recommending one monthly flow for the entire lower Dungeness. This became the objective of two meetings of the Dungeness Instream Flow Group in December, 1992 and February, 1993. The following section describes the outcome.

JUSTIFICATION OF RECOMMENDED MONTHLY FLOWS

INTERPRETATION OF IFIM DATA

The Dungeness Instream Flow Group selected monthly maximum fish habitat flows through a six-part process:

Part 1: Monthly Occurrence of Species and Life Stages

The Flow Group developed a list of species and life stages based on the WDF Stream Catalog (Phinney *et al.* 1975), and updated with personal field observations by the Flow Group members (Table 2).

Part 2: IFIM Peak Fish Habitat Flows

IFIM results (Wampler and Hiss 1991, pages 64-74) were interpreted to determine the respective flows for maximum habitat area for each species, life stage, and reach (Table 1).

Part 3: Priority Species and Life Stages

Species and life stages were rated on the basis of (1) status of Dungeness stocks, (2) relative priority of life stages in the agencies' previous review of instream flow data from other rivers, and (3) reliability of habitat suitability curves. The sum of the three scores determined the rank of each species-life stage combination (Table 3, column 7).

Stock Status

Species were ranked on the basis of stock status. Stocks considered depleted scored "1" in Table 3, column 4 whereas stocks not considered depleted or of unknown status scored "0". Thus chinook salmon, pink salmon, and steelhead have priority because of their clearly depleted populations. Coho are not considered chronically depleted and Dolly Varden status is not well documented.

Priority of Life Stages

Life stages were ranked for the following two criteria: Weight customarily given to that stage in past IFIM studies, and reliability of habitat suitability data.

- <u>Precedents</u>. From August through March, WDE customarily ranks salmon spawning higher than rearing and adult migration; from April through July, the agency customarily ranks rearing higher than spawning and adult migration (Caldwell, pers. comm.). Steelhead rearing gets equally high emphasis with spawning and migration (Beecher, pers. comm.). These two ranks were designated "1" or "0" in Table 3, column 5.

- Reliability. The coho rearing table from the Dungeness IFIM (Wampler and Hiss 1991) suggests a very low flow for maximum habitat area, but WDE has found that habitat suitability curves for coho rearing often imply habitat at lower flows than the actual rearing flow requirement as determined by other means (Caldwell, pers. comm.). This is supported by Seiler *et al.* (1992), who found that higher summer low flow on Bingham Creek produced higher adult coho returns, based on a wide and representative range of summer rearing flows. Higher summer flows may have led to higher survival because at extreme low summer flows, factors such as predation, competition, and food supply become limiting rather than the depth and velocity measured in the IFIM. Predation, competition, and food supply are not accounted for in the IFIM model. Curves relating flow to habitat area for rearing of chinook, steelhead, and Dolly Varden are more reliable and were designated "1", while the coho rearing curve was rated "0" in Table 3, column 6.

Part 4: Priority Stream Reach

Where flows for maximum habitat area differed between upper and lower reaches, the upper reach data (Table 1) were given priority, because the upper reach represents more stream miles on the Dungeness than does the lower reach. This preference does not totally ignore conditions on the lower reach, since the relation of habitat area to flow in the lower reach was roughly similar to the habitat-flow relation in the main channel of the upper reach for most species and life stages (Table 1). This preference was reflected in Table 3, column 8.

Part 5: Seasonal Priority of Main Channel versus Side Channels

Habitat area was derived separately for main and side channels for the upper study reach (Table 1); the lower reach did not have side channels. As a general rule, side channels were included in the total habitat area used for selecting the maximum flow, because they provide especially high habitat value in proportion to the flow they receive. However, because these channels are seasonal, it is appropriate to use main channel habitat area to determine maximum fish habitat flow for the low water months. These considerations determined the upper reach maximum habitat flows selected in Table 3, column 8.

Priority of Side Channels

There is a precedent from White River flow negotiations to consider the habitat value of side channels whenever in doubt (Winter, pers. comm.). In general, side channels provide more spawning and rearing habitat per stream mile, regardless of total discharge, provided that the side channels do not change course over the season. They provide better rearing habitat for all species than the main channel considered alone, due to increased stream margin during moderate flows and more storm refuge during high flows. Side channels also are considered better steelhead spawning and incubation habitat than mainstem, due to slower current and the consequent reduced likelihood of scour.

Seasonality of Side Channels

Successive side channels become wet at 250, 330, 370, 400, and 450 cfs in the upper reach (Wampler and Hiss 1991). This means they are usually wet during the spring runoff and intermittently wet during the winter. Thus, it is appropriate to consider habitat area from all channels combined (Table 1, column 5) from November through July, but from data for the main channel only (Table 1, column 4) from August through October. Two observations support this choice: (1) In the low water months, the main channel provides better chinook and chum spawning habitat than side channels; and (2) adult returns of Dungeness pink salmon are proportional to rainfall at Sequim during the summer of the spawning year, when only the main channel is wetted (Lichatowich, pers. comm.).

Part 6: Flows for Maximum Fish Habitat

Based on the above selection of species, life stages, reaches, and channels, the flow for maximum fish habitat immediately below the irrigation diversions was determined for each month (Table 3, column 9). Three flow levels resulted:

November through March...575 cfs
April through July.......475 cfs
August through October...180 cfs.

CAUTIONS IN INTERPRETATION

Recommended Flows Assume Existing Habitat Condition

Flow and Aggradation

Flow for maximum fish habitat and streambed gravel aggradation cannot be addressed separately in the long term. Human influence accelerated the natural erosion process and led to an unnaturally high rate of bedload aggradation. This condition appears linked to streambed instability. In 1975 Dungeness side channels ran mainly through forest, whereas now these channels flow primarily through open gravel bars (Johnson, pers. comm.).

Our calculations suggested that in August, pink spawning as well as steelhead and chinook rearing ideally required about 425 cfs, far more than the river has ever had during that month. We believe this exaggerated flow requirement resulted from gravel buildup over the past several decades. This aggradation creates a wider, shallower channel with higher bars. If fish need water of a certain depth and can normally use side channels, then aggradation will require the river flow to be much higher than in the past to provide the same depth of water in the main channel and access to the side channels.

This intensified flow requirement suggests that irrigation diversion may have become a greater problem now than it was historically, despite reductions in water use over the last several decades. If the streambed aggradation problem can be solved, then the flow required for maximum fish habitat could decrease.

Channelization

Gravel aggradation is not an argument for bulldozing a single channel for adult fish passage during low water, since the upper reach data and scientific literature (Winter, pers. comm.) clearly show the value of keeping side channels. Channelizing would remove this essential habitat diversity and lead to other types of fish habitat damage. Rather, observed blockage or impeded passage over riffles at low water should be addressed in the short term preferentially by increased flows. However, installing gravel berms to concentrate and deepen flow over shallow riffles may also be acceptable in extreme cases. Over the long term, passage problems can be resolved by ensuring that side channels remain, for the most part, stable over the spawning and incubation season. Some kinds of carefully-designed bank protection and gravel removal, coupled with conservative watershed management, can promote such channel stability without destroying essential physical and biological complexity.

Recommended Flows and Water Availability

Historic Low Flows

Historic low flow was not considered in our method; rather, our recommendations are based solely on fish habitat requirements. Therefore, the proposed flows provide a biological benchmark against which any flow can be evaluated in terms of percent fish habitat gained or lost. An example of this use is given in the following section on "Habitat Benefits from Increased Flows".

Sliding Scales

Basing recommended flow on annual precipitation or some other measure of water supply might provide predictability or flexibility to farmers; however, it would probably not benefit fish habitat, which needs adequate summer flows as much in drier years as in wetter ones. In any case, a sliding scale may not greatly increase flow below diversion in wet years, since the range of flows customarily diverted during the irrigation season over the last decade (57 to 118 cfs (Wampler and Hiss 1991)) falls within the range of variation in available flows upstream of diversion in late summer (Table 4, columns 4 and 6).

ISSUES NOT ADDRESSED

This report does not address fish habitat issues for which data are lacking or are no longer directly relevant. Nonetheless, flows derived in this document should support an interim agreement while investigation into other basin-wide flow issues continues, and habitat improvement projects are implemented.

Seepage into Streambed Gravel

The Instream Flow Report (Wampler and Hiss 1991, page 78) documented instream flow loss due to seepage into streambed gravel between the 101 and Woodcock Bridges. However, the Dungeness Instream Flow Group's recommended flows are for the vicinity of the 101 Bridge. This makes it unnecessary to estimate loss of flow to intragravel seepage for negotiating instream flows below irrigation. However, gravel seepage remains a motive for improving habitat quality between the 101 Bridge and points downstream.

Independent Streams

Flow supply to "independent" streams of Dungeness Valley, such as Meadowbrook, Cassalery, and Gierin Creeks, was not considered due to lack of data on the relative importance of irrigation ditches compared to other groundwater sources in feeding these streams. If it is decided to manage the independent streams to maintain their existing flows, then surface diversion from the Dungeness would probably be more efficient than reliance on seepage from the ditches in their present condition, for it is unlikely that all the ditch seepage contributes to surface flow in these streams.

Smolt Migration

Recommended flows are expected to be adequate for downstream smolt migration. Studies elsewhere indicated that flows for coho smolt outmigration may be as little as 5 to 10 percent greater than ambient flow, and such variation can be expected to occur naturally (Caldwell and Winter, pers. comms.).

Channel Maintenance

Channel maintenance refers to the natural process of scour and deposition that maintains the physical diversity of fish habitat. Winter storm flows are the key to channel maintenance, and we can expect the magnitude of storm flows to remain the same unless a potential reservoir is given an exceptionally high capacity to divert peak river flows.

HABITAT BENEFITS FROM INCREASED FLOW

To help irrigators and fishery interests agree on how much more habitat will become available as a result of a given difference between any two instream flows below the diversions, one must choose a time period, species, and life stage. The August-October period is of greatest current interest, for naturally diminishing instream flows available for irrigation coincide with salmon migration and spawning.

Chinook and pink salmon spawning are the highest-ranked species-life stage combinations for this period (Table 3). Of the two, chinook habitat is more difficult to achieve by increasing flow than pink spawning habitat (Figure 2). Chinook habitat continues to increase over the entire range of flows leading up to the maximum habitat level, rather than reaching a maximum at some lower level.

Figure 3 shows how fish habitat for spawning chinook increases with flow up to 180 cfs (the desired optimum flow for all species and life stages combined). The corresponding habitat area increases vary from 1 to 11 percent for each 10 cfs increase in flow. For instream flows up to 100 cfs, fish habitat increases rapidly with each increase in flow. Above this point, the incremental gains are less than at lower flows but continue until the overall maximum habitat area is reached at 180 cfs.

CONCLUSION

Based on the needs of priority species and life stages, the following flows are recommended for maximum fish habitat area in the Dungeness downstream of the irrigation diversions:

November through March	575 cfs,
April through July	475 cfs, and
August through October	180 cfs.

Any increase in instream flow below the diversions will help attain maximum fish habitat area.

REFERENCES

Hiss, J.M. and J. Lichatowich. 1990. Executive summary of the Dungeness River IFIM Study. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington and Jamestown Klallam Tribe, Sequim, Washington.

Phinney, L.A., P. Bucknell, and R.W. Williams. 1975. A catalog of Washington streams and salmon utilization. Vol. 2: coastal region. Washington Department of Fisheries, Olympia, Washington.

Seiler, D., S. Neuhauser, P. Hanratty, P. Topping, M. Ackley, and L.E. Kishimoto. 1992. Washington studies to increase regional salmon production: program to improve wild salmon management. Annual performance report, October 1990 - September 1991. Washington Department of Fisheries, Olympia, Washington.

Wampler, P.L. and J.M. Hiss. 1991. Fish habitat analysis for the Dungeness River using the Instream Flow Incremental Methodology. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington.

TABLES

Table 1. Flows providing maximum habitat area for each species and life stage, as determined from IFIM. Source: Wampler and Hiss (1991).

Species	Stage	Lower reach	Upper reach: Main channel	Upper reach: All channels
Chinook	Migration[A]	390	240	575
	Spawning	200	220	575
	Rearing	80[B]	50[B]	475
Pink	Spawning	140	150	575
Coho	Spawning	120	110	575
	Rearing	40[B]	30[B]	375
Chum	Spawning[C]	200	220	575
Steelhead	Migration[A]	120	80	80
	Spawning	180	260	600
	Rearing	180	130	475
Dolly Varden	Rearing	220	160	650

[A] WDE ordinarily does not consider adult salmon migration and holding models as reliable as those for most other life stages.

[B] Probably an underestimate due to deficiency in model for this species and life stage.

[C] The Dungeness Instream Flow Group assumed maximum fish habitat flow to be same as for chinook, based on roughly similar size of fish and consequent spawning substrate preference.

Table 2. Timing of life stages in anadromous salmonids on Dungeness River. Shaded area = "occurs in river". X within shaded area = "of interest to Dungeness Instream Flow Group and included in Table 3". Sources: for salmon, Phinney *et al.* (1975); for steelhead and Dolly Varden, Beecher (pers. comm.).

Species	Stage	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook	Migration[A]					▒	▒	X	X	X			
	Spawning[B]								X	X	▒		
	Rearing[C]	X	X	X	X	X	X	X	X	▒	▒	▒	▒
Pink	Spawning								X	X	X		
Coho	Spawning	X										X	X
	Rearing[D]	▒	▒	▒	X	X	X	X	X	▒	▒	▒	▒
Chum	Spawning[E]								X	X	X	X	X
Steelhead	Migration							X	X				
	Spawning[F]		X	X	X	X	X						
	Rearing[G]	X	X	X	X	X	X	X	X	▒	▒	▒	▒
Dolly Varden	Rearing	X	X	X								X	X

[A] River entry is virtually complete by July; holding period is of primary interest.
[B] Spring chinook spawning is virtually complete by end of September.
[C] Most Dungeness chinook have left fresh water by September of their first year of life (Lichatowich, pers. comm.).
[D] Coho rearing curve was developed primarily for fish size and water conditions occurring in spring and summer.
[E] Chum spawning has been observed earlier here than was reported in the WDF Stream Catalog (Phinney *et al.* 1975)(Johnson, pers. comm.).
[F] Steelhead spawning is virtually complete by June (Beecher, pers. comm.).
[G] Steelhead rearing curve was developed primarily for yearling fish rearing in spring and summer.

Table 3. Monthly ranking of species and life stages, maximum habitat area flow (cfs), and recommended flows based on rank of species and life stages.

Month(s)	Species	Life stage	Status rank[A]	Stage rank[B]	Reliability[C]	Total score	Maximum habitat flow[D]	Species combined[E]
Jan	Coho	Spawn	1	1	1	3	575	575
	Steelhead	Rear	1	1	1	3	475	
	Chinook	Rear	1	0	1	2	475	
	Dolly V.	Rear	0	0	1	1	650	
Feb-Mar	Steelhead	Spawn	1	1	1	3	600	575[F]
	Steelhead	Rear	1	1	1	3	475	
	Chinook	Rear	1	0	1	2	475	
	Dolly V.	Rear	0	0	1	1	650	
Apr-Jun	Chinook	Rear	1	1	1	3	475	475
	Steelhead	Rear	1	1	1	3	475	
		Spawn	1	0	1	2	600	
	Coho	Rear	0	1	0	1	375	
Jul	Chinook	Rear	1	1	1	3	475	475
	Steelhead	Rear	1	1	1	3	475	
	Chinook	Migr.	1	0	1	2	575	
	Steelhead	Migr.	1	0	1	2	80	
	Coho	Rear	0	1	0	1	375	
Aug	Chinook	Spawn	1	1	1	3	220	180
	Pink	Spawn	1	1	1	3	150	
	Steelhead	Rear	1	1	1	3	130	
	Chinook	Rear	1	0	1	2	50	
		Migr.	1	0	1	2	240	
	Chum	Spawn	1	0	1	2	220	
	Coho	Rear	0	0	0	0	30	
Sep	Pink	Spawn	1	1	1	3	150	180
	Chinook	Spawn	1	1	1	3	220	
	Chum	Spawn	1	1	1	3	220	
	Steelhead	Rear	1	1	1	3	130	
	Chinook	Migr.	1	0	1	2	240	
Oct	Pink	Spawn	1	1	1	3	150	180
	Chum	Spawn	1	1	1	3	220	
	Steelhead	Rear	1	1	1	3	130	
Nov-Dec	Coho	Spawn	1	1	1	3	575	575
	Chum	Spawn	1	1	1	3	575	
	Steelhead	Rear	1	1	1	3	475	
	Dolly V.	Rear	0	0	1	1	650	

[A] Scored "1" for "considered depleted", "0" for "not considered depleted, or insufficient information".
[B] Spawning ranked higher than rearing or migration from August through March; rearing ranked higher than spawning or migration from April-July.
[C] Coho rearing ranked lower than other species and life stages.
[D] Upper reach flows corresponding to peak habitat area using all channels from November through July; or upper reach flows using only the main channel from August through October.
[E] Desired optimum flow was chosen intuitively from overlapping peak regions of the habitat preference curves presented in Wampler and Hiss (1991) for highest-ranking species and life stages.
[F] The previous month's recommended flow was substituted for 600 cfs for simplicity.

Table 4. Recommended monthly flows (cfs) below irrigation diversions by month (from Table 3), compared to monthly exceedance flows at U.S. Geological Survey gauge upstream of the irrigation diversions. Exceedance flow indicates the percentage of time during which the flow exceeds the stated level. For example, in January the flow exceeded 150 cfs, 90 percent of the time.

		Exceedance flow at gauge		
Month	Recommended flow	90%	50%	10%
Jan	575	150	360	640
Feb	575	190	330	630
Mar	575	190	250	410
Apr	475	220	360	420
May	475	400	560	800
Jun	475	460	710	1,000
Jul	475	300	510	730
Aug	180	180	270	370
Sep	180	140	180	250
Oct	180	120	190	360
Nov	575	150	270	550
Dec	575	200	370	680

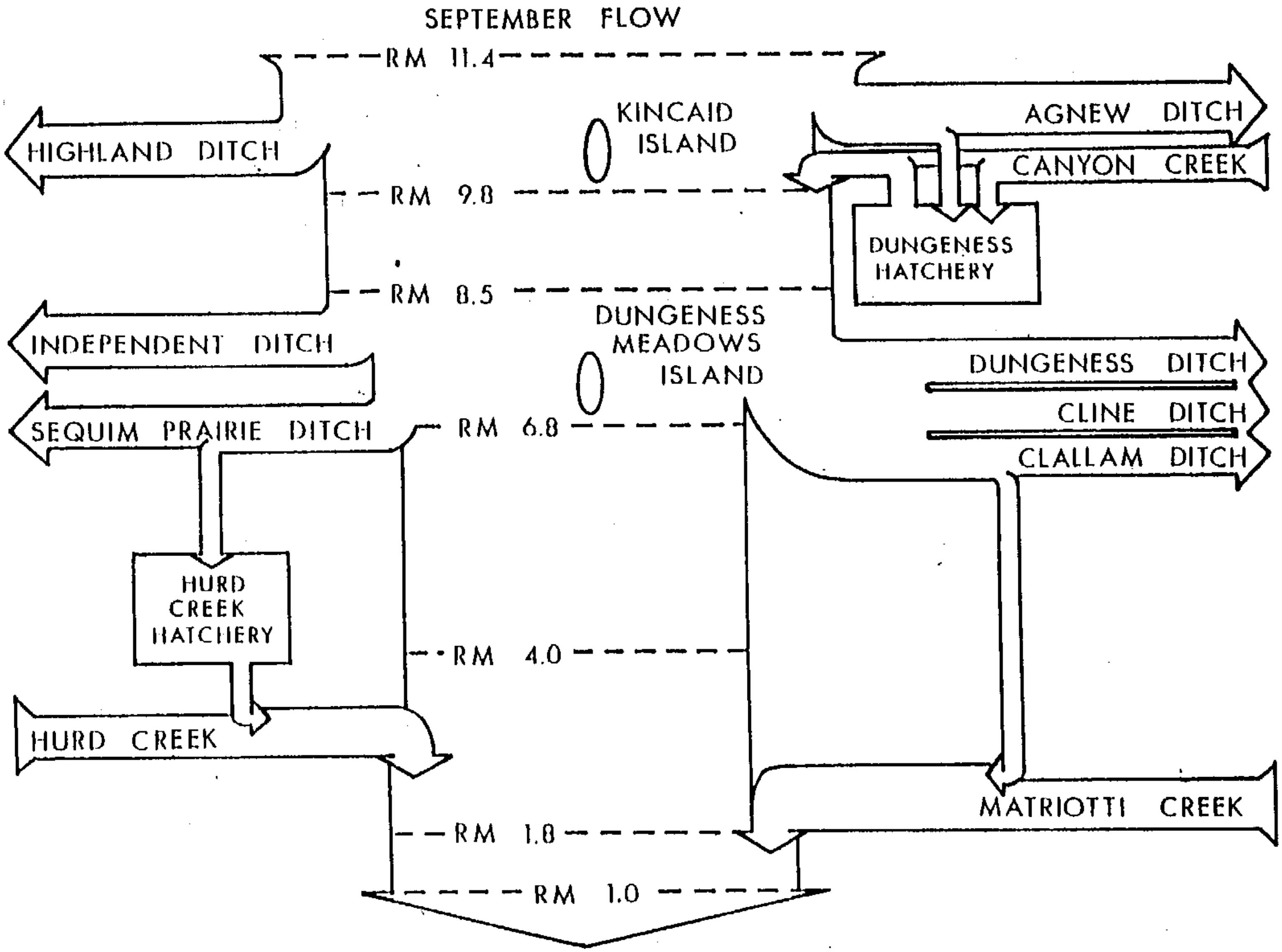

Figure 1. Dungeness River reaches affected by irrigation withdrawal. Vertical scale represents approximate river mile. Arrow width represents relative amount of typical summer flow.

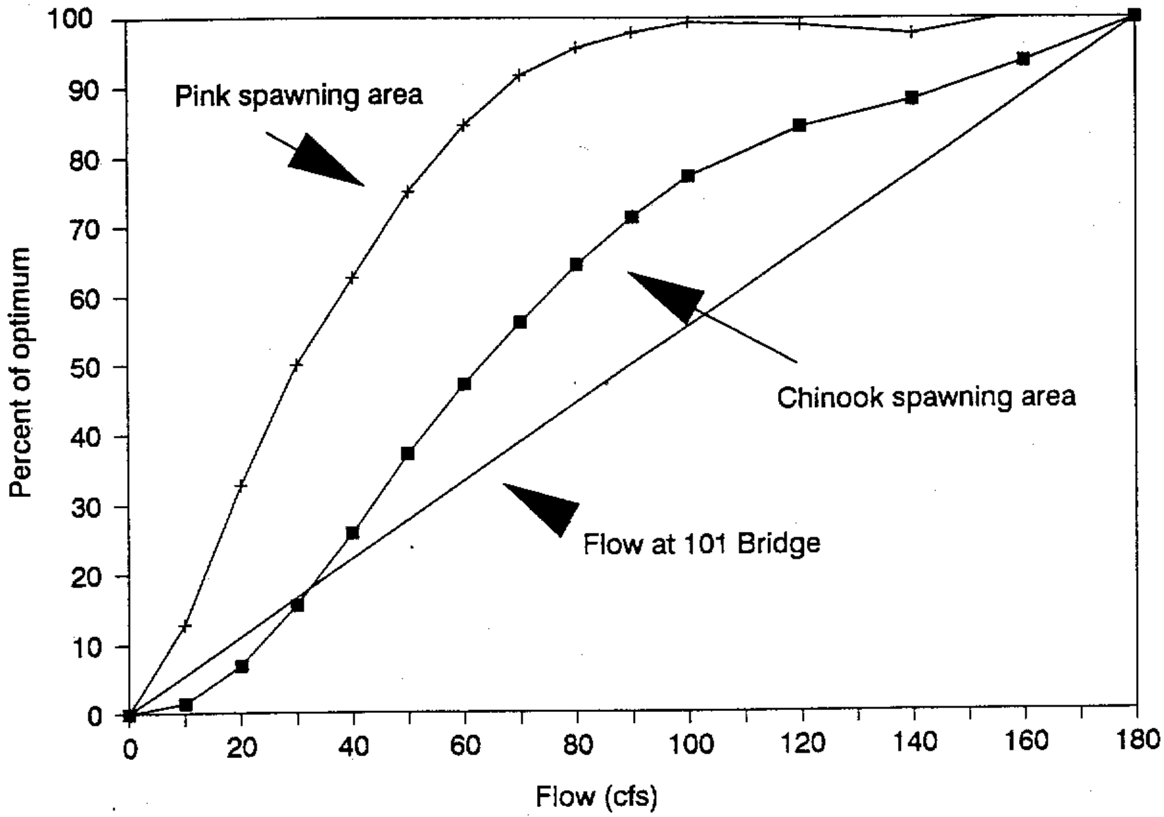

Figure 2. Chinook and pink salmon spawning area in upper IFIM study reach versus instream flow at U.S. Highway 101 Bridge.

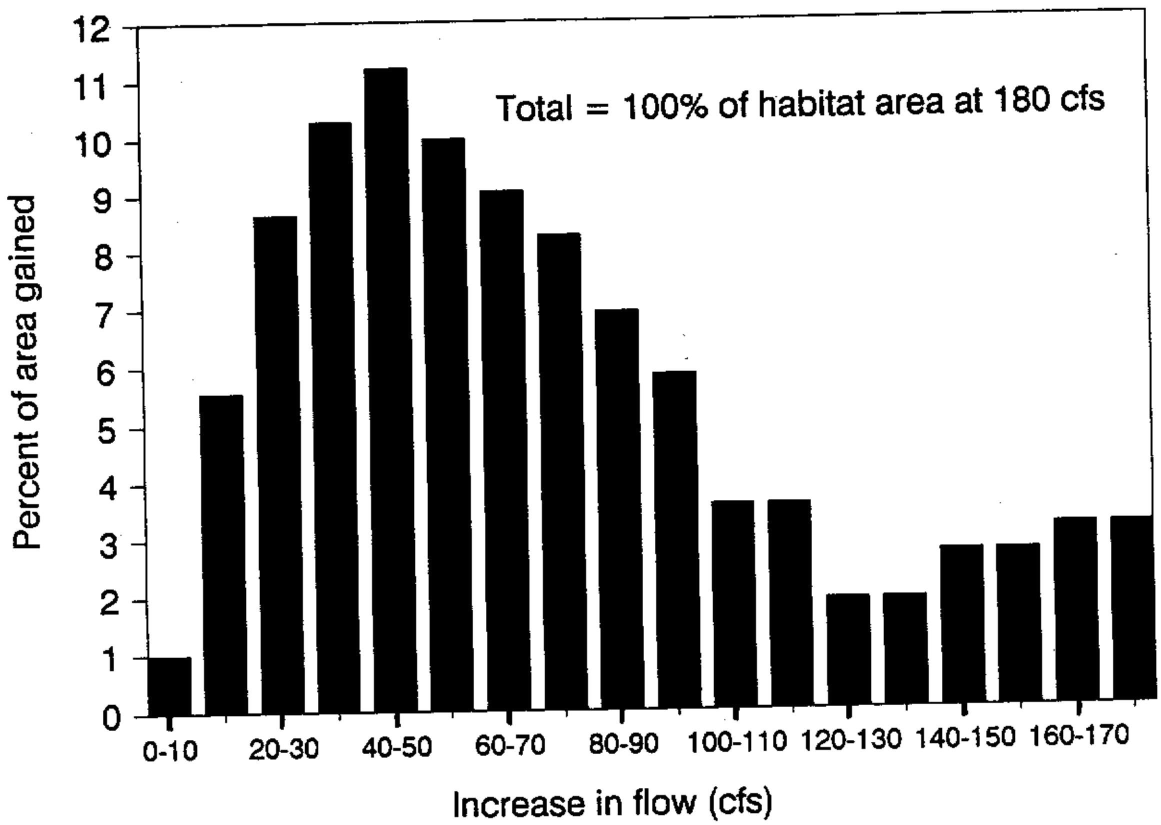

Figure 3. Chinook spawning area in upper reach gained for each increment in instream flow below the 101 Bridge, expressed as percent of habitat area available at 180 cfs.

We determined habitat availability by using hydraulic model calibration measurements at the same site as the preference curve study. We used the hydraulic model to estimate habitat availability when utilization measurements were made at a flow different from the calibration flow. We ran HABTAT (with a dummy preference curve) for the flows at which we measured utilization, and generated a matrix of depth and velocity availability at the utilization study flows.

In the case of charr (Dolly Varden/bull trout), fish density was low, so we needed to sample a greater length of stream to obtain a reasonable number of observations. We assumed that habitat availability at the upper IFIM study site was proportionally representative of the several miles between the site and the Hwy 101 bridge; this was a criterion in selecting the hydraulic model site, so the assumption was reasonable.

We determined habitat utilization by snorkeling through a study site, marking fish positions, and measuring depth, velocity and substrate at the fish position. In most cases field crew snorkelled upstream, carefully determining fish position and bevavior to avoid measuring at positions taken up by fish that have been disturbed. In the case of charr, with low fish density, the field crew worked downstream with the current to cover large distances to obtain an adequate sample size.

We measured depth with a top-setting wading rod. We measured mean column velocity at 0.6 depth using a Swoffer propeller current meter or a rotating cup current meter of a size suited to the stream.

For each study we tabulated the following in each range of depth and velocity: number of fish observed (O), proportion of total habitat (f[H]), and expected number of fish (E) if fish were distributed in proportion to habitat availability (i.e., randomly with respect to depth and velocity). We calculated expected number of fish as the proportion of total habitat that occurred within a range multiplied by the total number of fish observed (E=f[H] x sum[O]). Initially we used ranges of 0.5 ft and 0.4 fps or less for tabulation (e.g., 0.00-0.39fps, 1.00-1.49 ft). The HABTAT program generated ranges when we specified limits for the matrix of available depths and velocities at the utilization study flow. Then we combined ranges until E for the combined range was at least 1, and in most cases at least 5.

For each site, in ranges meeting the minimum E criterion, we divided number of fish observed by number expected (O/E), then determined the maximum value of O/E for a site and habitat attribute. All values of O/E at a site and habitat attribute were then divided by the maximum value of O/E to determine preference values (P) ranging from 0 to 1.0: P=(O/E)/(O/E)max.

We tabulated preferences for different ranges of depth and velocity in a spreadsheet, using a column for each study (in some cases there were several studies at one site). Where several ranges have been combined (e.g., 0.5-0.79 ft, or 1.30 fps and greater), the preference for that combined range was entered in each cell corresponding to the component range. For example, if the preference for 0.5-0.79 were 0.3, then 0.3 would be entered in cells corresponding to 0.50-0.59, 0.60-0.69, and 0.7-0.79.

For each study, we tabulated number of fish observed (N). Number of observations (N) was the weighting factor applied to each study in developing the habitat preference curves. For each component range, we added the products of the sample size and preference (sum[NP]) to yield a cumulative weighted preference factor (CWPF). The cumulative weighted preference factor was then normalized by dividing each CWPF by the maximum CWPF to produce a composite preference factor with a value between 0.00 and 1.00. The upper tails of curves were weighted differently. Sites were only weighted up through the highest range where either the number of fish expected or observed was greater than 0.