A DISCUSSION OF GAME FISH IN THE STATE OF WASHINGTON AS RELATED TO WATER REQUIREMENTS

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INTRODUCTION

The Washington State Department of Game has prepared this report in partial fulfillment of a flow study contract with the Washington State Department of Ecology. The Game Department has been selected to determine instream flow requirements of various game fish in the state of Washington and to develop methodology for applying known water needs to streams for flow recommendations.

The purpose of this report is to provide information necessary for determining stream flows which will preserve the high quality sports fishery presently found in Washington State. Appropriation of Washington States' water for agriculture, industrial, and municipal uses has placed fishery resources under a severe strain, and a very real and immediate need for maintaining aquatic habitat exists. Spawning and rearing requirements are stressed in this work as they are of primary concern in development of a flow study program for game fish.

Maintenance of a river system for fish production involves not only adequate flows for various life cycle requirements but preservation of stream habitat.

METHODS OF TAKING SPAWNING MEASUREMENTS

Redd measurements for spawning game fish sould be selected from an area that presents a variety of hydraulic conditions to the fish. Unless the fish is given a choice of water depths, velocities and gravel size, the measurements taken will reflect the hydraulic conditions available in that specific stream and not the conditions in which the fish would really prefer to spawn.

For example, in some of the streams measured, all the velocities would be from 0.5 to 0.8 fps and all the depths from 0.4 to 0.8 ft. At first glance, the resulting data would give the impression that a narrow range of preference existed, when in reality 0.8 fps was the fastest water available at spawnable depths. These narrow ranges of available options for fish are often found in streams at low discharge or low gradient.

Measurements taken in streams with these narrow ranges of conditions are useful but should not be weighed as heavily as measurements taken in a stream that offers a variety of conditions to the spawning fish.

Velocity measurements should be taken directly upstream from the pit at a distance which insures that the velocity is not affected by pit turbulance, approximately 0.5 ft. This upstream velocity will actually be slightly different than the velocity where the fish started digging the redd, (see correction factor experiments). Meter height above the substrate should be 0.4 ft. for salmonids of 4 lbs. or heavier and 0.25-0.30 ft. for smaller trout. This variation is to accommodate nose-level velocity for fish of different size.

Depth measurements on the redd should be taken to the nearest 0.1 ft. at the pit, tailspill, and on both sides of center. The average of the two side measurements reflects the approximate depth before the redd was constructed.

The length of a redd is that distance from the upstream edge of excavation to the downstream edge of the tailspill. To compute the area, several equidistant width measurements should be taken along the length of the redd.

Gravel size can be evaluated by seive measurements of a sample or by visual approximation with a staff graduated in 0.1 ft. intervals as reference.

The size of the spawning fish should be recorded in all streams sampled.

Water temperatures should be taken in all cases, along with any significant observations (location, number of males, water clarity, etc.).

If information is needed on reproduction, the redd may be excavated and the eggs counted, noting the ratio of dead eggs.

It is of great importance that the redd being measured is active (fish present in site) or very fresh (fish present in area, gravels clean and free from algae growth). Measurements made on older redds will not reflect the hydraulic conditions that existed when they were dug unless the stream discharge happened to be the same.

CORRECTION FACTOR EXPERIMENTS

In the interest of improving velocity criteria for spawning salmonids three experiments with water velocity were performed:

1) Comparisons of velocities at 0.25 and 0.40 ft. above the stream bed to relate velocity measurements made at these two depths for salmonids of different size.

Results: 0.15 fps should be added to 0.25 ft. velocity data to approximate the comparable velocities at 0.40 ft.

2) Relating velocities taken immediately (0.5 ft.) upstream of a trout redd with the velocity 3 ft. downstream at the spot where the fish actually began digging the redd.

Results: A correction factor of 0.1 to 0.2 fps should be added to the upper velocity limit of the data results to compensate for the faster downstream conditions.

3) Comparing velocities at the head of a steelhead redd with those at the actual point of original construction.

Results: A correction factor of 0.3 fps should be added to the upper velocity limit of the data results to compensate for the faster downstream conditions.

These results are presented with the understanding that additional field measurements are needed to accurately define these correction factors. Experiments number 2 and 3 may require a floating correction factor varying with water velocity and fish size.

VELOCITY VARIATIONS AT 0.25 AND 0.40 FT. ABOVE STREAM BOTTOM

Present methods of determining velocity criteria for spawning salmonids involve taking measurements at fish nose-level, 0.25 to 0.40 ft. above stream bed. The relationships between velocity measurements taken for fish of different sizes and at their corresponding depths needs to be explored. This experiment was designed to find the relationships between water velocities at 0.25 ft. and 0.40 ft. above the stream bottom.

Methods: Four overall water depths were used as constants for the sampling groups; 0.4, 0.7, 1.0 and 1.5 ft. Each sampling group consists of 25 samples with the total of all 4 being 100 samples.

Each sample is the result of 2 measurements, one at 0.25 ft. and one at 0.40 ft. above the stream bottom. The velocity at 0.25 ft. was subtracted from the velocity at 0.40 ft. to give a sample result. The base of the meter remained stationary during each sample measurement with depth adjustment being made by a metal rod attached to the meter.

Measurements were made on three separate days, July 24, 26, and 27, 1973 on three separate sites; lower Kennedy Creek, upper and lower Deschutes River. Separate sites were chosen for the variation in discharge, gravels and channel characteristics. Gravels on Kennedy Creek, ranged from 1/4 to 2 inch and 1/2 to 4 inch on the Deschutes River. All samples were taken at sites where successful spawning could be anticipated.

Equipment: All depth and velocity measurements were made with a Type AA current meter.

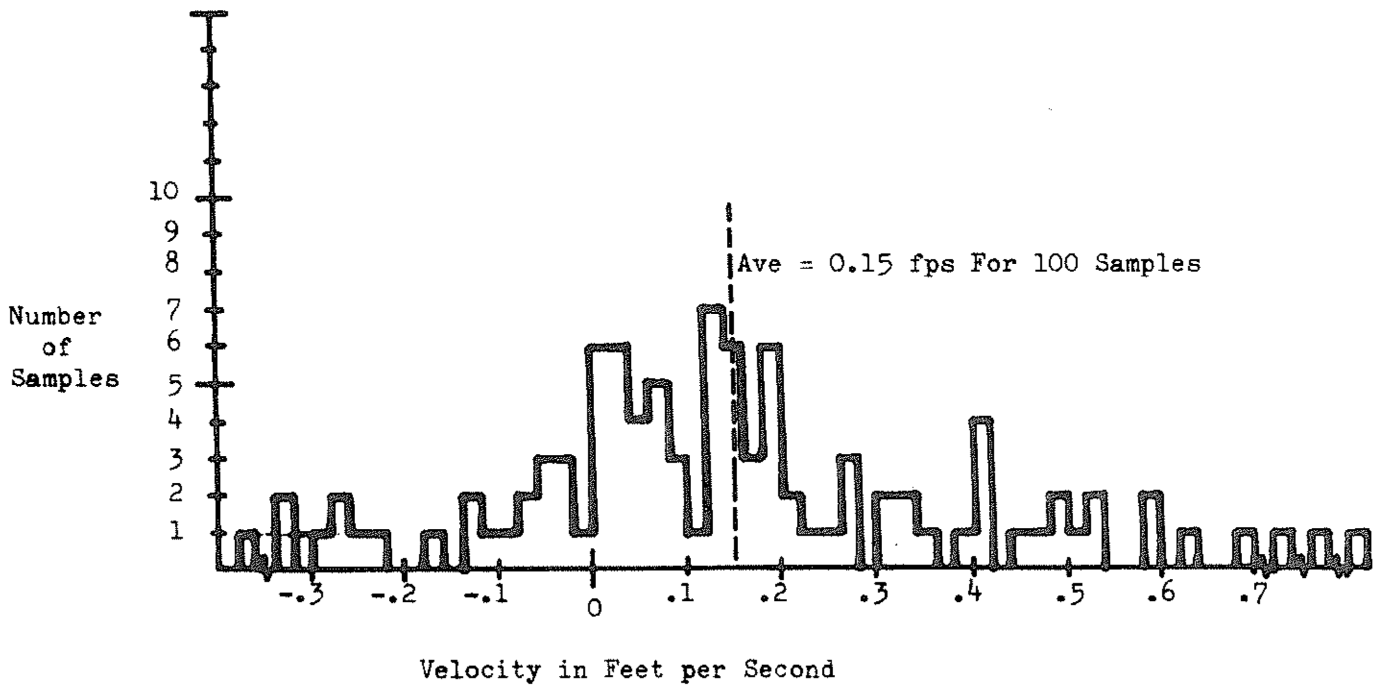
Results and discussion: Overall results (See Figure 1) exhibit a relatively normal distribution averaging 0.15 fps faster at 0.40 ft. A breakdown by sampling depths (See Figure 2) shows a negative result at the 0.40 ft. sampling group which can be attributed to an irregular velocity pattern in shallow riffle areas over 1/4 to 4 inch gravels. Results at the more commonly used spawning depths by resident salmonids (0.7 and 1.0 ft.) have similar results to each other averaging 0.17 and 0.16 f.p.s. faster at the 0.40 ft. nose-level depth. The 1.5 ft. sampling group has a definite increase in results averaging 0.32 f.p.s. faster at the 0.40 ft. depth.

Of the four sampling groups the two at 0.7 and 1.0 ft. should be weighted most heavily as these represent the more favored spawning depths by smaller (usually resident) salmonids in tributary streams. Gravel size, velocity, and water depth are a function of discharge and stream gradient. When measurements indicate shallow spawning depths, they can usually be associated with low discharge and small gravels. Large salmonids (steelhead, salmon, etc.) generally prefer deeper and faster water with larger gravels, commonly found in higher discharge (often mainstream) conditions. Gravel size will affect water turbulance and the variations between velocities at 0.25 and 0.40 ft.

Recommendations: When it is necessary to adjust water velocities taken at the depths of 0.25 and 0.40 ft. over gravels of 1/4 to 4 inch, an adjustment factor of 0.15 f.p.s. should be added to the 0.25 ft. velocity data to approximate the comparable velocities at 0.40 ft.

FIGURE I - DISTRIBUTION OF ALL VELOCITY SAMPLES

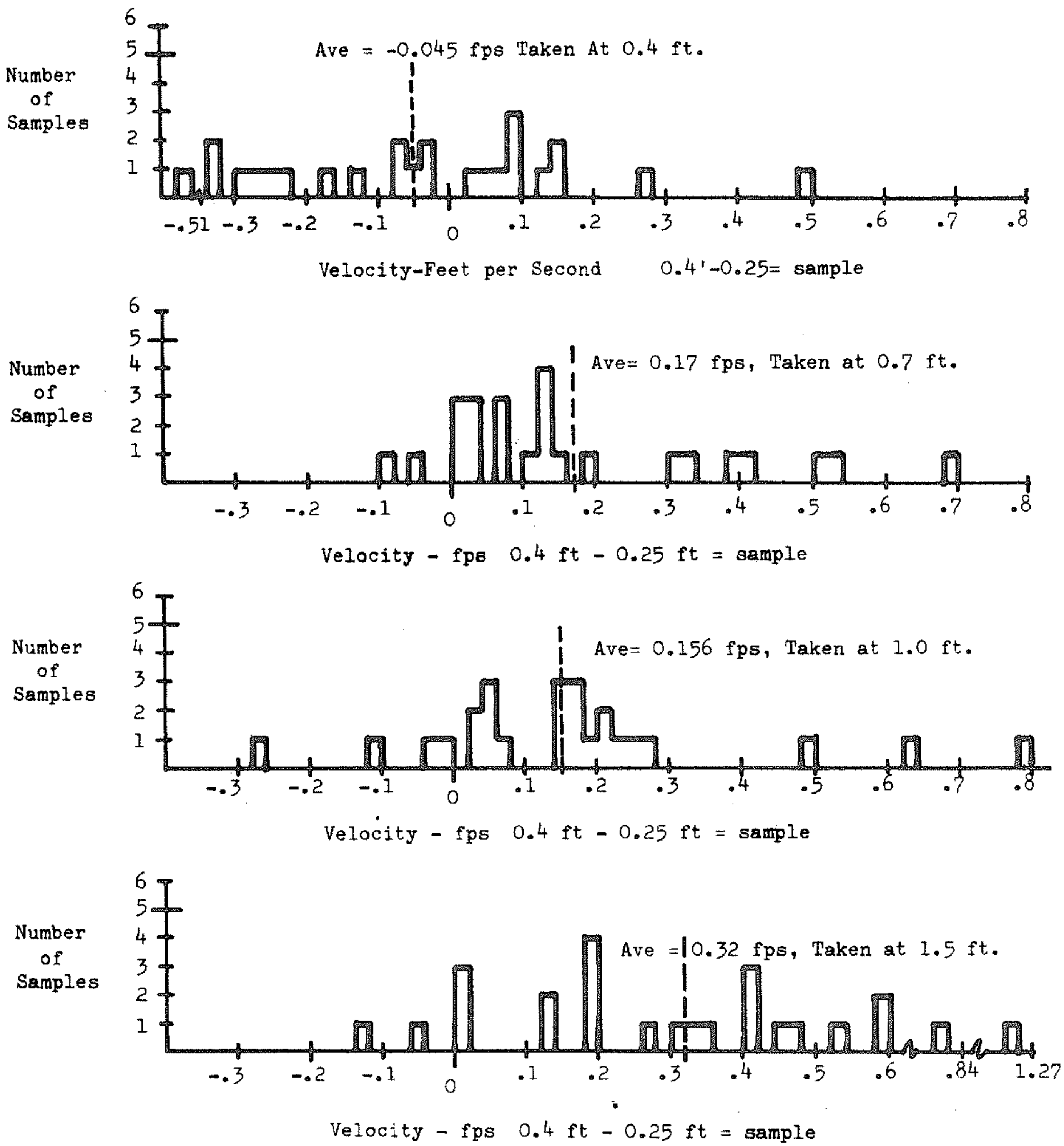
25 at each of four depths: 0.4, 0.7, 1.0, and 1.5 ft. (100 Total)



Each Sample = 0.40' vel minus 0.25'vel.

FIGURE 2- DISTRIBUTION OF VELOCITY SAMPLES

25 at each of four depths: 0.4, 0.7, 1.0, 1.5 ft.



WATER VELOCITIES FOR SPAWNING TROUT

Present methods of making velocity measurements of fish spawning sites require measurements immediately (0.5 ft.) upstream of the redd. Initial construction of a redd begins with a female digging a pit and working upstream 1 to 5 feet covering past excavations with gravel and thereby lengthening the redd. This experiment was run to explore the theory that velocity measurements made 0.5 ft. upstream of the head of a redd are dissimilar from the velocities at the point where the fish started digging.

Methods: Two separate sampling times, 4-26-73 and 6-10-73, were chosen in Lower Kennedy Creek (Mason County) to run this test. Kennedy Creek was chosen for the abundance of 1/4 to 3 inch gravels available in spawning-type settings. Four measurements were made for each sample: an upstream depth and velocity, followed by depth and velocity readings 3 ft. directly downstream. In each sampling trip, 10 samples each at constant upstream depths of 0.4, 0.7, 1.0, 1.5 and 2.0 ft. were taken, giving a total of 20 samples at each of the five selected depths. All sample sites were in locations where successful spawning could be expected to occur, generally above riffles. Velocity measurements were made at 0.3 ft. when possible.

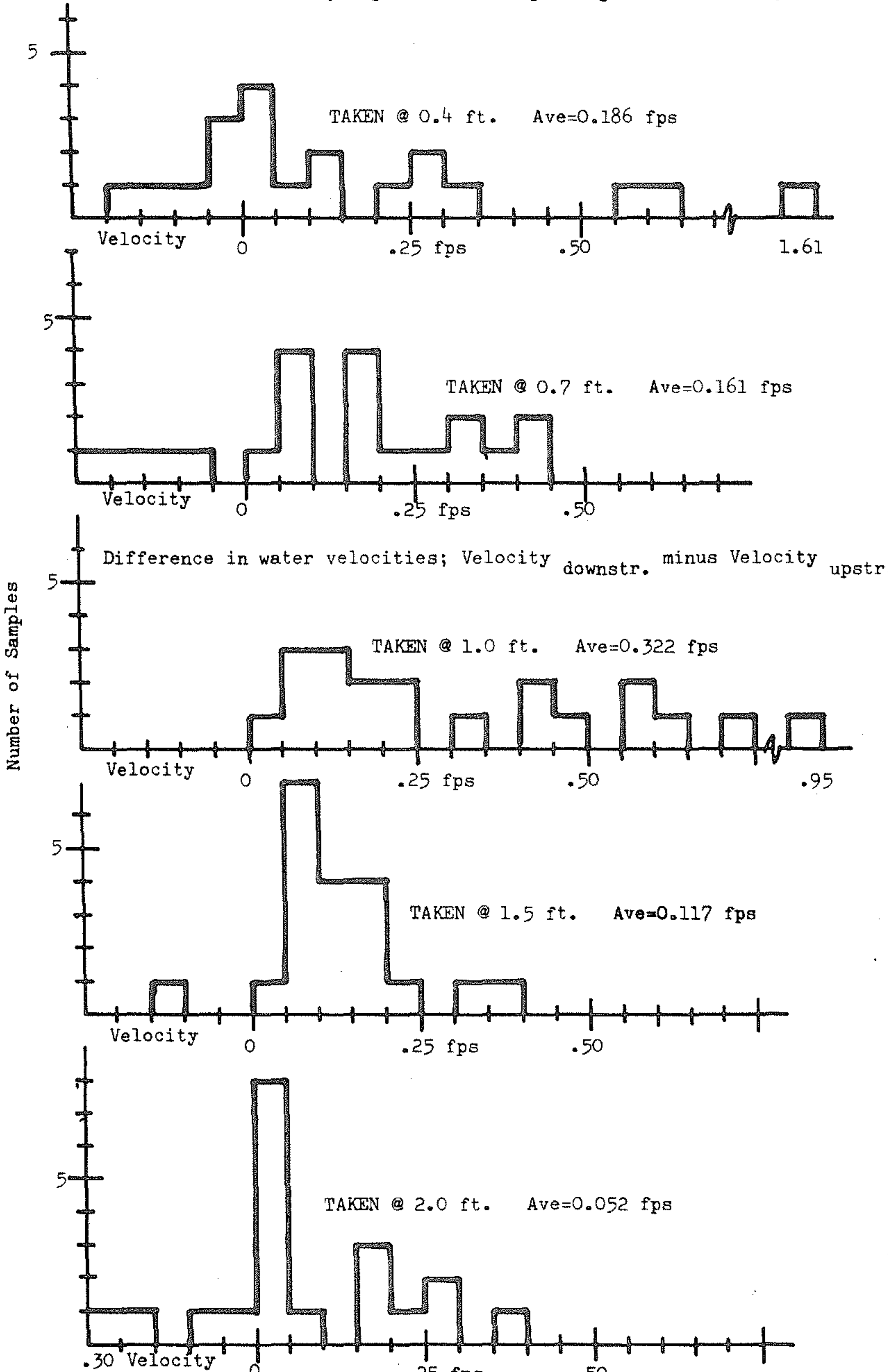
Equipment: All depth and velocity measurements were made with a Type AA current meter.

Results and Discussion: Figures 3 and 4 show the results of velocity downstream minus velocity upstream and depth upstream minus depth downstream. The tables show that the downstream measurements were generally faster and shallower. The downstream depths are in all cases the same or shallower than the upstream depths, as would be expected in areas immediately above riffles.

Velocities were the primary concern and a wide range of results were obtained. As can be seen from the velocity graphs, the downstream measurements averaged from 0.05 fps to 0.32 fps faster. These results cover conditions under which most species of trout would spawn, with the exception of steelhead and salmon (see following pages on steelhead redd experiment). The distance between upstream and downstream measurements (3.0 ft.) could be greater than the distance between 0.5 ft. upstream of a pit and where a fish started digging for short redds of small trout less than 12 inches long. In these cases a shorter distance would have a proportionately reduced velocity change.

Recommendations: When developing velocity criteria from measurements made upstream of trout redds, a correction factor of 0.1 fps for small redds (trout 12 inches or less) and 0.2 fps for larger redds (trout from 12 to 20 inches) should be added to the upper velocity limit of the data results.

FIGURE 3- Water Velocity Experiment For Spawning Trout- Velocity



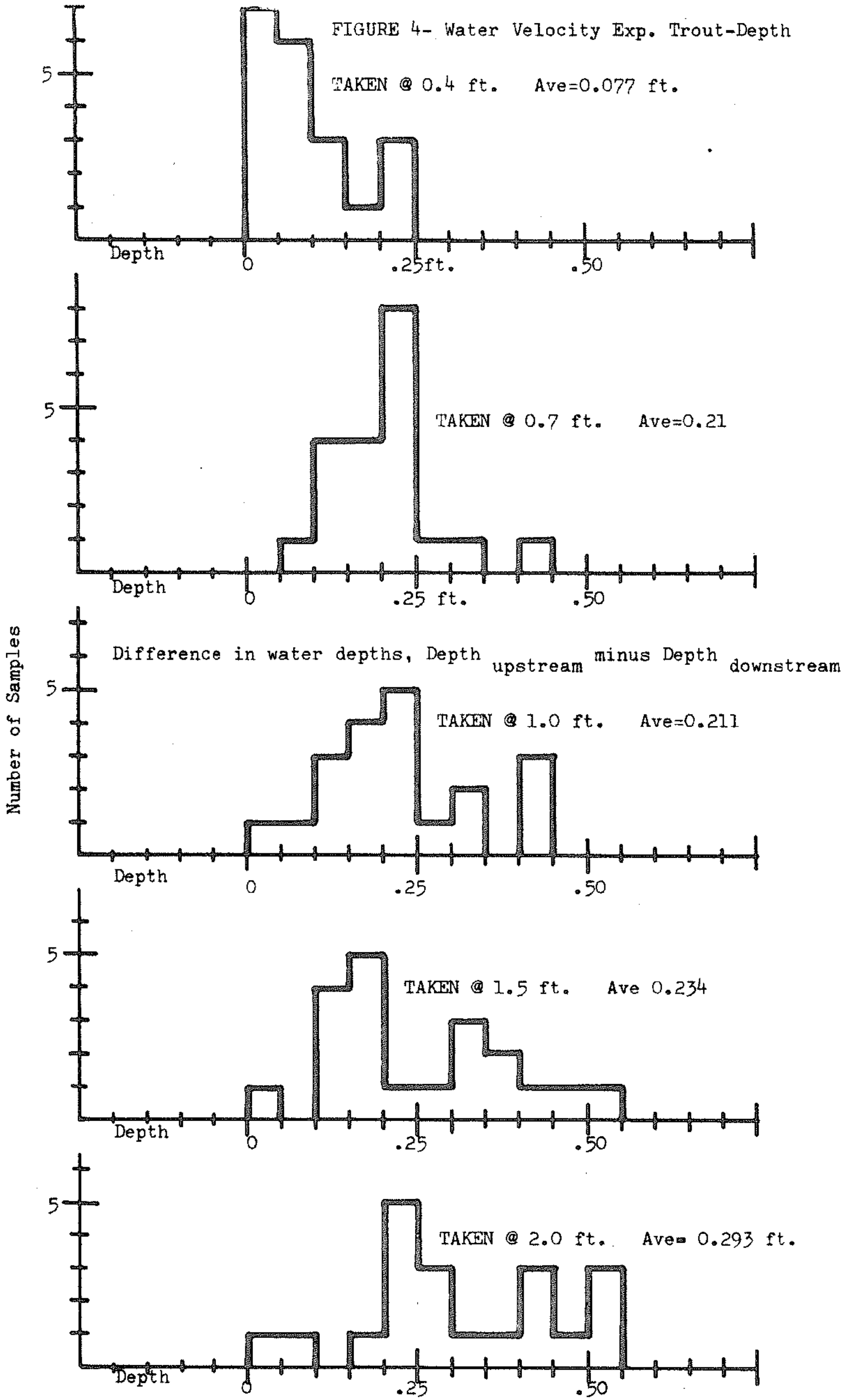


FIGURE 4- Water Velocity Exp. Trout-Depth

WATER VELOCITIES FOR SPAWNING STEELHEAD

This experiment was undertaken to determine the difference between velocities 0.5 ft. upstream of a steelhead redd and the estimated point of original excavation.

Methods: On 4-24-73, 19 fresh steelhead redds in 5 different waters of the Toutle River drainage were sampled to find variations between velocities at 0.5 ft. above a redd and 4 to 5 ft. above the downstream edge of tailspill. In shorter redds 4 ft. was used while recordings were made at 5 ft. for longer redds. Four velocity measurements were made on each sample, two on each side, one even with 0.5 ft. above the pit and one 5 ft. above the bottom end of the tailspill. These results were then averaged for each sample to obtain a center-line estimation.

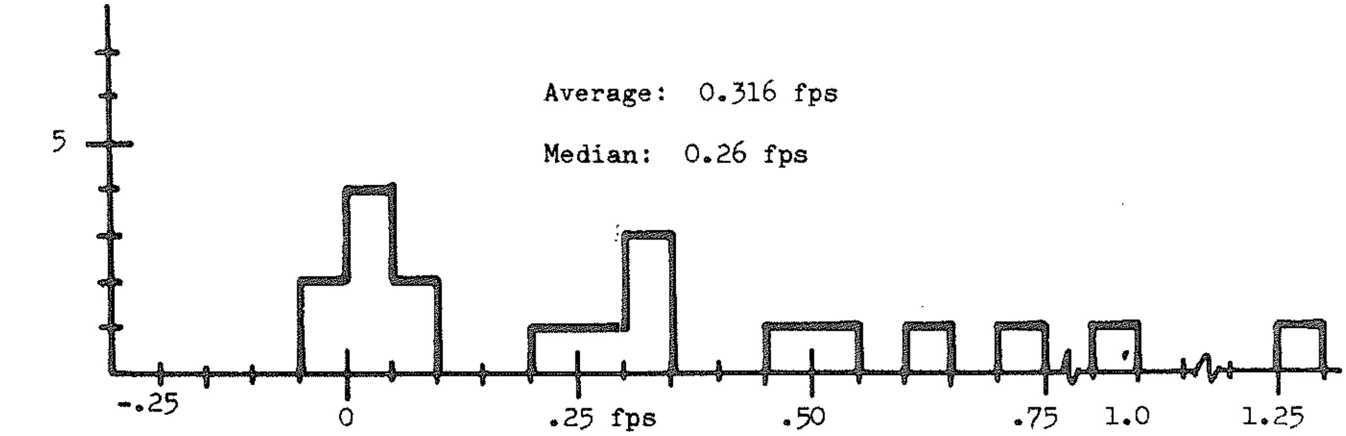
Equipment: All depth and velocity measurements were made with a Type AA current meter.

Results and Discussion: The following page (Figure 5) shows the results of velocity downstream minus velocity upstream, depth upstream minus depth downstream and the distance between the head of a redd and estimated point of original excavation. The tables show that the downstream measurements are generally faster and shallower. The downstream depths are consistantly shallower, as would be expected in areas above riffles.

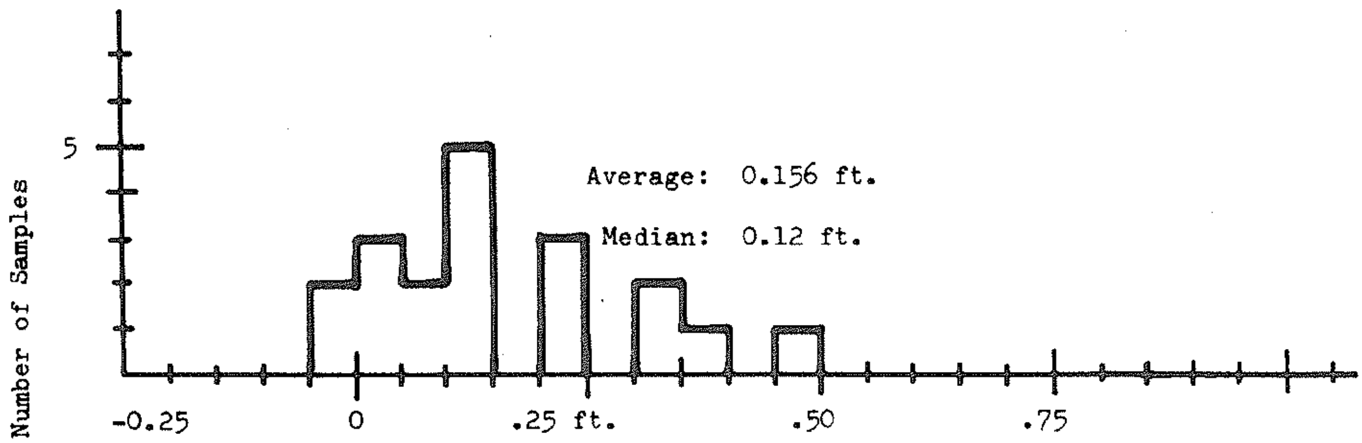
Velocities were the primary concern and results show an increase averaging 0.32 fps faster downstream.

Recommendations: When developing velocity criteria from measurements made upstream of steelhead redds, a correction factor of 0.3 fps should be added to the upper velocity limit of the data results.

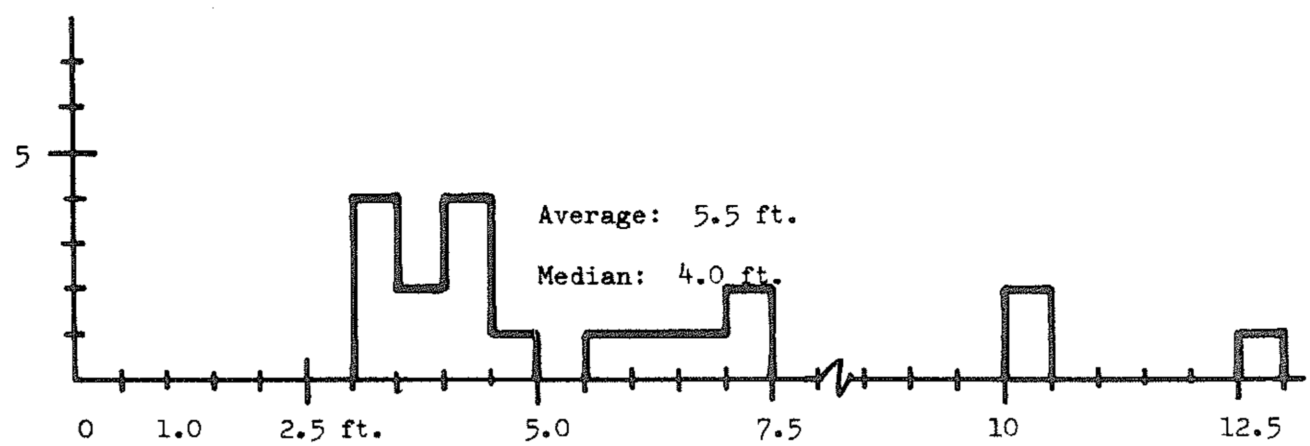
FIGURE 5 - Water Velocity Experiment For Spawning Steelhead



CHANGE IN VELOCITIES FOR 19 STEELHEAD REDDS



CHANGE IN DEPTHS FOR 19 STEELHEAD REDDS



CHANGE IN DISTANCE BETWEEN HEAD OF REDD AND ESTIMATED POINT OF INITIAL CONSTRUCTION, FOR 19 STEELHEAD REDDS.

A PARTIAL LITERATURE REVIEW CONCERNING THE EFFECTS OF STREAM DISCHARGE, BANKSIDE COVER, AND TEMPERATURE UPON SALMONOIDS

Introduction

The following is a discussion of three essential stream parameters; discharge, cover and temperature. Each is presented as it relates to the low-flow summer period and salmonoid production. Primary concerns involve aquatic insect production and microhabitat abundance. Interactions between the three topics are discussed as they relate to productivity. A summary and recommendations are included.

Discharge as Related to Food Production

Aquatic insects constitute a major portion of the diet of salmonoids. This food source is available to fish through organic drift and substrate foraging. Aquatic food supplies do not shift within stream sections as stream levels rise or fall, thus the permanent wetted area of a channel, i.e., the low flow, is the governing factor in food production (Bell, 1971). This food producing capability of a stream is perhaps the most significant factor in determining its carrying capacity (Hooper, 1973).

Aquatic insects usually have at least a one-year life cycle and do not re-establish themselves in areas that are alternately wetted and dried (Bell, 1971). The following is a list of the groups of aquatic insects that constitute approximately 80% of a salmonoid fish diet and the depths and velocities at which they are commonly found (Kennedy, 1967, Needham and Usinger, 1956).

	Percent Contribution	Velocities	Depths
Trichoptera	25.8	3.0 fps	1 ft.
Ephemoroptera	25.3	1.2 to 2.6 fps	less than 1 ft.
Diptera	24.2	3.0 fps	
Plecoptera	4.5	evenly distributed across riffle	

The greatest number of organisms is found in sections with velocities between 2.0 and 3.5 fps. The average weight of organisms per sample was highest in sections with velocities of 2.1 to 4.3 fps with a definite peak around 3.0 fps (Needham and Usinger, 1956). A study on coho salmon found peak insect production on riffles at about 2.0 fps, with more coho per area in pools below large riffles than in pools below small riffles. This would indicate that riffle food production has a governing influence on adjacent fish populations. (Pearson, Conover, Sams, 1970). Overall, the highest aquatic insect production is observed in riffle areas with velocities from 1.5 to 3.5 fps and at depths from six inches to three feet (Hooper, 1973).

Current velocity is one variable which is directly related to flow volume (Hooper, 1973). A Montana study found current velocity the most important factor governing rainbow trout populations with the density of trout per unit area of pool surface increasing significantly as velocity increased (Lewis, 1969).

Therefore, a sufficient discharge should be maintained throughout the summer months to provide velocities above 1.5 fps. over large riffle areas at depths of 0.5 ft. or deeper. This lowest yearly flow will govern the food production and biological productivity of a stream system.

Cover as Related to Territories

The territorial habits of stream salmonids are characterized by the fact that each individual frequents one strongly dominating, strictly localized station within its territory (Kalleberg, 1958). The fish spends about 95% of its time at this station allowing for feeding excursions of short duration followed by immediate return to the territorial station (Wickham, 1967). These stations all have a high spatial correlation to cover comprised of: large rocks, turbulant surface waters, submerged logs, undercut banks, overhead cover and shade (Hooper, 1973).

A fish which has succeeded in obtaining a station with favorable feeding conditions usually retains the territory partly by aggressive actions during feeding and partly because he grows faster than his neighbors who have less desirable stations. The slow growing individuals are more rapidly eliminated from the population, since they remain for a greater period of time within the size group which runs the greatest risk from predation. Thus the competition for space becomes competition for food and survival (Kalleberg, 1958). Also, by establishing territories, or microhabitats, fish tend to spread their populations throughout a system leading to a more efficient utilization of the food supply.

The abundance of adequate cover (or quality of stream habitat) will govern the number of territories and thereby fish populations (Hooper, 1973). This limited number of territorial stations will regulate a "density barrier" for each stream and thereby limit the number of adult fish produced. Therefore, despite adequate stream flows for food production, the number of fish will still be regulated by this available territory density barrier (Royal, 1972).

Two essential cover considerations are stream bank foliage and current velocity. Removal of foliage from stream banks drastically reduces the number of territories created by thigmotactic response (fish in near contact with an object), overhead cover, and shade since many salmonoids exhibit a photonegative response and subsequent ability to use a shaded area as a territorial station (Hooper, 1973). A reduction of flows during the summer months will cause the water surface to recede towards the center of a channel and thereby greatly reduce territorial contributions by stream bank foliage. Current velocity (discharge related) affects turbulance of surface waters, organism drift, and visual isolation of territories (Kalleberg, 1958, Chapman, 1966). An increase in velocities (discharge) causes greater surface turbulance which may be used as cover, increase organism drift thereby supplying more food/area/unit time, and increases visual isolation of territories. Increased velocities allow territories to be compressed and will result in a higher density barrier for that stream.

Natural predation by other fish, birds, and assorted enemies can be reduced by the presence of adequate cover thereby enhancing salmonoid production.

Of primary concern in determining a necessary flow for summer periods is the choice of a flow that provides sufficient cover to maintain the desired fishery. In situations where stream bank foliage and overall habitat quality are decreased, an increase in summer flows will be necessary to provide a constant number of territories for maintenance of each streams density barrier.

Temperatures

The temperatures of a salmonoid's habitat affect growth, weight, size, digestion, disease incidence, swimming speed, foraging rates, oxygen requirements, gas saturation levels, and egg survival. Heat has a synergistic effect on water quality and must be considered when measuring other stresses within the environment (Bell, 1973). The overall importance of acceptable water temperatures for salmonoids cannot be over emphasized. Even though high temperatures in a stream may not kill fish they vastly increase their sensitivity to stress.

Generally, cold-water fish cease growing at temperatures above $68^{\circ}F$ due to the increased metabolic rate. Food requirements at least doubling between 50° and 68° F create a strain on the fish to find enough food and a strain on the stream to produce food and maintain habitat quality.

A significant factor in maintaining cool stream temperatures is the presence of stream bank foliage (trees, shrubs, grasses, etc.) which shade the water. Even a partial shading on a wide river will greatly reduce the number of thermal units reaching the water. Miles of denuded streambanks along eastern Washington rivers have created thermal blocks, low oxygen concentrations, and temperature enhanced stresses in those waters. Restoration of these waters for a trout fishery may by necessity involve a massive replanting of deciduous trees to provide shade and cover during the summer months.

Adequate flows should be maintained during the summer to provide for acceptable water temperatures.

Summary

The salmonoid producing potential of a stream is a complex matrix of biological and physical factors largely regulated by the balance between food production and microhabitat availability. Preservation of three essential factors is imperative for maintenance of a good salmonoid producing stream; adequate summer flows for food production, streambank cover, and water quality. Deterioration of any one factor will negate the benefits of the other two. The volume of water flowing during summer months will have the greatest influence of any seasonal flow on fish populations excluding floods with high silt concentrations. Streambank cover plays a complex role in creating microhabitats, providing shade in summer, reducing erosion, and contributing to food resources. Poor water quality is dominated by high temperatures which will magnify the effects of most habitat stresses.

Maximum utilization of a balanced fish producing system will require using species with different microhabitat preferences thereby filling all available territories. Removal of predaceous scrapfish, such as squawfish, will channel more of the biological productivity to salmonids.

Recommendations:

1) Maintain adequate summer flows for salmonid food sources which include aquatic insect production.
2) Prevent removal of streambank cover by stricter state controls.
3) Begin an investigation into a possible streambank replanting program for critical eastern Washington waters.

SALMONOIDS - GENERAL*

Several families of game fish will be treated in this paper; trout, chars, kokanee, whitefish and grayling. These fish comprise the majority of the desirable stream sport fishery in this state, although spiny-rays may be as important in parts of central and southeastern Washington. Many of these species will migrate to sea when possible with coastal cutthroat and steelhead being the only anadromous fish discussed separately.

FOOD: A brief summary of the typical diet of several salmonoids is shown below:

Steelhead	Fish, squid, amphipods
Rainbow	Zooplankton, insects, fish
Cutthroat	Insects, shrimp, crayfish, fish eggs, worms, sm.fish
Sea-Run Cutthroat	Fish, crustaceans
Brown	Fish, insects, worms, crayfish
Golden	Plankton, insects
Dolly Varden	Fish, snails, amphibians, crustaceans, insects
Eastern Brook	Insects, crustaceans, fish
Lake	Plankton, insect larvae, fish
Kokanee	Plankton, copepods, insects, cladocerans
Whitefish	Aquatic insects, insect larvae
Grayling	Aquatic and terresterial insects

HABITAT: Preference varies widely between species with most preferring continuously flowing streams of cool waters with cover and riffle/pool ratios conducive to good food production and rearing.

TEMPERATURE: Tolerance by salmonoids range from near freezing to 80° F. Maximum growth will be attained at temperatures of 45 to 65° F

*Primary Sources: Carlander, Kenneth D.
Calhoun, Alex
Leitritz, Earl
Carl, Clemens and Lindsey

depending on species. Digestion of foods will be slow at low temperatures with higher temperatures increasing food and oxygen requirements.

OXYGEN: For successful propagation and growth, trout require well oxygenated water of 7 to 10 ppm. A minimum of 5 ppm is necessary for adequate rearing with 1.0 ppm to 3 ppm being lethal, depending on temperatures.

pH: Wild brook trout can exist from 4.1 to 9.5 and rainbows from 5.8 to 9.5. The extremes in either case will not produce high quality fish. Recommended pH range is 6.7 to 8.2. Generally, slightly alkaline water will support more fish than acid water, with the lower pH value normally having a lower mineral content.

SPAWNING: Most of the salmonids covered here prefer to ascend rivers, tributaries, and lake inlets to spawn, although downstream spawning is also common. The fish will pair up and the female will dig a redd in which her deposited eggs are fertilized by the male and then buried with gravels. Several of these pockets of eggs may be found in each redd. The position of the redd is usually immediately above a riffle, along side the bank or a gravel bar where depths, velocities and gravels are adequate. Whitefish and grayling do not make a redd but deposit their eggs over stream gravels.

Many of the salmonid species (especially Brook Trout) will spawn on lake bottoms where upwelling or seepage will aerate the eggs. Spawning may occur on lake bottoms where no seepage exists, but with the exception of lake trout, egg survival is questionable.

Timing: (See Figure 6) The time of the year for spawning varies widely between and within species. Length of daylight and water temperatures govern ripening of the eggs which may vary 2 to 6 months between warm lowland and cool high elevation streams, for the same species.

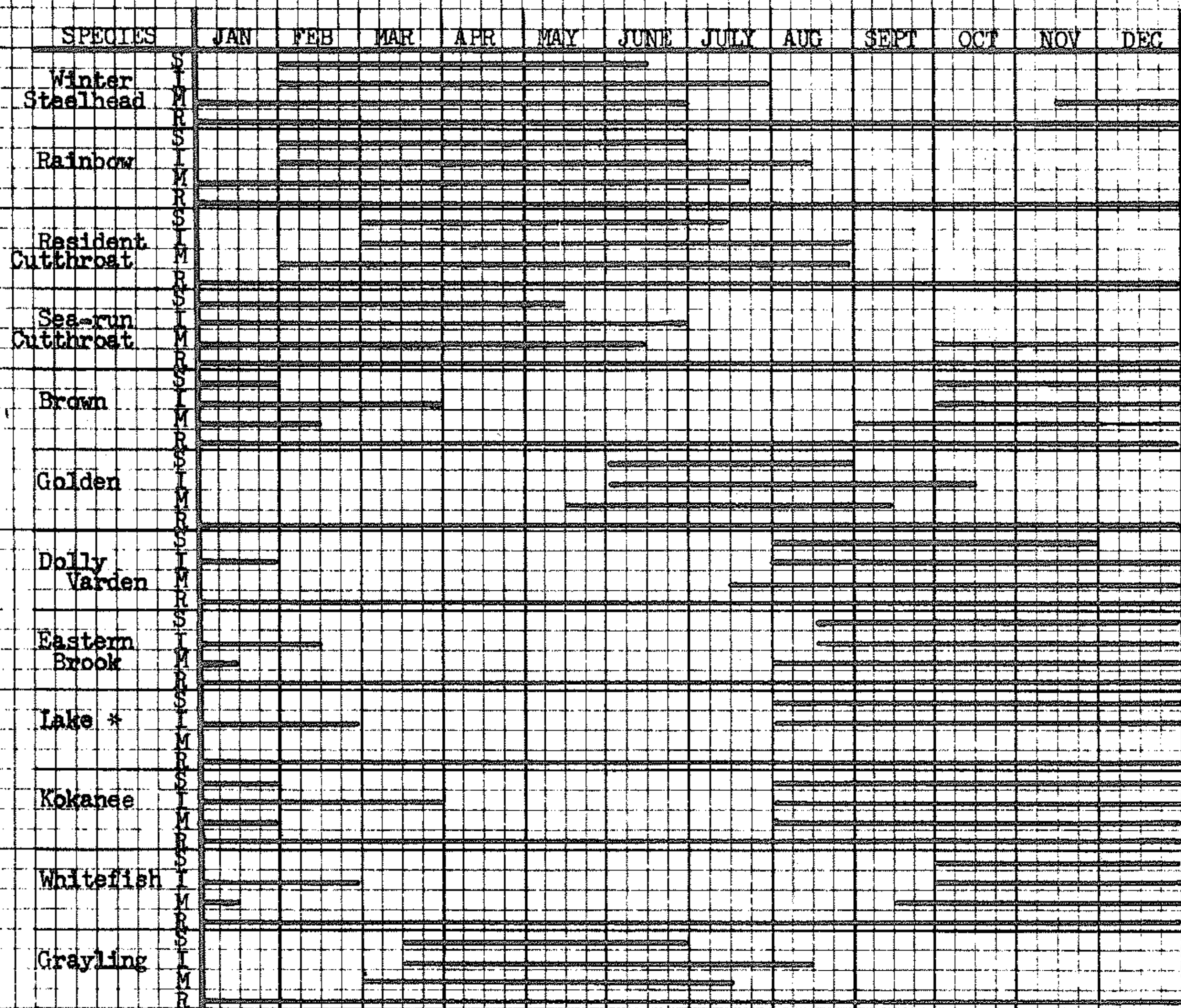
Temperatures: (See Table 1) Again a wide variety exists between and within species. Preferred spawning temperatures generally range from 40 to 55° F, with most fish using whatever temperatures are available when they are ripe for spawning.

Water Depth and Velocities: (See Table 1) Trout will spawn where depths, velocities and gravels are suitable. Most species have a fairly wide range of acceptable conditions with minimum water depth and maximum water velocity being governed largely by the size of the fish. Variations in preferances are greater between fish of one species when they are of different size (Ex. an 8 inch v.s. an 18 inch Kokanee) than between fish of different species the same size (Ex. 10 to 12 inch rainbow, cutthroat, brook and kokanee).

When developing water criteria for species of fish in a river study program, it is advisable to utilize measurements made on fish of the same species and size as those which will be utilizing the system. Measurements made in a similar drainage basin with corresponding run off patterns and substrate composition would be ideal.

Gravels: Generally 1/4 to 3 inch gravels are preferred with smaller fish often being limited to a 2 inch maximum. Larger fish such as steelhead will have a 5 inch maximum with 1/4 to 4 inch preferred. Excessive fines will reduce subsurface flow and suffocate the eggs.

FIGURE 6- TROUT LIFE HISTORY SUMMARY



S= Spawning

I= Incubation

M= Migration (up & down)

R= Rearing

* = Life spent in lakes

note: When streams flow into a lake many of the emerged fry will migrate downstream and rear in the lake.

Primary sources: Calhoun, Alex
Carlander, K.D.

TABLE 1

TROUT SPAWNING DATA SUMMARY

SPECIES	SOURCE	VELOCITY CRIT. fps	DEPTH CRIT. ft	GRAVEL inches	TEMP °F	MEAS No.	CRITERIA
Steelhead	Ore.	1.96-2.28	1.14-1.40			51	95% Confidence
winter	A.K.S.	1.27-2.85	above 0.8			115	80%
summer	A.K.S.	1.42-3.18	above 0.8			90V, 83D	80%
summer	A.K.S.	1.48-3.00	above 0.5			46	80%
winter	Engman	0.75-3.84	0.33-over 3		40-53	62	Range
summer	Idaho	0.80-5.1	0.7-over 5	70% ½-4	36-47	54	Range
winter	J.W.H.	1.2 -3.3	0.7 -2.3	¼-4	40-55	114	90%
winter	J.W.H.	1.45-3.57	0.4 -1.2	¼-5	46-48	19	Range
Rainbow	A.K.S.	1.60-2.98	above 0.6	¼-2*	40-55*	51	
	Calif.	1.4 -2.7	0.7 -1.1			10	
Cutthroat	Hooper	1.0 -3.0					
	Cedarhome	0.25-0.85	0.25-0.5			3	Range
resident	J.W.H.	0.35-1.25	0.2 -0.9	¼-2	40-55	23	Range
sea-run	J.W.H.	0.5 -1.83	0.4 -1.3	¼-4		16	Range
mixed	J.W.H.	0.35-2.37	0.2 -1.5			53	Range
Brown	A.K.S.	0.67-2.24	above 0.8	½-3*	45-55*	115	80%
	Calif.	1.0 -2.5				87	Range
Golden	J.W.H.	Similar to resident rainbows					
Dolly Varden	J.W.H.	1.13-2.15	0.7 -1.4	0-6	44	6	Range
Brook	A.K.S.	0.03-0.76	above 0.3			122	80%
	J.W.H.	0.33-1.36	0.4 -2.0	¼-3	35-50	120	80%
	O.G.C.	0.7 -2.1	above 0.8			115	
	Hooper	0.2 -3.0					
Lake	J.W.H.	Spawn on lake bottoms					
Kokanee	J.W.H.	0.4 -1.36	0.3 -1.1	0-3	44-54	177	80%
	A.K.S.	0.47-2.39	above 0.2			106	80%
Whitefish	J.W.H.		above 0.4	0-6	32-42		
Grayling	J.W.H.		above 0.4	0-6	40-52		

A.K.S. : Allan K. Smith, Oregon Game Commission
J.W.H. : John W. Hunter, Wash. Dept. of Game
O.G.C. : Oregon Game Commission

* J.W.H.

RECOMMENDED SPAWNING CRITERIA

Present methods of determining water depth and velocity criteria for salmonoids involve making field measurements on spawning sites and utilizing a percentage (often the middle 80%) of the measurement results. This resultant criteria is then commonly presented in a manner which appears significant to two or three figures on the right of the decimal point. As previously discussed (see Methods of Taking Spawning Measurements), these results are often a reflection of the stream's hydraulic conditions. Measurements from many streams of varying discharge are needed to accurately describe spawning preferences for each species of fish. Even within a species the depth and velocity preferences will vary with the size of the fish which will regulate minimum depths and maximum velocities. Interspecies spawning preferences for salmonoids of the same size will be closer than intraspecies requirements for fish of varying size. Water velocities and depths obtained from making measurements on a river will therefore be a function of fish size, stream discharge, and channel characteristics.

The information available on spawning measurements (Table 2) exhibits a wide variation of data results within each species. Rather than being conclusive within itself each source should be considered a sample and weighted according to the number of measurements and number of streams sampled. An effort should be continued to expand the number of samples for each species so that a more comprehensive criteria evaluation can be made in the future.

Upper velocity criteria figures should be adjusted as recommended in the Correction Factor Experiments.

TABLE 2

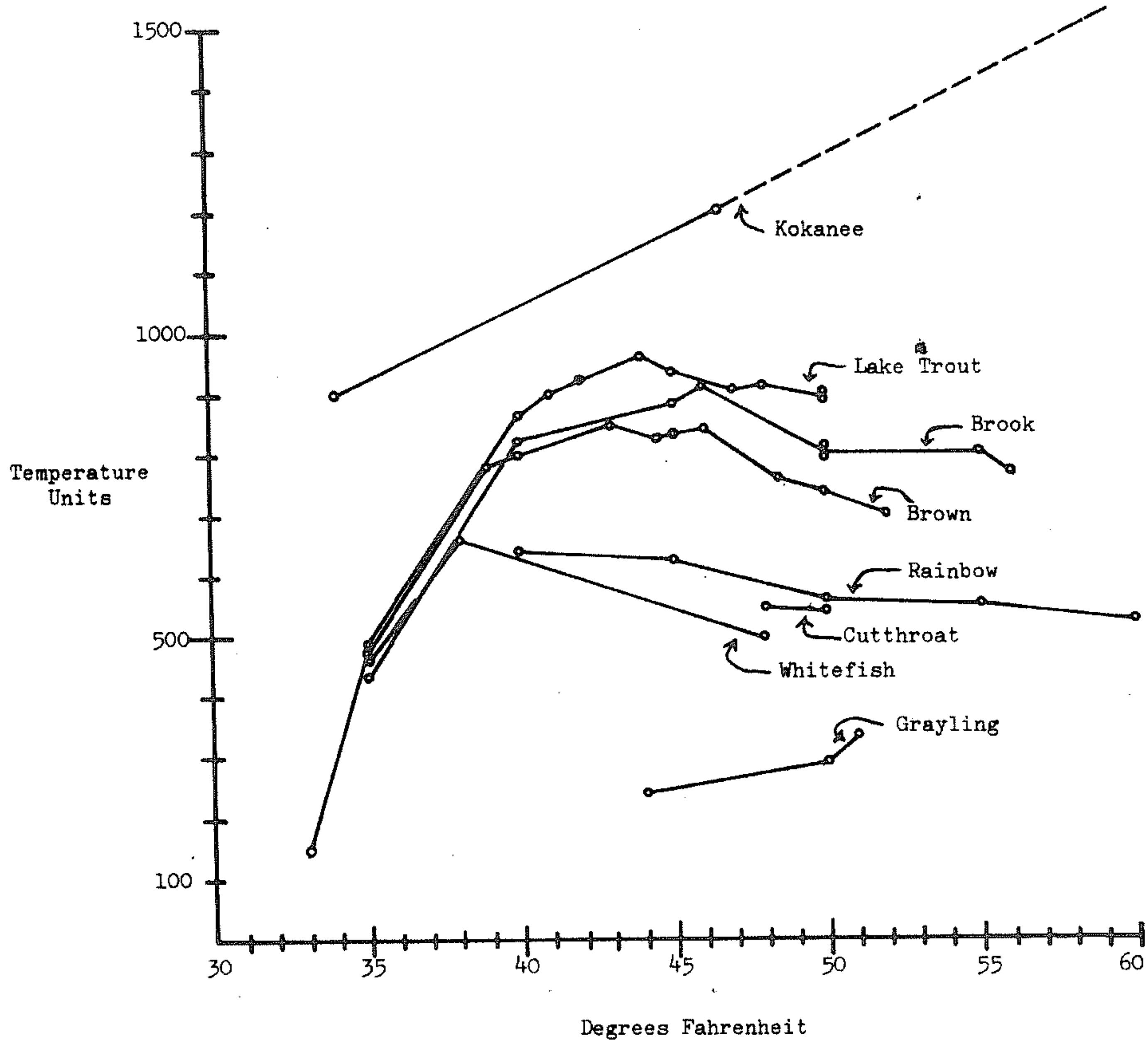
RECOMMENDED SPAWNING CRITERIA BY SPECIES

	Velocity f.p.s.	Depth ft.
Steelhead	1.2 - 3.3	above 0.7
Rainbow	0.7 - 3.0	above 0.3
Cutthroat	0.5 - 2.0	above 0.3
Brown	0.7 - 2.5	above 0.3
Dolly Varden	0.7 - 2.5	above 0.3
Brook	0.4 - 2.1	above 0.3
Kokanee	0.4 - 2.5	above 0.3

Generalized Spawning Criteria for Rainbow, Cutthroat, Brown Trout, Dolly Varden, Brook and Kokanee.

Velocity	Depth
0.5 - 2.5 fps.	above 0.3 ft.

FIGURE 7 - Temperature Units Required For Salmonid Eggs To Hatch



One Temperature Unit equals one degree fahrenheit above freezing for 24 hours.

Primary Sources: Calhoun, Alex
Carlander, K. D.

Steelhead (Salmo gairdnerii)

DESCRIPTION: Pre-smolt fish are described under rainbow trout. Saltwater fish and fresh stream migrants are blue-black to a very dark green on the back and tail. The sides are a bright silver with a few spots visible above the lateral line. After a few days in fresh water the fish will become darker and the pink lateral streak will become more prominent. Rays on fins are as described for rainbow.

GENERAL: After hatching these rainbow trout will usually spend two years in fresh water. In the late spring of their second year they will reach a migratory size of six to eight inches. During this period the fish will smolt and go to sea. These steelhead will generally spend two years at sea before reaching sexual maturity. Diet of the young fish is the same as described for rainbow. Steelhead at sea feed mostly on fish with some squid and amphipods.

SPAWNING: There are two distinct types of steelhead in Washington. Winter steelhead re-enter fresh water streams from November to June and summer steelhead usually move upstream from May through September. Adult fish range from two to seven years old at maturity, with four of five years being predominant. Steelhead are considered main-stream spawners but they will spawn in tributaries and side channels. Spawning can occur more than once a lifetime with repeat spawners making up from 5 to 10% of the total run. Females will lay near 3,000 eggs in a nest at water temperatures of 40 to 55 degrees Fahrenheit. Incubation will take 31 days at 50 degrees Fahrenheit and 48 days at 45 degrees Fahrenheit.

Measurements made by A. K. Smith (OGC) on 115 winter steelhead redds had the following results:

Water velocity range: 1.07 to 3.34 fps	Average: 2.06 fps
Water depth range: 0.6 to 3.5 feet	Average: 1.37 feet
80% velocity criteria: 1.27 to 2.85 fps	
Water depth greater than 0.8 feet	

Measurements by A. K. Smith (OGC) on 90 (velocity) and 83 (depth) summer steelhead redds gave the following results:

Water velocity range: 1.20 to 4.20 fps	Average: 2.30 fps
Water depth range: 0.4 to 2.7 feet	Average: 1.33 feet
80% velocity criteria: 1.42 to 3.18 fps	
Minimum recommended water depth: 0.8 feet	

Measurements by A. K. Smith (OGC) on 46 summer steelhead redds gave the following results:

Water velocity range: 0.82 to 3.47 fps	Average: 2.24 fps
Water depth range: 0.4 to 1.3 feet	Average: 0.71 feet
80% velocity criteria: 1.48 to 3.00 fps	
Minimum recommended water depth: 0.5 feet	

Measurements made by R. G. Engman (WDG) and Orcutt, Pulliam and Arp are summarized on the following data sheets.

Measurements made by J.W. Hunter (WDG) on 19 winter steelhead redds for the correction factor experiment (this paper) game the following results:

Water velocity range: 1.45 to 3.57 f.p.s. Average: 2.22 f.p.s.
Water depth range: 0.4 to 1.2 ft. Average: 0.8 ft.

The following is a discussion of measurements made by J. W. Hunter (WDG) and results may be found on the following data pages.

For 232 individual redd measurements in 19 streams water depths averaged 1.7' in pit, 1.1' over tailspill and 1.3' in the adjacent surrounding area. Range of depths concerned with overall redd construction were 0.5' to over 2.4' with the shallower measurements usually associated with smaller rivers. Most of the redds measured were found immediately above riffles, along side banks or gravel bars.

Comparison of water depths between the active redds and the overall sample shows the active sites have a deeper pit and tailspill with corresponding deeper surroundings (Table 5). The fairly consistent differences suggest that the older redds measured were constructed during a deeper flow, or exhibit gravel redistribution from river flow.

One hundred and fourteen velocity measurements were taken on 60 fresh and/or active redds. The range 1.23 ft/sec. - 3.48 ft/sec. and average 2.25 ft/sec. were comparable to studies done previously (Figure 8) and show a relatively normal distribution with 75% of all measurements falling between 1.6 ft/sec. - 2.9 ft/sec.

Size measurements on 128 individual redds averaged 4.17 square yards with variability being as great within a stream as between streams (Figure 8). The Skookumchuck River had the smallest redds due to the lack of suitable spawning gravel resulting in irregular shaped redds positioned wherever gravel was available. Size was determined by breaking the redd into trapezoids and determining area.

Inter-redd spacing does not appear to be crucial. Redds were found individually and in tightly grouped clusters sometimes overlapping each other prohibiting measurement. Commonly two or more redds were located in close proximity to one another when sufficient gravel and flows were present.

Gravel sizes varied widely in individual samples with an average of 1/4 - 4 inch predomination; extensive fines and boulders to 8 inches were present in many samples. Few redds were found where large boulders predominated or where fine gravel and silt compacted the stream bed.

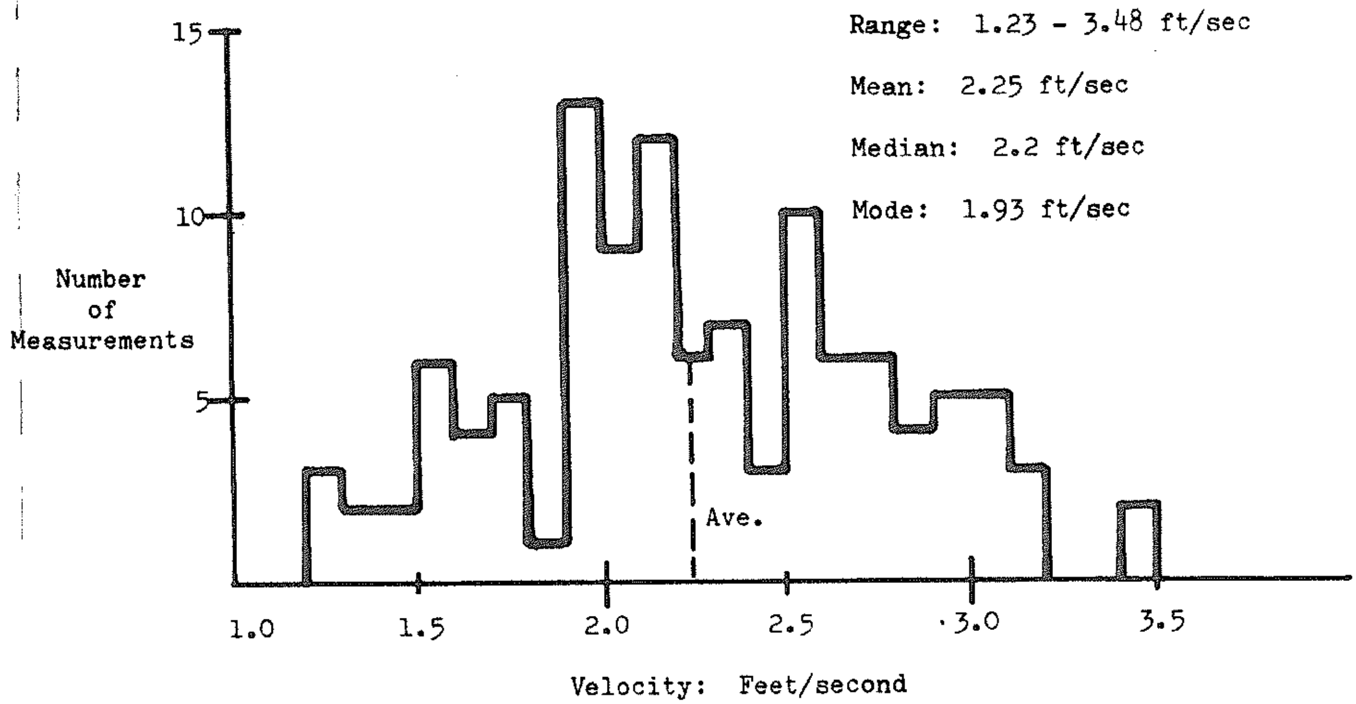
An effort was made to find a relationship between water depths and velocities. No apparent correlation was noted for all stream studies or within individual rivers.

All redds measured by J.W. Hunter were from winter steelhead.

TABLE 3

River	Date 1972	Temp.	Gravel	Yd.² Ave. Size	# Meas. for Size	@ .4' ft/sec Ave. Flow	No. of Meas.	Ave. Water Depth-Ft. Pit	Tail	In-Side	Out-Side	Total No.
Neissen Cr.	4/19	42°F	1-3"	2.91	4		0	1.0	.4		.6	5
LeDoux Cr.	4/19	42°F	3-4"	3.63	1		0	1.0	.5		.8	1
Wallace	4/20	44°F	2-3"	6.38	8	2.32	5	1.4	.8	.86	1.3	10
W. Wynoochee	4/24	40°F	½-3"	4.77	8		0	1.4	.95	.8	1.2	8
Wynoochee	4/25	40°F	½-3"	4.55	17	2.13	1	1.5	1.0	1.0	1.2	20
Illabot Cr.	4/28	43°F	½-3"	4.78	7		0	1.5	1.1	.8	1.3	19
S. Toutle	5/1	44°F	1-4"	5.44	6	2.12	6	2.1	1.4	1.6	1.8	8
N. Toutle	5/2	45°F	1-5"	3.64	15		0	1.6	.9	1.3	1.3	20
Green	5/3	49°F	1-4"	4.24	8	2.62	6	2.3	1.5	1.0	1.7	29
Chehalis	5/4	47°F	½-4"	3.90	1		0	1.4	.7	1.0	1.2	4
E. Fork	5/4		0-3"	3.55	6		0	1.4	.7		.8	17
W. Fork	5/5	53°F	¼-4"	3.21	4		0	1.2	.7	.7	.8	14
N. Newaukum	5/8	48°F	2-4"	2.34	1		0	1.7	1.2	1.3	1.6	1
Nisqually	5/11	48°F	1-4"	3.81	21	2.42	44	2.0	1.4	1.6	1.8	29
Humptulips	5/15	53°F	¼-4"	3.03	6		0	2.0	1.4	1.4	1.6	11
Skookumchuck	5/17	42°F	¼-4"	1.42	2	2.15	4	1.4	.7	1.0	1.1	5
Bogachiel	5/18	51°F	¼-4"	4.45	5	1.80	6	2.4	1.8	2.0	2.0	10
Hoh	5/19	45°F	½-4"	4.64	5	2.14	20	1.7	1.2	1.2	1.5	10
Clearwater	5/19	51°F	¼-4"	3.31	3	2.08	22	1.6	1.0	1.0	1.2	11
Totals and Averages				4.17	128	2.25	114	1.7	1.1	surroundings	1.3	232

FIGURE 8 - Distribution of Flow Measurements @ 0.4 ft. 114 samples



Distribution of Redd Size: 128 Samples

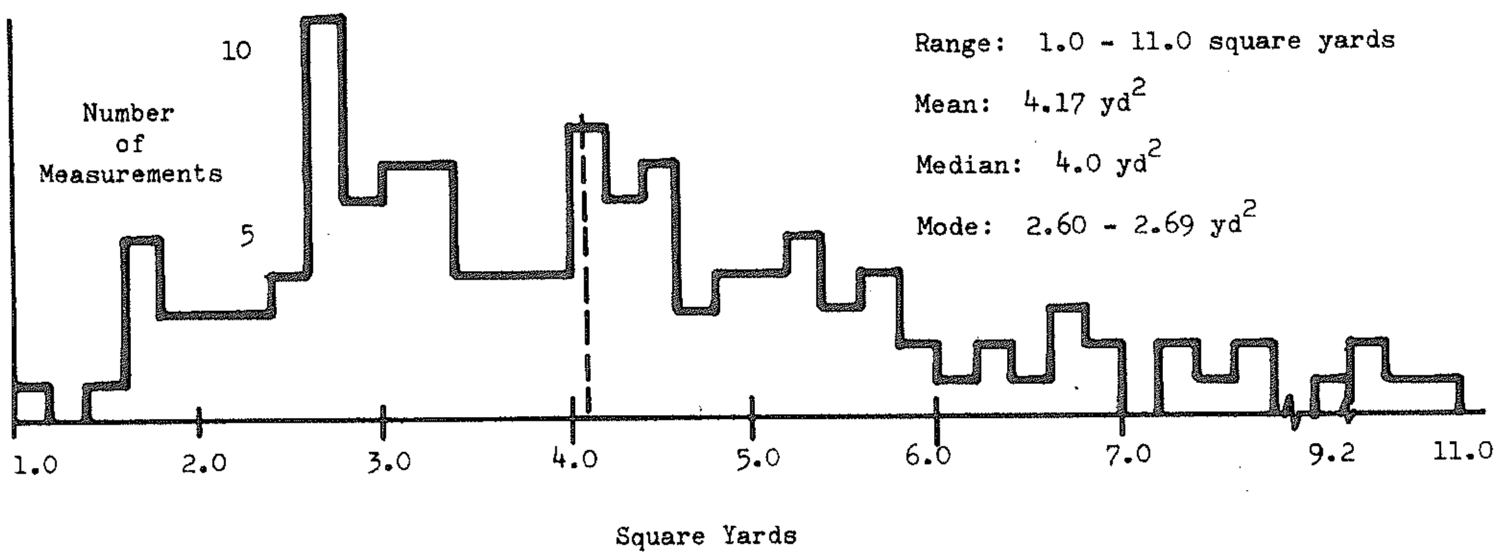


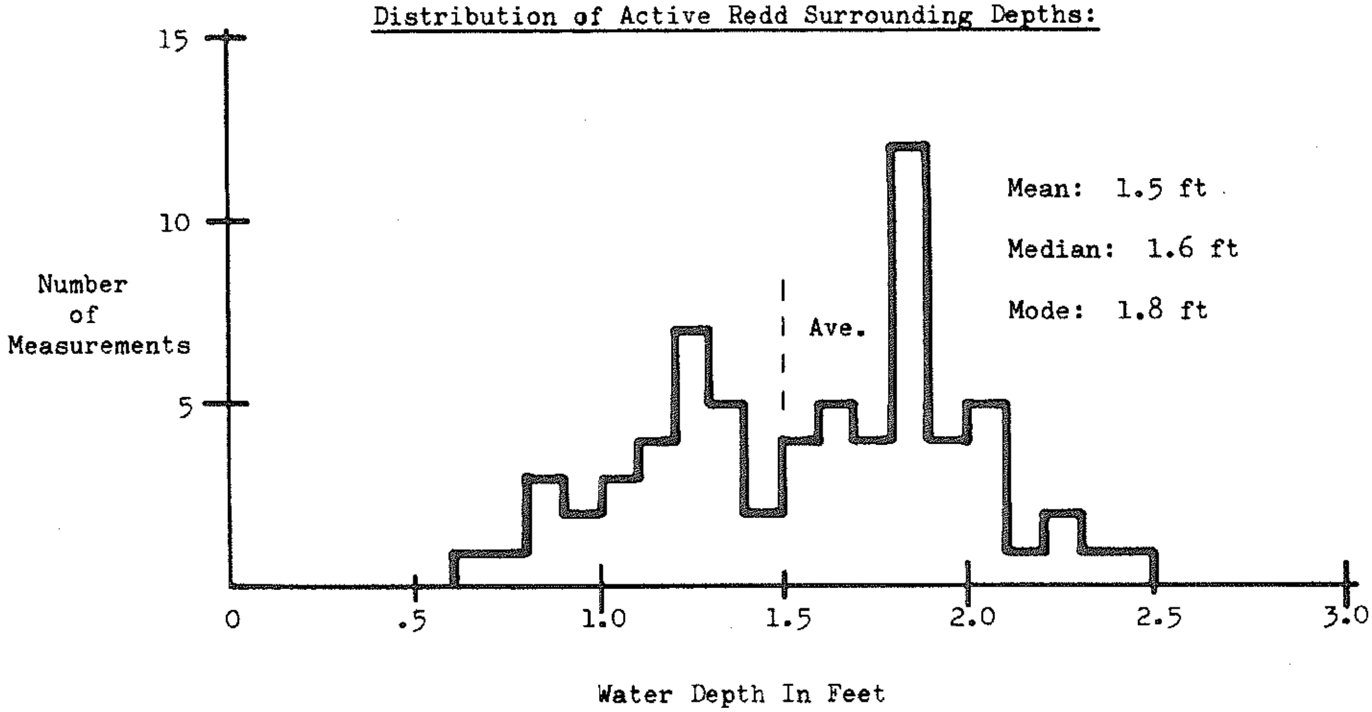
TABLE 4

Western Washington Steelhead 4/19/72-5/19/72		Wash. Winter Steelhead 1968-1971	Idaho Summer Steelhead 1958-1959
Flow measurements:	(Fresh and/or active)	ft/sec	ft/sec
114 @0.4 ft	Range: 1.23 - 3.48 ft/sec	.75 - 3.84	
	Ave: 2.25 ft/sec		2.3 - 2.5
5 @ Surface	Range: 2.0 - 3.95 ft/sec		0.8 - 5.1
	Ave: 3.42 ft/sec		2.8 - 3.5
Redd size: 128 samples		square yards 62 measured	square yards 54 measured
	Range: 1.0 - 11.0 yd^2	1.23 - 12.22	2.5 - 13.4
	Ave: 4.17 yd^2	5.25	6.5
Water depth: 232 measured			
	Ave. Pit: 1.7 ft.		
	Ave. Tail: 1.1 ft.		
	Surroundings: 1.3 ft. Ave Range: 0.5 ft. - over 2.4 ft.	Range: 0.33-over 3	Range: 0.7-over 5
Temp. Range: 40° - 53°F		40° - 53°F	36° - 47°F
Gravel Size: ¼ - 4"			70% (½ - 4")

TABLE 5 - Steelhead Redd Measurements, Active Redd Water Depths

Active Redd Water Depth (67 redds)	Total Sample - (232 redds)
Pit:	Pit:
Range: 0.8 - 3.0 ft	
Ave: 1.86 ft	Ave: 1.7 ft
Tailspill:	Tailspill:
Range: 0.3 - 2.3 ft	
Ave: 1.23	Ave: 1.1 ft
Surroundings: (Approx. depth at construction	Surroundings:
Range: 0.6 - 2.4 ft	Range: 0.5 - over 2.4 ft
Ave: 1.52 ft	Ave: 1.3 ft

Distribution of Active Redd Surrounding Depths:



Rainbow (Salmo gairdnerii)

DESCRIPTION: Rainbow exhibit a wide variety of coloration with back generally bluish-green, silver sides and belly. Small dark spots on the body are scattered and irregular in size. A red streak often extends along each side of the body. No teeth on back of tongue. The rays on the dorsal fin number 10 to 12, and on anal fin, 8 to 12. The gill rakers in first arch number 17 to 21. Scales number 115 to 161 in oblique rows. Breeding males will possess more red coloration.

GENERAL: Sea-run rainbows are called Steelhead and will be discussed in that section. Resident rainbow trout eat a variety of foods including immature and adult aquatic insects, zooplankton, terresterial insects, and fish. Preferring temperatures below 70 degrees Fahrenheit, rainbows will tolerate from 32 to over 80 degrees Fahrenheit. Acclimation will occur to concentrations of zero to 3.5% salt and to a pH of 5.8 to 9.5. These nonanadromous fish usually spawn at 3 years; males mature younger than females and may spawn at age one or two.

SPAWNING: Occurs in the spring when the female will lay 800 to 9,000 eggs that will hatch in 31 days at 50 degrees Fahrenheit or 48 days at 45 degrees Fahrenheit. Preferred gravel size will range from one fourth to three inches with larger fish being able to move larger gravel. Measurements made on 51 redds by A. K. Smith (OGC) gave the following criteria which is the middle 80% of the data:

Water velocity: 1.60 to 2.98 f.p.s.	Average: 2.29 f.p.s.
Water depth: 0.6 ft. or deeper	Average: 1.12 feet

Measurements made on ten redds in California with 12 to 14 inch fish gave the following results:

Water velocity: 1.4 - 2.7 f.p.s.	Average: 2.26 f.p.s.
Water depth: 0.7 - 1.1 ft.	Average: 0.92 ft.

Most redds averaged about 2.5 square feet in size.

Cutthroat (Salmo clarki)

DESCRIPTION: Body color is olive-green on the sides, darker green above and silvery underneath. Irregular spots are heavily scattered across the body and fins, concentrated toward the tail. The tips of the anal and ventral fins may be yellowish to orange. Red slash marks are visible under each side of the lower jaw. Small teeth on back of tongue distinguish it from the Rainbow. The tail is slightly forked, being squarer in large fish. Rays in the dorsal fin number 8-11 and in the anal fin 8 to 12. Scales number 120 to 180 in oblique rows. Gill rakers in first gill arch number 14 to 22.

GENERAL: Most Cutthroat six to nine inches long will migrate to sea with the spring high waters if possible. These sea-run Cutthroat are discussed under Salmo clarki clarki. The ones that can't or don't migrate spend their life in fresh water on a diet of Diptern, Coleoptera, Ephemeroptera and other insects, shrimp, crayfish, salmon and trout eggs, worms and small fish. Older fish become more predatious on small fish. Has a strong tendency toward hybridization with other trout.

SPAWNING: The three to four year old mature fish will migrate up streams to spawn in the spring. Gravel size will generally be zero to three inches, larger fish being able to move larger gravel. Depth and velocity measurements by J. W. Hunter (WDG) are on the following data sheets along with sea-run cutthroat data. The larger sea-run variety apparently prefers slightly deeper and faster water. Redd size ranges from about one to ten square feet with resident cutthroat. Spawning temperatures range from 40 to 55 degrees Fahrenheit. Cutthroat do not die after spawning. Females generally lay from 400 to 1,500 eggs which will hatch in 28 to 40 days or 30 days at 50 degrees Fahrenheit with two days longer for each degree Fahrenheit below 50 degrees Fahrenheit. D. Hooper (PG & E) recommends a velocity of 1.0 to 3.0 fps. Results from three measurements made by J. Cedarhome (DNR) were; velocity: 0.85, 0.53, and 0.25 fps and depth: 0.5, 0.43, and 0.25 ft.

Coastal Cutthroat (Salmo clarki clarki)

DESCRIPTION: The sea-run cutthroat has a deep blue back and silvery sides. The slash under the throat (common to resident cutthroat) will disappear in sea water. Their longer heads, more numerous scales and small teeth on the back of the tongue will distinguish salt water cutthroats from steelheads.

GENERAL: Resident cutthroat will migrate to sea when six to nine inches long in the spring and become sea-runs that generally feed in tide-influenced areas with occasional visits up streams. The salt water diet consists of small fishes (salmonids, sand lance, rockfish, sea perch, sculpins, flatfishes) and crustaceans. Their freshwater diet is typical of Salmo clarki.

SPAWNING: The three to four year old fish will migrate upstream from February to May when water temperatures range from 40 to 55 degrees Fahrenheit. Gravel size ranges from zero to five inches with larger fish being able to move larger rock. Redd size will range from 2.5 square feet to 15 square feet with large specimens making a redd of steelhead proportions. Measurements made by J. W. Hunter (WDG) are on the following data sheets. The 53 measurements made on resident and sea-run cutthroat consist of both these two groups and a group which was undecided as to whether the fish were resident or sea-run. The larger sea-run fish seem to prefer deeper and faster water than the resident cutthroat.

FIGURE 9: Resident and Sea-Run Cutthroat Redd Measurements - Depths

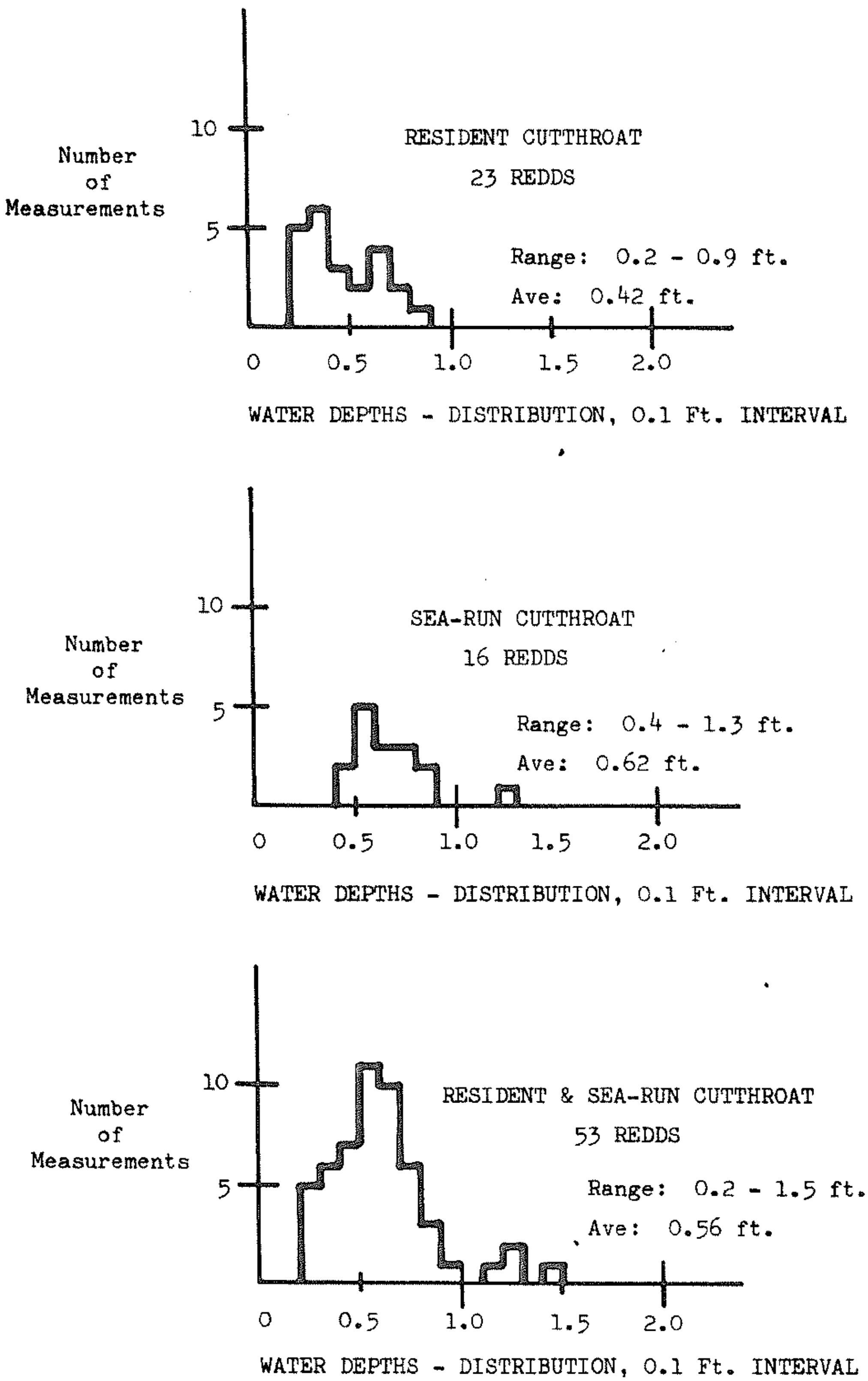
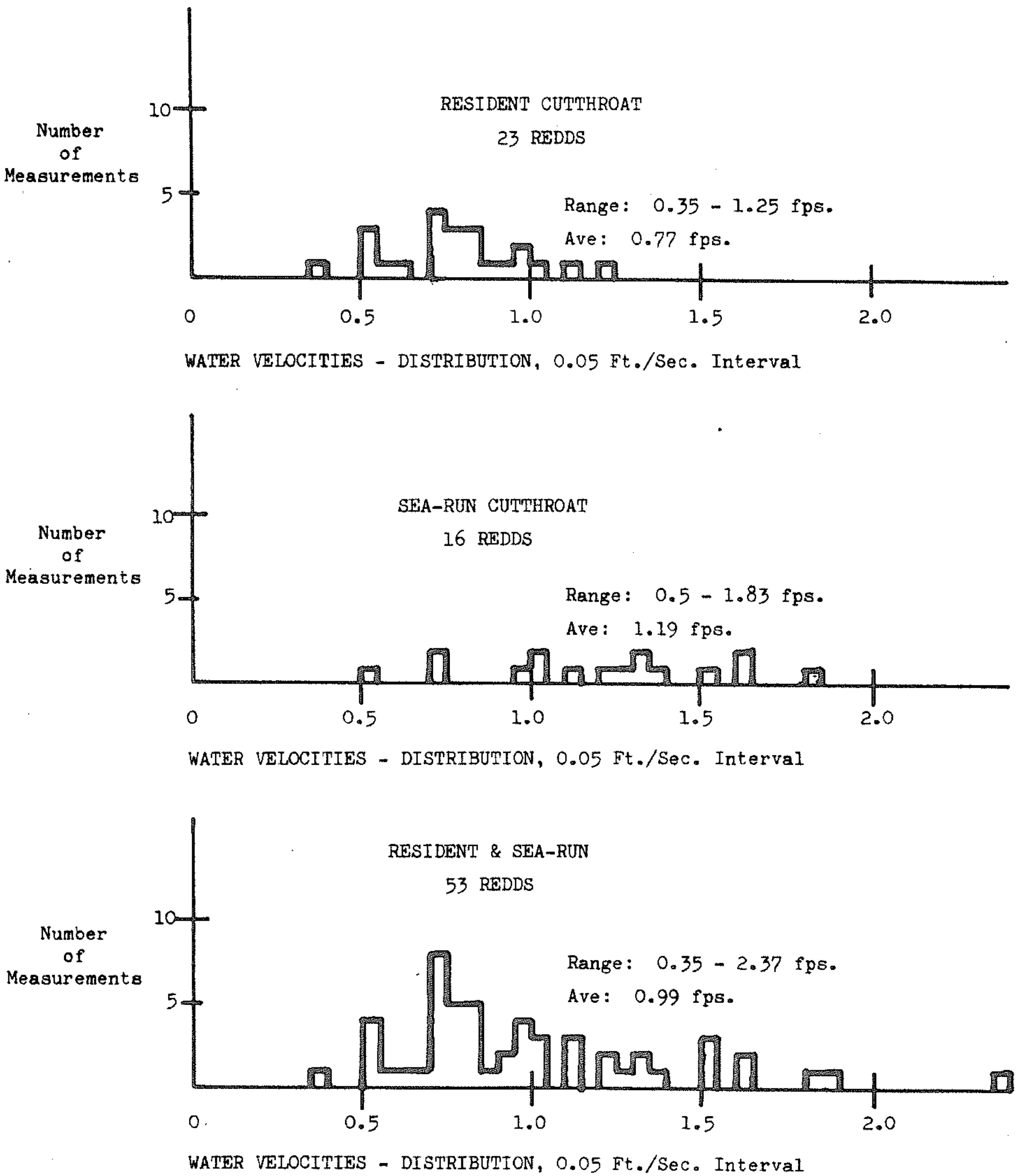


FIGURE 10 - Resident and Sea-Run Cutthroat Redd Measurements - Velocities



Brown Trout (Salmo trutta linnaeus)

DESCRIPTION: Brown is the ground color with the usually olive brown back and sides becoming a dull yellowish or whitish ventrally. The sides are usually marked with large dark brown or black spots which are characteristically ringed with light halos. The number and intensity of the spots diminishes ventrally. The adults have squarish tails and the young have moderately forked tails. There are 115-150 cycloid-type scales in the lateral line. The dorsal fin has 10 to 11 rays, anal fin 9 to 12. Gill rakers 16 to 19. The dark spots on a light background will separate the brown from brook and lake trout which have light spots on a dark background. The black spots are lacking on the head and caudal fin, a characteristic which will separate the brown from rainbow trout. Male brown trout develop a hooked lower jaw during the spawning season.

GENERAL: Browns prefer cool lakes and stream, although they have a greater ability to withstand warm waters than many other trout species. Small browns eat mostly invertebrate food consisting of earthworms, crayfish and insects such as mayflied, caddis flies and stoneflies. As brown trout grow larger they consume more crayfish and fish, with young fish making up to 70% of the diet. This habit has earned brown trout the reputation for eating more fish than other trout species.

The minimum dissolved oxygen level tolerated at 68 degrees Fahrenheit is approximately five ppm or 4.5 mg/l in winter and 2.5 to 3.0 mg/l in summer. Brown trout are most active and growth is best when water temperatures range between 65 degrees and 75 degrees Fahrenheit although this species has tolerated water temperatures up to 81 degrees Fahrenheit for short periods.

Resting brown trout appear to prefer velocites from 0.4 to 0.7 f.p.s. Resting sites are frequently in shaded areas and near the bottom. A strong thigmotactic response (fish in near contact with an object) may substitute for a lack of overhead cover. Areas less than two inches deep and less than eight inches square within the suitable velocity range are avoided along with high turbulence and open water areas.

The upper critical temperature for brown trout acclimated at 41 degrees Fahrenheit was 72.5 degrees Fahrenheit, at 50 degrees Fahrenheit was 75.5 degrees Fahrenheit, at 68 degrees Fahrenheit was 76.8 degrees Fahrenheit and the ultimate limit was 77.5 degrees Fahrenheit. Tests with sac fry acclimated at 41 to 43 degrees Fahrenheit indicated that 71.5 degrees Fahrenheit was the lethal limit for 50% in seven days.

SPAWNING: Browns spawn from October to January preferring to ascend cold, clear tributaries of the parent body of water. Spawning fish prefer shaded areas and points where percolation of spring waters exist. Preferred water temperatures for spawning range from 45 degrees to 55 degrees Fahrenheit. Gravel preference ranges from 0.25 to 3.0 inches in diameter with a larger fish being able to move larger gravel.

Water velocity measurements made by A. K. Smith (Oregon Game Commission) over 115 redds on 5 different streams (taken at 0.4 feet above stream bed) ranged from 0.60 to 3.80 feet per second. The average velocity was 1.458 fps with a standard deviation of 0.5413. His recommended criteria was 0.67-2.24 fps. Measurements made in California in the Pleasant Valley spawning channel ranged from 1.00 to 2.5 fps with an average of 1.53 fps over 87 redds and taken at 0.25 feet above the redd.

Water depth measurements made by A. K. Smith on 115 redds ranged from 0.5 to 3.3 feet with an average of 1.396 feet and a standard deviation of 0.5441. He recommends a minimum depth of 0.8 feet.

The number of eggs deposited by a female ranges from 400 to 2,000 and is proportional to the size of the fish. The hatching period varies from 40 to 70 days.

Golden Trout (Salmo aquabonita)

DESCRIPTION: In body form the golden is similar to the rainbow but the scales are smaller and hardly overlap. Distinctive parr markings of adult fish, deep orange color of fins and belly and reddish gill covers are distinguishing features. A red band extends from the gills to the length of the body. Another red stripe runs along the belly from the throat to the anal fin. The ventral, pelvic and anal fins are tipped with white. The upper parts of the body are yellowish-olive and sides below the lateral line are golden yellow.

GENERAL: Because it subsists largely on plankton, the golden is best adapted to high, rock-bound lakes which contain this food source. Goldens are primarily insectivorous, if given the opportunity, and prefer caddis fly larvae and midges, but also thrive on a microcrustacea diet of straight plankton.

Average size of mature females is around nine inches. Goldens can reproduce efficiently in high, cold mountain lakes, but must have stream spawning grounds to produce a population large enough to withstand moderate fishing pressure. This game fish is considered large at 12 inches and a fish of two pounds or more is unusual.

The golden can tolerate temperatures as high as 72 degrees Fahrenheit, but is not usually found in waters that warm. They sometimes occur simultaneously with rainbow trout (with which they readily hybridize) or eastern brook trout. They tend to lose out in competition with brook trout and should not be stocked in brook waters.

SPAWNING: Spawning takes place from June to late August depending upon when the ice thaws off the lake. Temperatures of 44 to 55 degrees Fahrenheit are preferred when the three or four year old female will lay from 300 to 2,000 eggs. Water depths and velocities would be expected to be similar to other trout of the same size.

Dolly Varden (Salvelinus malma)

DESCRIPTION: The general color is olive-green, becoming white on the belly. Many round, light spots appear on the sides and upper portions of the body. Near the lateral line the spots are usually orange or red and larger than adjacent markings. Pectoral, pelvis, and anal fins are often edged in white. Sea-run fish are silvery and the spots pale. The dorsal fin has 10 or 11 rays, the anal fin usually 9 rays. Gill rakers in the first arch number 14 to 22 and the scales are in 186 to 254 oblique rows. The Dolly lacks the vermiculations found on the other two char, the brook and lake trout.

GENERAL: The Dolly Varden will migrate out to sea when able and reach sizes of 15 pounds in three or four years. Fresh water diet consists of fish, snails, leeches, amphibians, crustaceans and insects. Many biologists consider Dollys harmful because of the large numbers of young fish they eat but a study involving stomach analysis of thousands of fish indicates a similar diet to cutthroat. Dollys will travel in schools when migrating upstream in the summer and these temporary concentrations may upset the balance of other species in the streams.

SPAWNING: Spawning occurs from August through November in streams. The eggs are small (500 to 550 to the ounce) and make up about one-fifth of the body weight of the female. Measurements made on six active redds with eight to ten pound resident fish gave the following results:

Water Velocity:	Range 1.13 to 2.15 fps	Average: 1.71 fps
Water Depth:	Range 0.7 to 1.4 feet	Average: 1.05 feet
Gravel:	30% 0 to 1", 60% 1 to 4", 10% 4 to 8"	
Redd Size (3):	49.38 feet^2, 42.92 feet^2, 21.51 feet^2	Average: 37.98 ft^2
Temperature:	44 degrees Fahrenheit	Date: 10-20-72

This small number of measurements is not enough to establish criteria but the system in which these measurements were taken offered a variety of depths and velocities so that these results indicate fish preference and are not just a reflection of the only hydraulic conditions available.

Eastern Brook (Salvelinus fontinalis)

DESCRIPTION: Brook trout, a char, have an olive green to black back, light sides and a white belly. Small red dots which center blueish rings are found on the sides and there are vermiculations along the back and dorsal fin. The lower fins are edged with white backed by black along their leading edge. Small scales, square tail and a stocky body contour are found on this fish. The dorsal fin has eight to ten rays, the anal fin seven to nine. Gill rakers number 16 to 22. The scales are in 197 to 236 oblique rows.

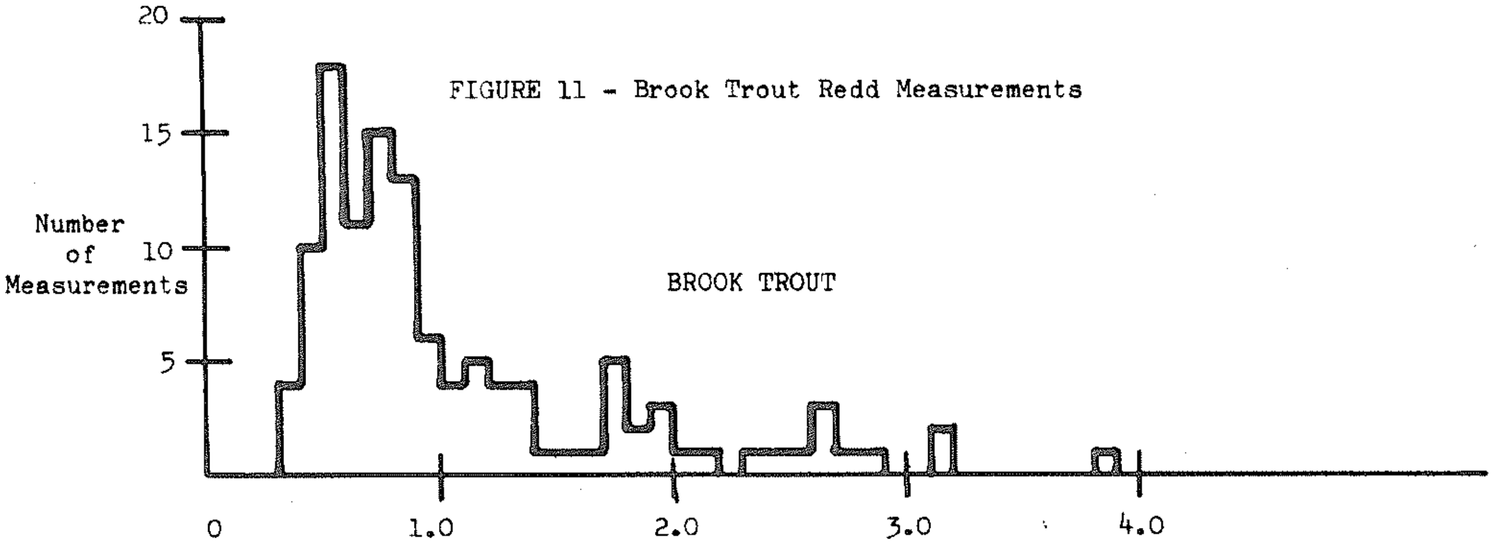
GENERAL: The brook is common in cool, clear headwater ponds, spring-fed streams and in large lakes having cool, well oxygenated, lower layers of water. Feeding is most active at 55 to 66 degrees Fahrenheit, optimum temperature is near 55 degrees Fahrenheit. Minimum temperature is near 38.5 degrees Fahrenheit. Upper lethal temperatures range from 70 to 80 degrees Fahrenheit depending on acclimation of the fish. Food consumption doubles every 5.5 degrees Fahrenheit up to 55 degrees Fahrenheit when it equals half the body weight per week. Food consumption falls off at higher temperatures.

The diet consists of caddis flies, stonefly nymphs, insect larvae, crustaceans, other fish and most aquatic organisms. Though a fast growing fish, the brook will be stunted when an excessive population exists. Hybridization with rainbow and cutthroat rarely occurs as the spawning times of the two "trouts" are in the spring and the brook in the fall. Young fish wander and give the brook wide distribution in introduced areas. May be called speckled trout.

SPAWNING: Sexual maturity may be reached in one year though two to three is more common. Spawning takes place in the late fall in cool water of 35 to 50 degrees Fahrenheit. Brook will spawn in graveled lake bottoms where seepage will aeriate the eggs or in spots where no seepage exists. Most spawning however occurs in streams (when available) and a redd is made following the manner of most trouts. Preferred gravels range from coarse sand to 3" rock with larger fish being able to move larger gravel. Eggs will hatch in 65 days at 46 degrees Fahrenheit, 45 days at 50 degrees Fahrenheit and 32 days at 56 degrees Fahrenheit.

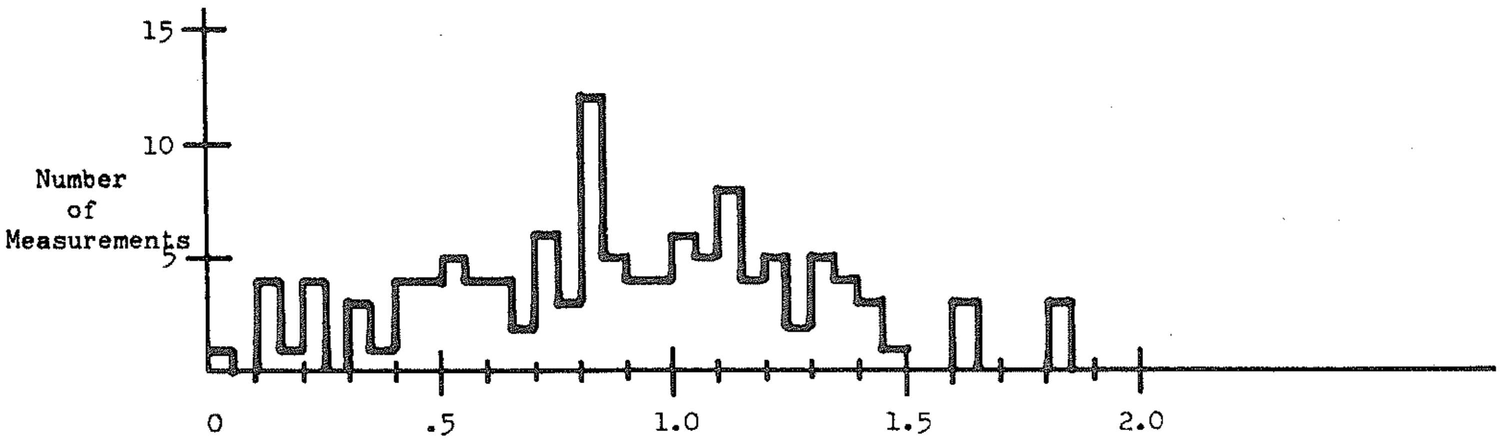
In lakes after spawning occurs the eggs will hatch in 90 to 120 days with cooler water temperatures. A yearling female may produce 250 eggs and a three year old over 2,000, approximately 3,500 eggs per kg. On the following brook trout data page, spawning data is summarized with recommended criteria by J. W. Hunter and A. K. Smith being the middle 80% of their data.

FIGURE 11 - Brook Trout Redd Measurements



WATER DEPTHS - DISTRIBUTION 0.1 Ft. Interval

120 Measurements



WATER VELOCITIES - DISTRIBUTION 0.05 Ft./Sec. Interval

120 Measurements

BROOK TROUT SUMMARY	J.W. Hunter W.D.G.	A.K. Smith O.G.C.	K. Thompson O.G.C.	D.R. Hooper P.G. & E.
Sample Size	120	122	115	
Velocity Range	0.0 - 1.83	0.0-1.32 fps		
Velocity Mean (Ave.)	0.87 fps	0.366		
Recommended Criteria	0.33 - 1.36	0.03 - 0.76	0.7 - 2.1	0.2 - 3.0
Water Depth Range	0.3-3.8 ft.	0.1-2.5		
Water Depth Mean	0.03 ft.	0.818		
Recommended Criteria	0.4-2.0 ft.	Above 0.3	0.8	

Kokanee (Oncorhynchus nerka)

DESCRIPTION: Body slender and compressed with teeth and jaws strongly developed and hooked in breeding males. Generally silvery in appearance, sometimes with a few dark markings on the dorsal fin. Both males and femlaes turn reddish during spawning season. Young exhibit a uniform green back without mottlings, sides silvery with no green iridescence. Parr marks short and oval, not extending above the height of the eye but generally above the lateral line; the light areas along the lateral line larger than the dark areas. Gill rakers on first arch 30 to 40, long slender and rough. Scales in the first row above the lateral line number 125 to 143. Rays on dorsal fin, 11 to 16; rays of anal fin 13 to 17 (trout and char have 12 or less in the anal fin).

GENERAL: Kokanee is a variety of sockeye salmon which completes its life cycle in fresh water. These fresh-water sockeyes are sometimes given the subspecies name of "kennerlyi" to distinguish them from the sea going form.

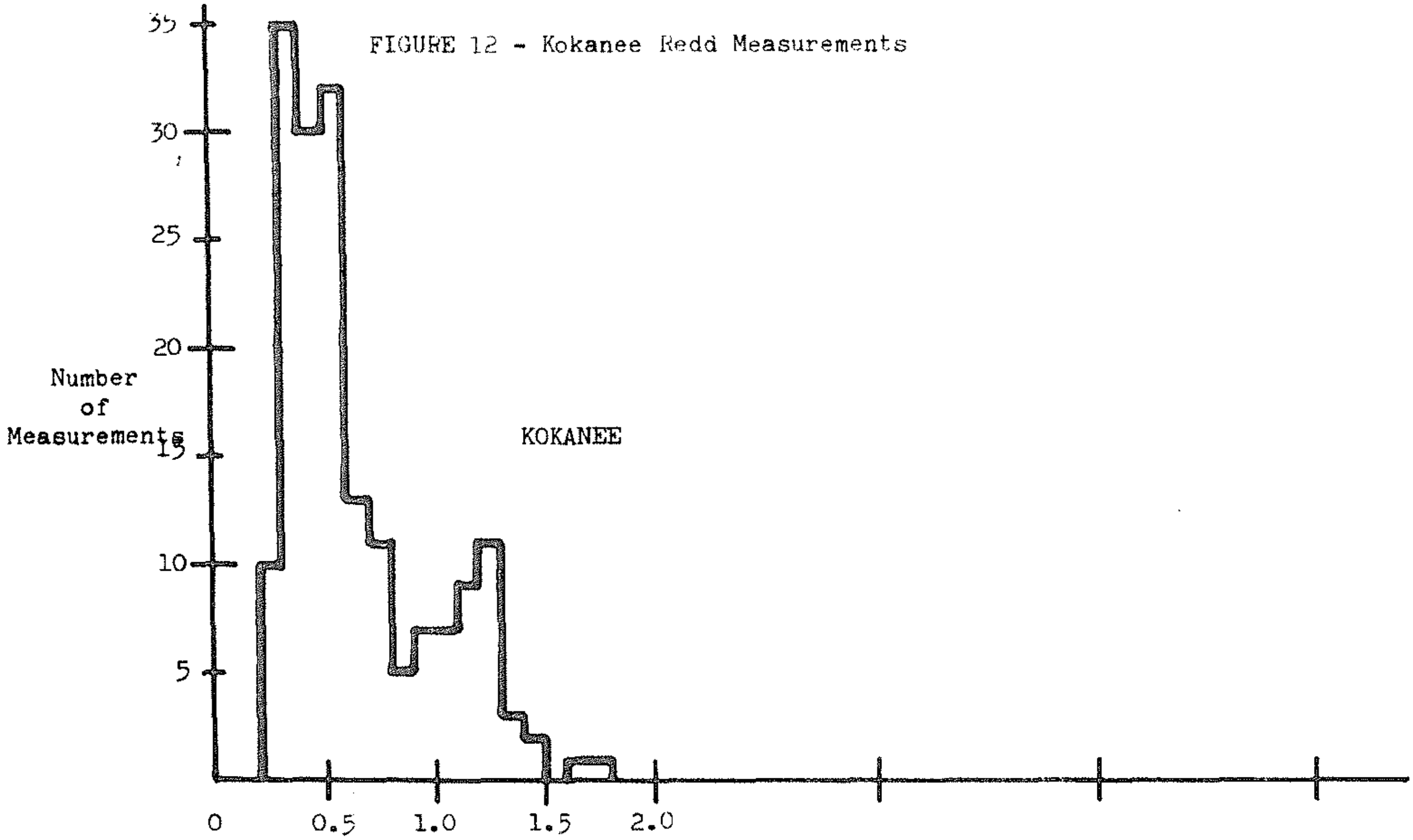
Diet consists largely of plankton and may be supplemented by copepods, cladocera and insects. Cool water is required with 50 degrees Fahrenheit being preferred and mortalities occuring at 60 degrees Fahrenheit. Life history cycles vary from two to seven years with four years generally predominating. Males grow faster than females.

SPAWNING: From the lake, upstream migration is only a short distance for spawning and may occur in gravelled lake bottoms in the absence of streams. Being a salmon, the kokanee die after spawning.

Spawning occurs from August to February at temperatures between 44 and 54 degrees Fahrenheit. Incubation of the female's 300 to 1,500 eggs is most favorable at temperatures between 44 and 48 degrees Fahrenheit. The eggs will hatch in three to five months and the fry then live on the yolk sac for 30 to 45 days. After their emergence from gravel, the stream spawned fry will migrate down to the lake where best growth is achieved for the kokanee. Length at maturity varies from 180 to 533 mm.

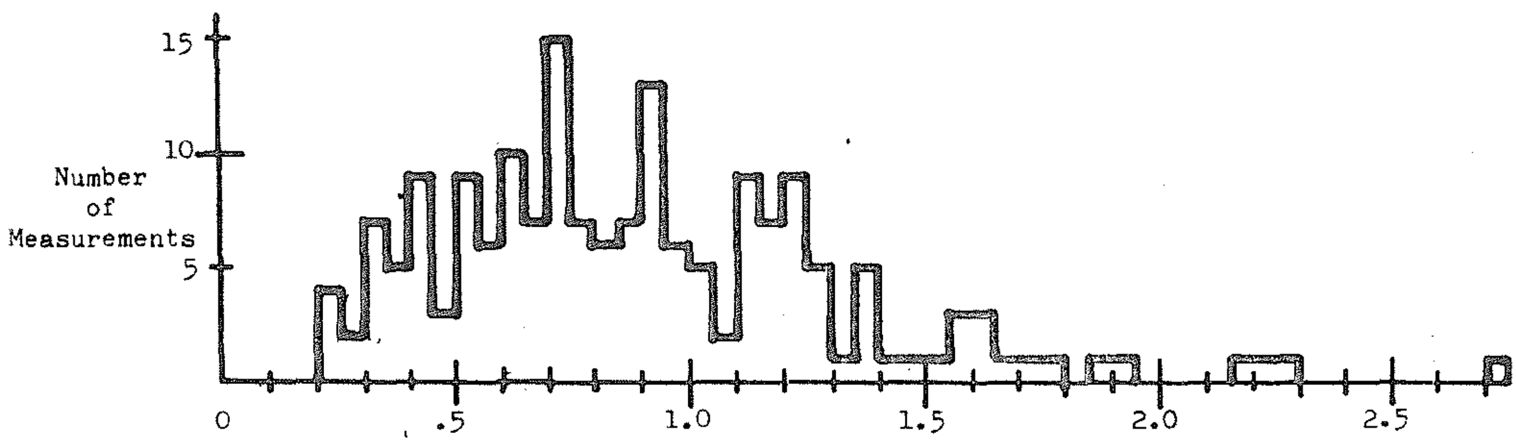
Measurements made on kokanee redds by J. W. Hunter (WDG) and A. K. Smith (O.G.C.) are shown on the following data page. The number of streams sampled were four and three respectively and the recommended criteria comprises the middle 80% of the data.

FIGURE 12 - Kokanee Redd Measurements



WATER DEPTHS - DISTRIBUTION 0.1 Ft. Interval

177 Measurements



WATER VELOCITIES - DISTRIBUTION 0.05 Ft./Sec. Interval

KOKANEE SUMMARY	J.W. HUNTER W.D.G.	A.K. SMITH O.G.C.	
Sample Size	177	106	
Velocity Range fps	0.20-2.70	0.36-3.55	
Velocity Mean (Ave.)fps	0.89	1.43	
Recommended Criteria fps	0.4-1.36	0.47-2.39	
Water Depth Range ft.	0.2-1.7	0.2-3.0	
Water Depth Mean ft.	0.6	0.748	
Recommended Criteria ft.	0.3-1.1	above 0.2	

Mountain Whitefish (Prosopium williamsoni)

DESCRIPTION: Whitefish are silvery in color, sometimes with a dark bronze back. There are few, if any, spots on the adipose fin and head. Average length is about one foot. A long pointed snout contains a small mouth without teeth. Gill rakers 20 to 26 and are short and thick. Large scales in 74 to 90 oblique rows, peduncle narrow with 20 to 23 horizontal scale rows, crossing a line around the narrowest part. Dorsal fin with 11 to 14 rays, anal fin with 10 to 13 rays. The adipose fin is very large.

Young fish up to about four inches have a row of about nine large, dark brown parr marks along the lateral line, plus one or two rows of distinct smaller marks above them.

GENERAL: Whitefish in their first year of life feed almost entirely at the bottom, only occasionally feeding on swimming or floating organisms. Food of first year fish consists mostly of aquatic insects. Fish two years and older have a more varied diet dependent on availability and environmental conditions, although the bottom feeding habit still persists. Adult whitefish depend on larger aquatic insect larvae such as caddis larvae and stonefly nymphs, though food habits will vary with locality, age and season. Whitefish will prey on eggs of spawning fish and often fill their stomachs with eggs of their own species.

Whitefish prefer cool streams with water deep enough to provide adequate cover, and where sufficient riffle areas provide an abundance of food. Slow-growing whitefish will live longer than a rapidly growing fish.

SPAWNING: Generally maturing in three or four years, the 1/8 to four pound female will lay about 7,000 eggs for each pound of weight. Spawning occurs from October to December when water temperatures are falling between 42 and 32 degrees Fahrenheit. Whitefish only travel 300 to 500 yards up tributary streams to spawn in fine gravel to coarse rubble at depths of five inches or more. Whitefish do not make redds as trout do but will spawn in groups of two to five depositing their eggs over the bottom in water often near one foot deep.

Mountain whitefish eggs require low temperatures for optimum development. Hatching will occur in five months at 35 degrees Fahrenheit and in 36 days at 52 degrees Fahrenheit. Most fry will hatch in March at 40 to 42 degrees Fahrenheit.

One additional species of whitefish inhabits Washington waters, the lake whitefish (Coregonus clupeaformis), which grows to four pounds and is distributed throughout the Columbia Basin irrigation system.

GAME FISH DISTRIBUTION

To define fishing priorities in the various areas of the state, a form letter was sent out to the Washington State Game Department's ten regional fish biologists. This form included most of the game fish in the state and requested information regarding fishing pressure, whether or not the fish were planted and their desirability.

The following is a summary of the results. This summary should be considered an approximation and viewed as an overall regional opinion not relating to one specific fish or to one lake fishery that may be an exception. Individual interpretation of the terms used will also add subjectivity to the results.

One reason this was done was to determine whether minimum flow studies for different areas of the state should be evaluated together or separately since the type of fish in each area may vary.

Presently reorganization of the regional system of the Department of Game is under way with the new regions shown by the overlay.

TABLE 6

WASHINGTON STATE FISHERY - SUMMARY

Game Department Regions: 1 - 10*

Species	Fishing pressure/region: None	Light	Moderate	Heavy	Planted by Region	Considered Desirable Region: Yes	No
Rainbow			3 9	1245 6780	All	All	
Steelhead			3 4	256 7890	All	All	
Cutthroat	3	9	4 8	15670	14567890	2-0	
Sea-run Cut.	1345		67890		7890	67890	3
Brown	67890	145	3	2	1235	123458	0
Golden	34890	567			567	5678	30
East. Brook		8	346790	125	All	All	
Dolly Varden	8	145790	36			1345 6780	
Lake Trout	3689	14570				14570	3
Kokanee	3	0	1789	2456	1456789	1245 67890	3
Silvers	34		60	27	279	27	360
Grayling	12345 7890	6				6	
Whitefish		136 7890	25	4		All	
Kamloops Trout	136 7890	5			5	589	30
Sturgeon	578	1346	290			All	
Crappie W&B		4-0	1	23	3 5+	123480	456
Bluegill	168	45790	2	3	5+	2348	150
Pumpkinseed	160	234 5789			5+	4	123 4780
Yellow Perch		4580	13679		5+	234680	14
Channel Cat	156 7890	24	3			234	0
Blue Catfish	All	2?			Presence Questioned	2?	
Wallete Pike	467890	135			1+	123	790
Black Catfish	480	59	67		5+	9	5670
Carp	26890	13457			1+ 5+		All
Suckers	All						All
Largemouth Bass		458	1236790		5+	1234 5890	46
Smallmouth Bass	6789	450	23		35	234 5890	4
Rock Bass	1345 6780	9				0	38
Warmouth Bass	1345 6780	9					38
Brown Bullhead		248	3			348	24

* Region 10 = 0, region numbers will not be seperated, Ex. 1-4 = 1234.

\+ Planted by other then Game.

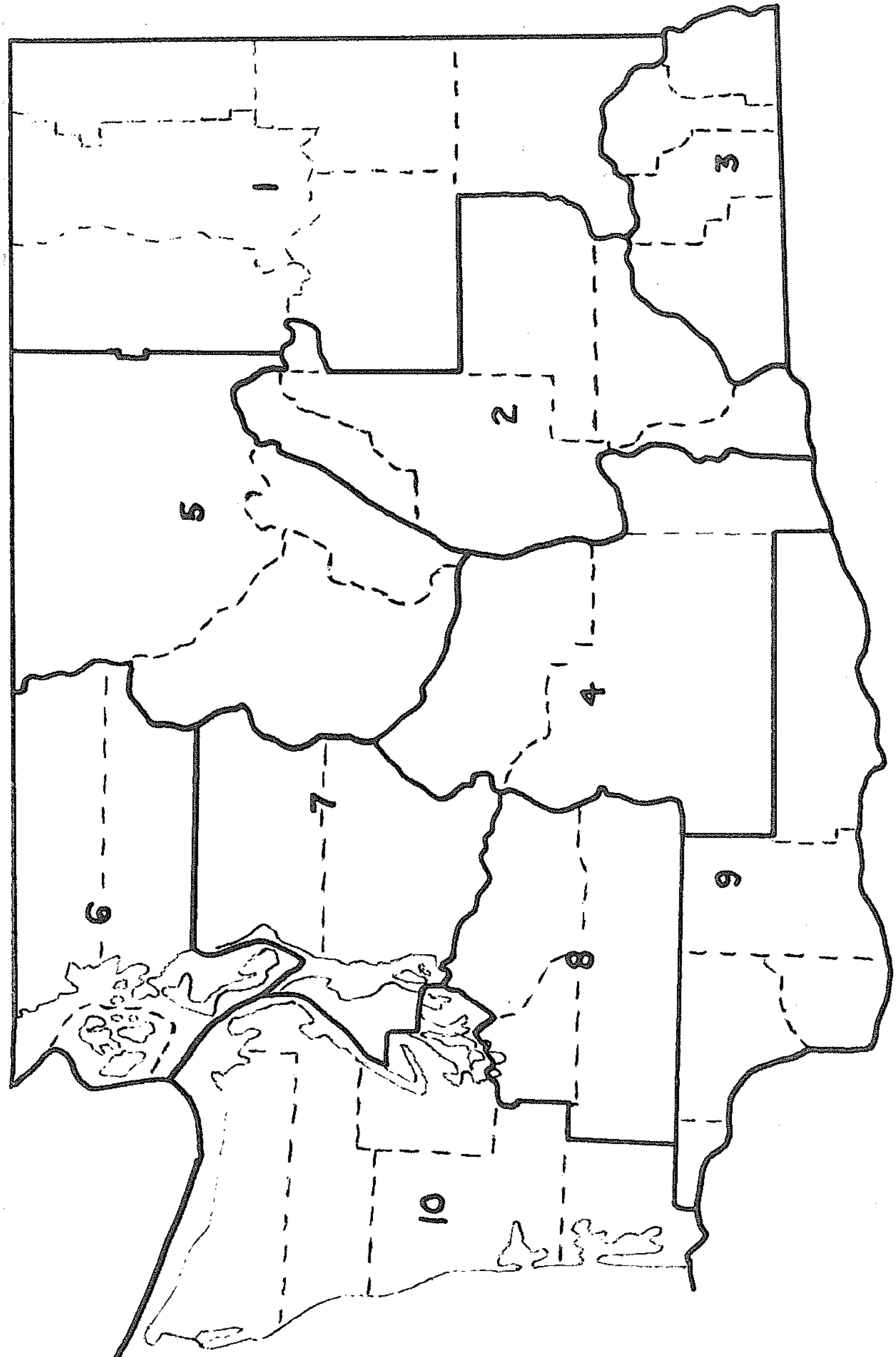


FIGURE 14- GAME DEPARTMENT REGIONS 1-10

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