FAO Fisheries Technical Paper No. 143
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FIRS/T143

DETERMINING DISCHARGES FOR FLUVIAL RESOURCES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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- MFS Editions provisoires des «Manuels FAO de science halieutique»
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- MAST Sinopsis sobre métodos y materias
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- MFS Ediciones provisionales de los «Manuales de la FAO de Ciencias Pesqueras»
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DETERMINING DISCHARGES

FOR FLUVIAL RESOURCES

by

J.C. Fraser
Department of Fish and Game
California, U.S.A.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1975

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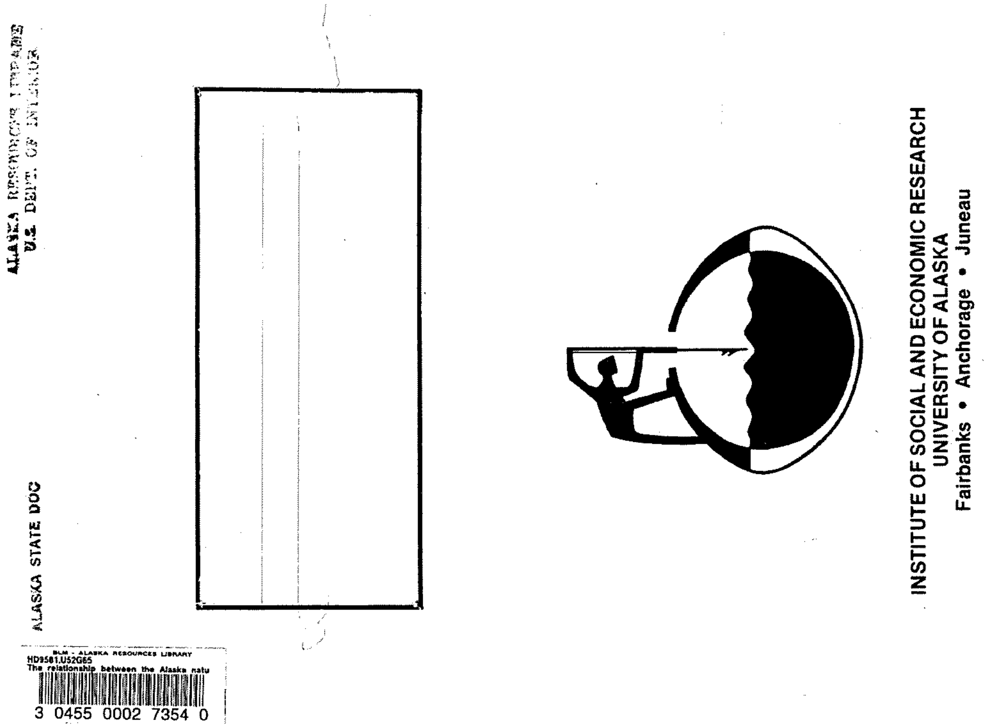

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PREPARATION OF THIS DOCUMENT

This is a review of the methods and approaches currently in use to determine adequately controlled discharges (streamflows) for maintenance of fishery resources. The many factors influenced by, or influencing streamflows in relation to fluvial resources and activities are outlined. Methods of determining streamflows for Pacific salmon in the states of California, Oregon and Washington are presented as examples of the quantification of streamflow needs of fish. Various "rules of thumb" currently in use for salmon and trout streams are reviewed, as well as approaches which involve geomorphology, rate of flow change, and the relation of past flows to year-class success. A check chart provides a basic means of ensuring consideration of the conditions and factors influenced by various streamflows for each month of the year.

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Stream flows. Water resources. Hydrology. Geomorphology. Water quality. Fisheries resources. Spawning grounds. Migrations. Rearing. Survival. Food control.

CONTENTS

INTRODUCTION

The primary purpose of this paper is to review methods and approaches which have been used for the determination of adequate quantities of water for aquatic life in streams, including their derivation. Hopefully, it will provide the basis or background for a critical review of the problem of determining streamflows and the formation of methods with greater reliability.

Although the treatment of the subject is aimed primarily at fishery resources, I have found it difficult to limit consideration of streamflows for this purpose only. The value of streams and the resources they support extend not only to fish but to many other factors of interest to man which I feel should be considered when control or abstraction of streamflow is contemplated. The factors of aesthetics, public health, navigation, fishing, hunting, riparian vegetation, unique or endangered species, floodplain ecology, water quality, waste transport, boating, swimming and other recreational activities should all be considered. However, the limited time for preparation has dictated adherence to the intended coverage except that, in this introduction I would at least like to touch upon a few of these other factors so that they are recognized. Perhaps they can be given greater attention in future deliberations on the subject of streamflow determination.

Actually the science, if one can take the liberty of calling it such, of determining adequate streamflows is in its infancy - born on the heels of intensive and hastily conceived water development projects. Albeit that such water development projects were intended to benefit man and that most of them have done so, many caused unforeseen downstream losses and benefits as the result of changed streamflow patterns.

Early water developments were carried out largely on a single-purpose basis with little or no thought to their potential for benefits to other purposes or to their potential for damage to other uses and values of the streams involved. In recent years much more attention is being given to multiple-use water developments and to their possible effects on other uses including those in downstream areas. Extensive studies have been made to facilitate development of fish populations and fisheries in the large impoundments created by these projects. Unfortunately, far less attention has been given to the streamflow needs below dams and diversions. The many mistakes that have been made and are still being made in this respect are of great concern to an increasing number of people.

Huge reservoir developments such as Kariba on the Zambesi River between Zambia and Rhodesia, Lake Volta impounded by the Akosombo Dam on the Volta River in Ghana and Lake Nasser behind the Aswan High Dam on the Nile River have been accompanied by studies of the rivers involved but largely in relation to development of fisheries in the new reservoirs. Vast sums of money have been expended on studies aimed at providing and improving the fisheries of Lake Volta and Lake Kariba, but very little effort was devoted to assessing the effects of probable changes in streamflows or to determining what flows should be maintained in the rivers below the dams.

Throughout Europe, Asia, Africa, North America and Australia, major impacts on streams have been effected by abstractions or dam development with little or no consideration for downstream water needs. An average annual run of 60 000 chinook salmon (Oncorhynchus tshawytscha) was eliminated from the San Joaquin River in California by the construction of the Friant Dam. A giant freshwater shrimp, highly valued by the Thai people, has been adversely affected by water control developments on the Chao Phraya River in Thailand. The absence of high-scouring flows and low flows which normally inhibited the larval stages of the black fly (Simulium damnosum) caused an increase in this vector of river blindness on the Volta River below Akosombo. The controls effected on the Nile River by the High Aswan Dam are believed to be causing problems for the sardine catch in the eastern Mediterranean. Sardine production in the Mediterranean has been observed to be closely connected with the Nile River outflow.

Man and man's interests are affected in many ways by streamflow and man's activities exercise many influences on the volume and timing of streamflow. All of these factors interact to cause the changes we are experiencing in the world's rivers. It is not within the scope of this paper to treat these factors in any depth, but a summary listing of the more important elements is provided in Appendix D. The many and complex interrelations of streamflow and such factors as human use, water sources, catchment, geomorphology, hydrology and biotic effects are also important to an understanding of the significance of a particular flow volume or discharge pattern. These complex relationships extend, at least in part, from the headwaters of the smallest stream, to the largest river, to the river's estuary and to the ocean. Plate 1 portrays a grouping of these factors as they apply to the catchment, stream, estuary and ocean.

Streamflows are affected by many actions of man in addition to his dam-building activities. Deforestation, irrigation, drainage, land disturbance and paving of the landscape with highways, streets and buildings can affect streamflow and its distribution in space and time.

The biotic effects of streamflow are extensive; to engage in a treatment of them is beyond the scope of this paper, but it must be noted that a knowledge of the physical, chemical and biotic elements of a stream are essential to the process of determining streamflows. Perhaps the most common failure associated with stream control activities is inadequate assessment of possible downstream effects. Careful analyses by a multi-disciplinary team is highly advisable. All too often water development engineers make only a cursory examination because they are not interested in the amounts and timing of water releases from the dam. Their interest in downstream areas is usually overshadowed by their interest in the proposed project's primary purposes, and so the significance of changed streamflow patterns is commonly overlooked or even deliberately set aside in the interest of economics or political purposes.

As we continue to develop the world's water resources it will be necessary to give greater attention to in-stream water needs. Streams have many values which are becoming more important to man's existence on this earth, and we must develop the techniques to decide, in advance, the effects of our activities and how to adjust them to minimize or eliminate the adverse effects. When we look at some of the mammoth projects being considered, such as the Pa Mong project on the Mekong River, the interbasin transfer scheme in England and many others, we realize the importance of being able to properly assess the downstream effects and to determine adequate streamflows more efficiently than we can at the present time. I fear that we still tend to be development-oriented, and so therefore our society is consciously quite willing to set aside stream values in the interest of water development. The Pa Mong project on the Mekong may be an example. The engineering report on feasibility of the project dismisses, with virtually casual treatment, the losses to existing fisheries and the possible loss of several species of fish. One might ask if anybody is looking at the value of keeping the river in its natural state? Is anybody taking a hard look at the long-term social impacts of bringing irrigation to the proposed service area of the project? The engineers' zeal to build a project may result in an inadequate evaluation of the project's effects on the Mekong River and its people.

Another example of possible inadequate evaluation of water development is the proposed flooding of the Kafue River Flats in Zambia. Fig. 1 illustrates, in part, the complex relationship between the hydrologic cycle of the Kafue River and the plant and animal life of the Kafue Flats. The annual flooding and recession of the river would be replaced by a standing pool. The delicate balance of a large and valuable ecosystem would be upset. Will the present river and its values be fully assessed before proceeding with its alteration? This magnificent marsh in the Kafue Flats with its tremendous production of wildlife and fish is to be sacrificed. Once a project such as this is proposed it seems automatically important to pursue it to completion, and the pre-project biological studies are frequently aimed at how to maximize the fishery in the resulting reservoir. Perhaps, at least in the case of the Kafue Flats, it might be better to engage in a study of reasons for not destroying the marshland. I raise this point not only because I consider destruction of the Kafue Flats to be an ecological calamity of international significance but as a means of pointing out that in studies to determine streamflows below proposed water projects, we should consider all aspects of in-stream and off-stream values of the river, and we should not necessarily resign ourselves to the inevitability of downstream resource losses.

ACKNOWLEDGEMENTS

Special thanks are due to William A. Dill, formerly with the FAO Division of Fishery Resources who encouraged the preparation of this report and to Dr. William C. Beckman, also of the FAO Division of Fishery Resources, who provided continued encouragement and made the arrangements for me to visit river-control projects in Thailand, India, Zambia, Ghana and England in 1972.

The assistance of William Pitney of the Oregon Game Commission, Dr. David Solomon of the British Ministry of Agriculture, Fisheries and Food, Mr. A.H. MacDonald, Central Inland Fisheries Research Institute in Zambia, and Mr. E.V. Toffoli, of the California Department of Fish and Game, in locating references and other information, is gratefully recognized.

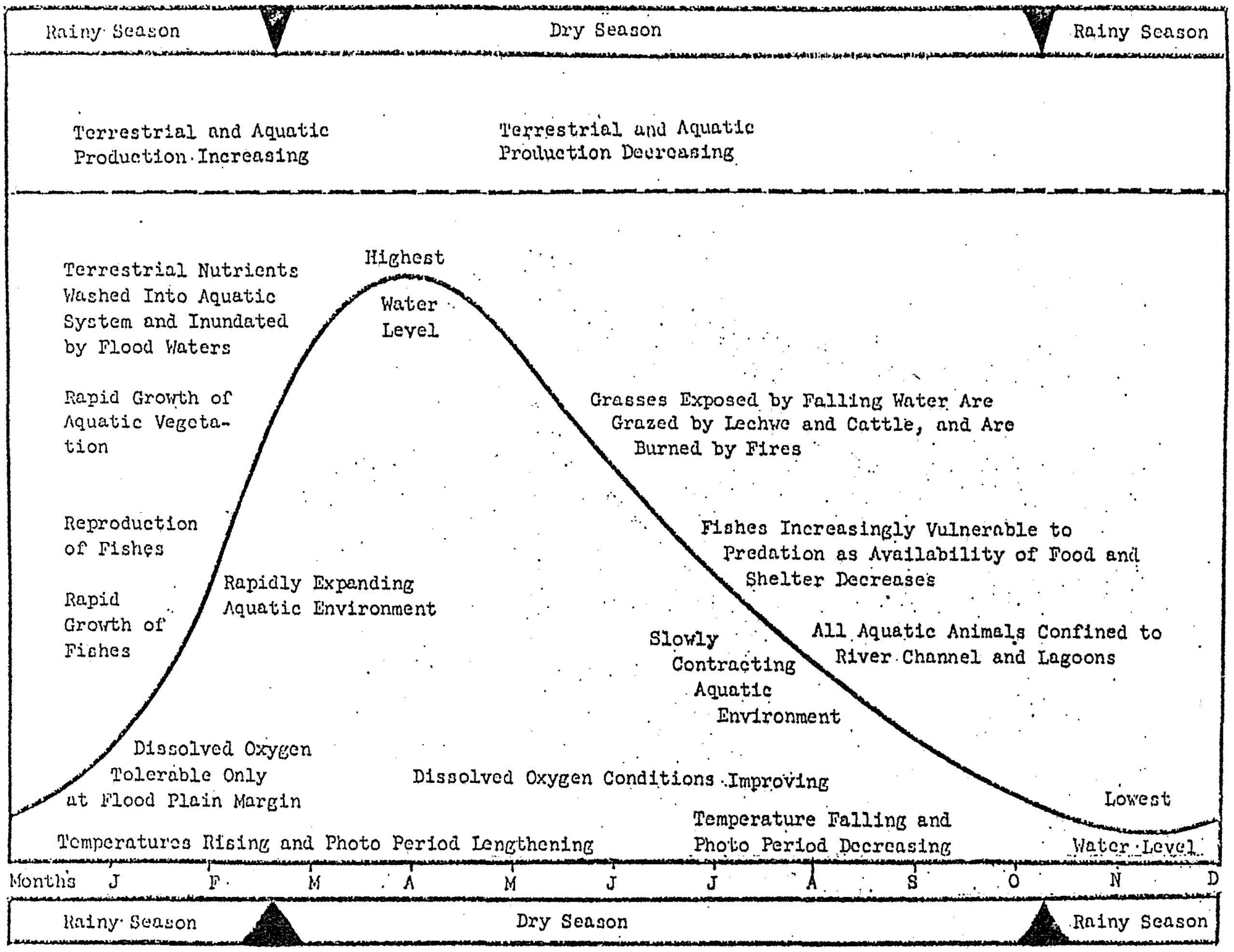


Figure 1. Generalized annual ecological cycle of the Kafue Flats.

(From a report prepared for the Food and Agriculture Organization of the United Nations by the University of Michigan in 1971 entitled, "The Fisheries of the Kafue Flats, Zambia, in Relation to the Kafue Gorge Dam.")

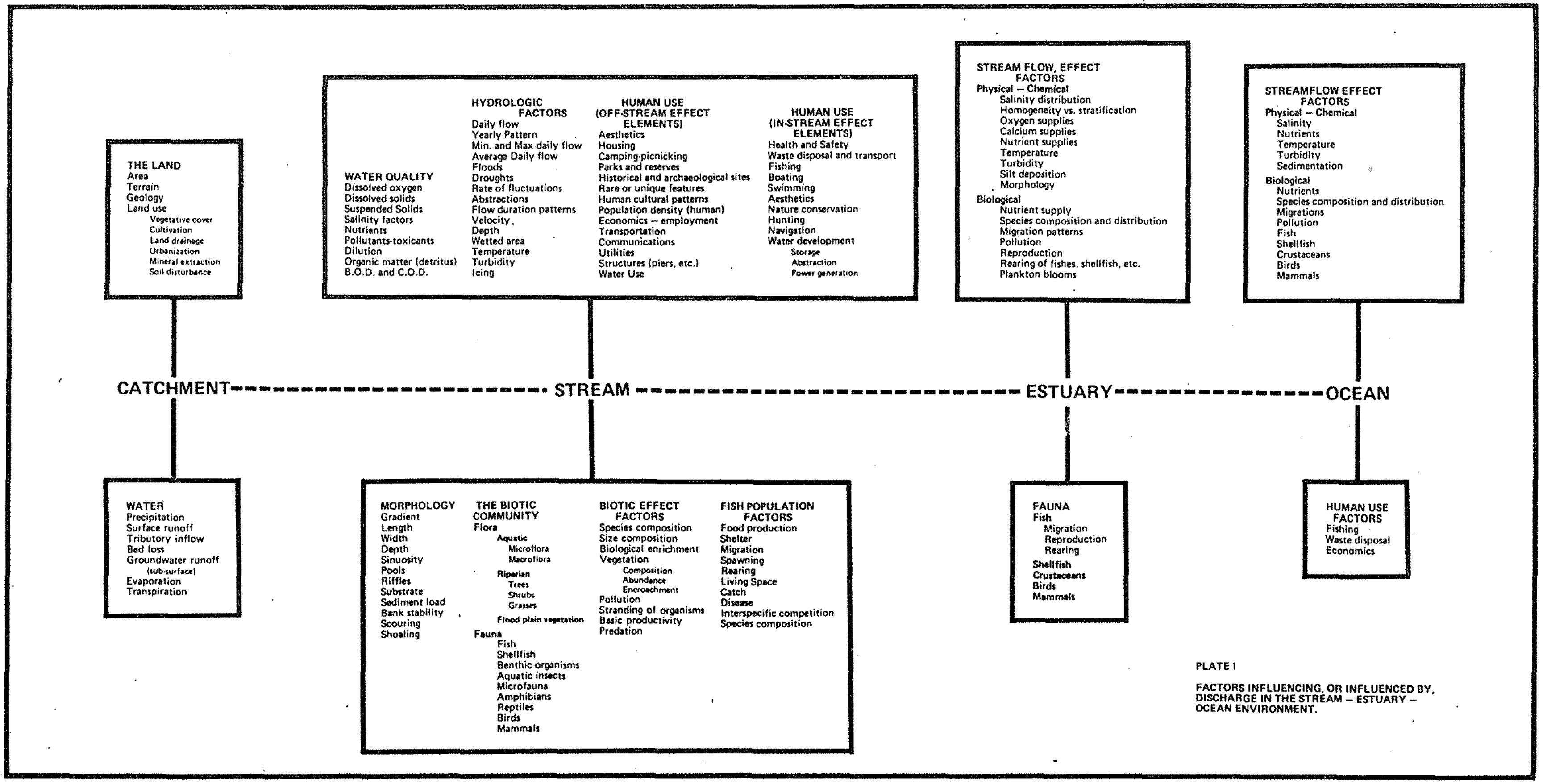


PLATE I

FACTORS INFLUENCING, OR INFLUENCED BY, DISCHARGE IN THE STREAM – ESTUARY – OCEAN ENVIRONMENT.

GENERAL CONSIDERATIONS

As noted previously, the state of the art of determining streamflows for fluvial resources is somewhat in its infancy. Most controlled streamflow releases have been the result of engineering estimates of the amount of water necessary to satisfy downstream water rights and activities of man involving considerable economic significance. Even these factors are not always carefully assessed despite the comparative ease with which their streamflow needs can be determined.

Determining minimum streamflow for navigation, downstream abstraction, industrial uses, etc., is a reasonably uncomplicated process in most cases. Determining minimum streamflows for such factors as fish, fishing, hunting, recreation,aesthetics and public health, is more complex.

At present we do not have a method or technique that can be applied universally to determine appropriate discharges for the benefit of lotic resources. Streams vary in characteristics as do the personalities of people. The sand-bank rivers of Africa bear little resemblance to the glacial rivers of Canada or Alaska. The forces of flow, the patterns of discharge, the morphology and consequently the biotic community will vary from stream to stream. These differences in rivers are reflected in the distribution of fish species between rivers and within reaches of the individual stream.

Organisms inhabiting lotic environments have a high degree of adaptation to the unidirectional flow, relatively unstable substrates, linear morphology and relative shallowness of streams. When these conditions are changed we cannot expect this assemblage or production of organisms to remain unchanged. We cannot expect the biotic community of an historically deep, muddy river to remain unchanged when a water project converts the river to a shallow, clear stream. This is a gross example and it must be recognized that major changes may take place in the biotic community with only a small change in the flow pattern.

An indispensable element in the determination of suitable discharge rates is a knowledge of the life histories of the aquatic organisms living in the system and likely to be affected by a change in the discharge pattern, either in volume or in time. Discharge recommendations made in the absence of such knowledge, cannot be expected to succeed. If the objective of specific discharges is to maintain a population of stream-dependent animals at a given level, then it is essential to consider, and if at all possible,to quantify the water flow needs of those animals.

In dealing with the problem of streamflows it must be remembered that a stream is a dynamic ecosystem which has evolved through adaptation to a pattern of changes associated with that particular stream. Beware of the often used misrepresentation that "stabilized flows will result in a stabilized stream environment". Stabilized flows may result in a "stabilized environment", but that environment may not support a biotic community similar to the original in quality or quantity.

Streams in areas of similar geology and terrain, and in close proximity, may have similar biotic communities, and it may be possible to apply the same basic criteria for determining suitable discharges, but even so, the flow requirements will rarely be the same.

Thus quantification of the water-flow needs of the various life history phases of the stream organisms is the recommended basis for determining discharges for aquatic organisms. The remainder of this report will be devoted to describing work that has been done along these lines for salmonids. Unfortunately, little work has been done on other groups, but the basic approach of measuring velocities, depths, and other flow characteristics in relation to spawning, food production, shelter, and rearing of salmonoid is believed to be generally applicable to other species as well. Much research and field investigation will be necessary to develop and apply suitable techniques to the tropical rivers where conditions are markedly different from the salmonid streams of the temperate climate. Hopefully, the subsequent sections describing the techniques applied principally to salmonid waters will provide the lead for such efforts.

Although emphasis has been placed on determining streamflows for fish, techniques are needed for the determination of streamflows for such other stream-related factors as aesthetics, recreation, waste transport and dilution, fishing, boating, effects on the estuary and the ocean, etc. Scarcity of previous work in some instances, and lack of time in all cases, has resulted in omission of these considerations from this report.

As an aid or a check list to the initial review of streamflow needs of a stream a Streamflow Check Chart is presented in Appendix E of this report. It is intended as a starting point toward more careful assessment of those factors which,at certain flows would either appear to present problems or for which a simple,positive or negative guess cannot be made on the basis of information available.

THE "GUESSTIMATE" OR "RULE OF THUMB"

Perhaps the most commonly-used basis for determination of controlled discharges from dams or diversions is some arbitrary formula or percentage of the natural flow or a guess by a biologist or engineer as to what might be needed. Frequently the pressures of time and economics force such bases for decision. These approaches are most usually resorted to when specific studies of the needs of downstream fluvial resources cannot be made for political or economic reasons. In still other cases it would appear that simple neglect or oversight in respect of downstream resources has resulted in resorting to last-minute guesswork decisions, or no decision.

In fairness to those who have developed "guesstimates" or "rules of thumb" it should be noted that the absence of better information or the funds to obtain better information has forced the use of such approaches, even in instances where the workers involved would have preferred a different approach.

To illustrate this approach, especially the development of "rules of thumb" the following examples are provided. The reader may also wish to note the "rule of thumb" used by the Wyoming Game and Fish Commission noted in the section of this report dealing with "Other Areas".

Use of a Percentage of the a.d.f. (Average Daily Flow)

Baxter (1961), former City Water Engineer to the Corporation of Edinburgh, Scotland, offers an approach which advocates the need for a variable flow regime based on the seasonal needs of the fish and the river, and incorporating provision for the release of freshets to ensure the preservation of migratory fish. He considers it impractical to express this need as a rate of flow but states that it is possible to arrive at a reasonable approximation of the flows required if these are visualized in terms of the average daily flow or "a.d.f.". It should be noted that although not defined by Baxter it is assumed that his abbreviation for average daily flow is synonomous with average annual dishcarge or, in other words, the average discharge for the years of record.

He states further that at the a.d.f., for example, the flow is approaching the conditions of a minor spate, particularly in a large river. The river is running bank to bank and, after a dry spell, the water is normally discoloured. At about 1/8 a.d.f. a river approaches dry-weather conditions with the flow confined to the deeper parts of the channel except in some streams.

After making a rather detailed analysis of the run-off of 15 rivers in Scotland and England in relation to their a.d.f., he concludes that, ".....broadly speaking, recession of the water from the width of bed occupied at about the a.d.f. begins in the wider reaches of a small stream at about ½ a.d.f. and at 1/8 the water may be occupying from only 1/3 to ½ of the stream bed. On the other hand, on the corresponding reaches of the larger rivers, at ½ a.d.f., the bed is still fully covered, and over the streams and fords the flow is essentially turbulent; it is only when the flow falls to about 1/4 a.d.f., that recession begins to show, but even at 1/8 the greater part of the bed is still fully covered, if only thinly so."

He explains the life history of migratory salmonids, mostly Atlantic salmon (Salmo salar). This is followed by an analysis of the required flow conditions. To ensure fulfilment of the life cycle and the maintenance of fish stocks he believes the following considerations are necessary:

(a) Flow conditions for inducing the fish to enter and ascend the river to their spawning grounds.

(b) Minimum flow for the maintenance of healthy conditions, both for the parent fish and for the fry and parr.

(c) Spawning requirements.

(d) Requirements of the ova in the spawning grounds.

Baxter then arrives at a series of conclusions regarding the flows needed to satisfy these considerations; some of these are listed as illustrative of his approach:

(1) "Experience shows - that in general - except during the early spring months - salmon will ascend most rivers in flows varying from 30-50 percent of the a.d.f. in the lower and middle reaches, to 70 percent in the upper reaches and streams of the headwaters." (These percentages are for rivers with open banks and normal gradients.)

(2) "More water is required by the spring fish than by the summer and autumn fish. This is usually attributed to the lower temperature conditions during the early spring. The spring fish require 50-70 percent of the a.d.f. to induce them to enter and begin their ascent of a river."

(3) "Where the natural augmentation of the compensation or residual flow is small, weekly freshets may be required from the time the fish are due to enter the river until possibly within a week or two of spawning time. If the impoundment or diversion is located in the upper reaches or headwaters of the river and the compensation or residual flow is supplemented by adequate natural inflow, only relatively few - and comparatively small - freshets may be required during the late summer or early autumn to take the fish farther upstream." Duration of freshets need not be for more than 18 hours, of which 12 should be at the full rate, i.e., 30-70 percent of the a.d.f.

(4) "The minimum flow, i.e., the basic compensation or residual flow, must be such as to maintain healthy conditions for aquatic life, including that of the food supply of the fry and parr."

(5) "In so far as the food supply of parr is dependent on the hydrological conditions, in the earlier part of the season this is adequately met by flows of 1/4 for the smaller, and 1/5 a.d.f. for the larger rivers with periodic freshets. Thereafter, the flows can be gradually tapered off to alternate with the naturally occurring "lows" of 1/8 a.d.f. since the fish become less active in their quest for food as the year advances."

(6) In reference to salmon spawning flows he states:

"The smaller the stream the larger the proportion of the a.d.f. required. In the headwaters of the River Tweed where the width of the spawning streams varies from about 70 feet in the upper reaches of the river to 15-25 feet in the tributary streams, observations over several years have established that from 25 to 30 percent of the a.d.f. is required. In the author's experience, this must be regarded generally as about the minimum which provides adequate water in the headwaters of a river. As one proceeds downstream the percentage of the a.d.f. required becomes progressively less, and in the middle and lower reaches of a river of medium or large size from 20 to 12.5 percent of the a.d.f. should normally provide an adequate depth of water and coverage of bed for the potential redds of the later-running fish which normally spawn in these reaches."

(7) For the period in which the eggs are in the gravel he suggests the normal minima are from 10 to 17 percent of the a.d.f.

(8) For angling he suggests that the minimum flow required in smaller rivers is 25 percent of the a.d.f. and 20 percent of the a.d.f. in larger rivers and 20-35 percent a.d.f. for summer angling.

(9) Baxter's requirements (with the exception of the freshets) are summarized in Table 1. To these flows he notes that there must be added the freshet water and that this should preferably be partly in the form of a block allocation to be used as needed.

Baxter makes a strong case for relating the seasonal and life cycle needs of salmon to a percentage or portion of the a.d.f. In reality he has simply applied his "feeling" and "general experience" in this respect to the natural flow regime of a stream. He has, in fact, selected a portion of the average flow which in his view and experience the fish could get by with. He has used a little biological information but for the most part his assumptions appear to this reviewer to be somewhat arbitrary and lacking in direct relationship to demonstrated needs of the fish. The fish's needs have not, for the most part, been quantified - they have been subjected to "feeling" type decisions. It is possible that a relationship exists between the a.d.f. and the water needs of the various stages of a salmon's life cycle. Baxter did not demonstrate it in his report.

As an indication of the effect of applying Baxter's criteria to two rivers in New Zealand, data are presented in Table 2 derived from Dalmer (1972).

TABLE 1

Schedule of Flows Proposed by Baxter (1961) for Atlantic Salmon in Streams of Scotland and England

Month	For the smaller rivers and streams % of the a.d.f.	For the larger rivers % of the a.d.f.	Remarks
October	15-12.5	15-12.5	During alternate weeks
November	25	15	
December	25-12.5	15-10	25 and 15 normally during first two weeks only
January	12.5	10	
February	12.5	10	
March	20	15	
April	25	20	
May	25	20	
June	25-20	20-15	During alternate weeks
July	20-15	15-12.5	During alternate weeks
August	15	15-12.5	During alternate weeks
September	15-12.5	15-12.5	During alternate weeks

Note: These schedules are not intended to be rigidly applied and require varying incidence to suit the conditions of the particular case and season, e.g., variations in spawning times. This applies also to the rates of flow, which may require adjusting either way.

TABLE 2

Application of Baxter's Flow Recommendations to Two Rivers in New Zealand

	Waimakariri River (in Cusecs - c.f.s.)	Rakaia River
Average annual mean discharge (11 years) (Baxter's a.d.f.)	4 218	10 921
Average 4% low flow	1 480	3 800
Lowest flows ever measured	618	2 730
Healthy conditions - 1/8 to 1/4 a.d.f. (Baxter)	527 to 1 054	1 365 to 2 730
Minimum flow - large rivers - 20% a.d.f. (Baxter)	844	2 184
Summer angling - 20 to 30% a.d.f. (Baxter)	844 to 1 476	2 184 to 3 822

It can be seen that for these two New Zealand rivers the Baxter recommendation for a minimum flow (to maintain "Healthy Conditions") of 1/8 to 1/4 a.d.f. could result in reducing the flows of these two rivers to levels below the lowest flows ever recorded for them. Such a reduction on a continuing basis could well be disastrous to the salmon populations of many rivers. For such recommendations to be seriously considered without determining their relationship to the actual requirements of fish and other organisms in the river would seem unwise.

The "ECE" Report

Another example of this "guesstimate" or "rule of thumb" type of approach is reflected in a 1969 report by Messrs. A. Arkuszewski, A. Stolarksi and A.G. Boulton to the Body on Water Resources and Water Pollution Control Problems of the Economic Commission for Europe entitled "Methods for Determination of Minimum Acceptable Discharge". The authors of this paper define the concept of "minimum acceptable discharge" as not only being the minimum needed for safeguarding public health and to meet the requirements of existing lawful uses of water, whether for agriculture, industry, water supply or other purposes and the requirements of land drainage, navigation and fisheries, but should also have regard to the character of the surroundings and, in particular, natural beauty.

Unfortunately, the authors then proceed to qualify this seemingly rational definition by stating: "The determination of minimum acceptable discharge requires consideration in the first place of what it is possible to achieve and in the second place what it is economically reasonable to aim at". Granted that these practical considerations eventually must be dealt with, it seems unfortunate that the initial process of determination must be influenced by these factors. The ECE report lists the following sequence of considerations and data in determining minimum acceptable discharge:

1. A continuous record of river discharges over a long period of time.

2. A topographical and geological survey of the river basin is necessary in order to establish the storage potential in the area.

3. The quality of the water and its temperature.

From these considerations and data the ECE report suggests that it will then be possible to indicate the levels at which it is possible to maintain the flows, and the cost of fixing a minimum acceptable discharge at these levels. I cannot help but observe the absence of an assessment of downstream water needs in this sequence of considerations. The ECE report seems to give little recognition to the economic and social needs of downstream uses as considerations or data to weigh in determining minimum acceptable discharges.

The report goes on to suggest simplistically that although it is desirable to consider each case on its merits it is also very inconvenient and ".....requires considerable amount of work in each case. It is for this reason that it is difficult to use it when working out plans for the development of large river basins". Without any further justification or rationale the report suggests that one can, for example, for the purposes of preliminary planning, assume the minimum acceptable discharge to be:

"(a) in small watercourses in mountainous regions 0.2 times the mean minimum discharge or even less for short periods when, in exceptional cases, it could be zero;

(b) in larger watercourses where there is a more regular pattern of discharge 0.5 times the minimum mean discharge;

(c) in all other cases 0.8 to 1.0 times the minimum mean discharge."

As an example of applying these principles the report calls attention to the River Severn in the United Kingdom, which has a mean annual discharge of 62 m^3/s, and an all-time recorded low discharge of 4.4 m^3/s. In a figure in their report (See Fig. 2 in this report which has been adapted from the one in the ECE report) the lowest discharge on any one day for each of 29 years is shown. With a minimum acceptable discharge having been set at 8.4 m^3/s the report notes that in 20 out of the 29 years it would not have been necessary to supplement the natural flow to meet the minimum acceptable discharge. It further suggests that the river could be saved from serious droughts by a relatively small capital outlay for a regulating reservoir. The report makes no analysis of the effect on downstream water needs if the "minimum acceptable discharge" were to become the basic or only flow of the river. Under increasing abstractions there is always the possibility this will happen. Although it is not clear from the report, its authors might be concerned primarily with alleviating undesirably low flows by establishing their "minimum acceptable flow" concept. The rationale behind its determination is difficult to capture from the text.

The "Montana Method"

Biologists with the State of Montana are engaged in studies to determine optimum fisheries flows for the sport fishing streams in that state. The "Montana Method" is based on percentages of the mean annual flow of record. Elser (1972) describes a 10 percent flow as being, at best, a short-time survival flow. A discharge of over 30 percent of the mean annual flow can be considered as a satisfactory fishery flow.

Thus under the "Montana Method" the flows intended to ensure adequate reproductive and rearing conditions for resident salmonids are a minimum of 30 percent of the mean annual flow for the period of October-March and a 60 percent minimum flow for the April-September period.

Elser (op cit.) reporting on studies made in 1971 to evaluate the "Montana Method" states that this method of estimating flows for fishery values appears to be far superior to any method which depends entirely on guesswork, or the techniques relying on judgemental interpretation of photographs to define the ecological needs of a stream. Their evaluation studies provided strong confirmation of the 30 percent and 60 percent flows as being suitable in relation to width, depth and velocity and therefore can be recommended as a low-flow pattern for resident salmonid fish.

Of the various "rule of thumb" methods of deriving acceptable streamflows for fish, the "Montana Method" seems to have the best justification in relating it to the quantified needs of the fish - at least in relation to the two factors of spawning and rearing.

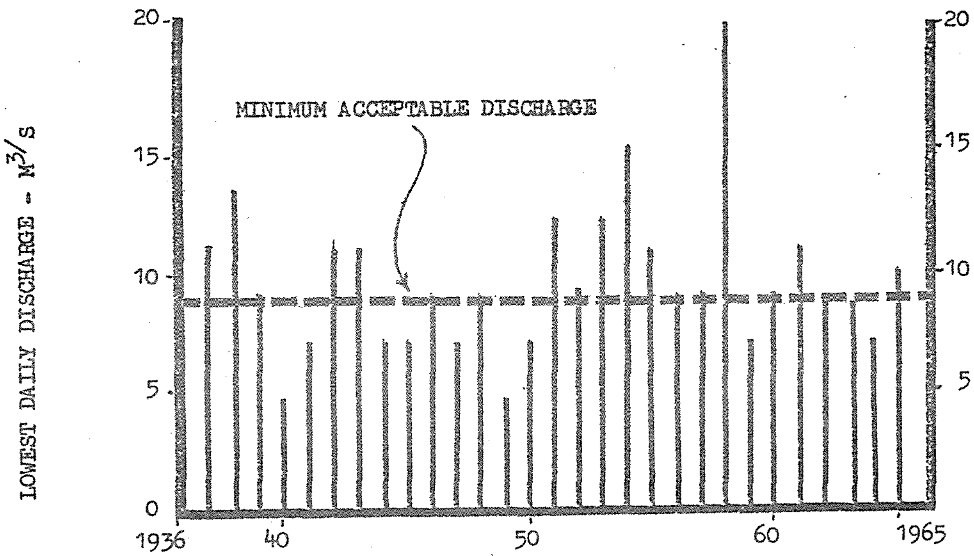


Figure 2. "MINIMUM ACCEPTABLE DISCHARGE" IN RELATION TO THE LOWEST DAILY DISCHARGE DURING EACH YEAR IN THE SEVERN-BEWDLEY RIVERS. (AFTER ARKUSZEWSKI, ET AL, 1969)

CALIFORNIA - DEVELOPMENT OF SALMON SPAWNING FLOW REQUIREMENTS

Perhaps the most significant developments in the area of quantifying the flow requirements of one phase of a fish's life cycle is the work of biologists and engineers in western North America. Here there were a number of pioneering efforts to develop the applicable criteria in the fifties and sixties. I shall emphasize the history and development of these techniques in California, Oregon and Washington since these are most familiar to me, but the reader should recognize that I may have unintentionally neglected to cite some contributors and that work from other areas also made significant contributions.

Development of Techniques

The initial efforts were stimulated by the work of Burner (1951) who described the characteristics of Pacific salmon (Oncorhynchus) spawning nests on the Columbia River. However, Burner's work was based on measurements of surface velocities and was mainly conducted on small rivers and streams. Other workers (e.g., J.L. Savage (1962) and Daniel W. Slater of the U.S. Fish and Wildlife Service) discovered that surface velocity and depth were not closely correlated with the spawning bed sites selected by Pacific salmon. They decided to measure the velocity at 0.3 ft from the bottom, which is the chinook salmon (O. tshawytscha) lateral line-measuring depth.

In personal correspondence, Slater noted that other evidence, such as observations of salmon spawning at 30 ft in the Columbia River and at 8 to 10 ft in the Sacramento River, led him to conclude that depth is only significant to chinook salmon spawning as it is related to the significant bottom velocity. Depth may be important in some other situations where turbidity shuts out light at depths, but he questions the importance of this since he has often observed chinook salmon spawning at night.

Descriptions of the early techniques were provided by Savage (1962) and Warner (1953 and 1955). Basically, these early efforts were directed at determining the amount of usable spawning gravel in a river at various water flows. Through the application of the following criteria the quality and suitability of spawning gravels were determined:

Depth - within the limits of 5 to 48 in
Velocity - between 0.5 to 3.5 ft/s.

To determine the quality of the gravel and to rate it in relation to velocity and depth, Warner (1953) and Slater developed a table of standards for salmon spawning gravel surveys which is reproduced as Table 3 in this report. These were based largely on a draft of Burner's report.

After measuring the surface velocity (note that later studies measured the velocity at 0.3 to 0.4 ft from the bottom) and depth of water over the gravel bed, the area and data were plotted on a map for each 300-ft section of the study area (to a scale of 1 in to 100 ft). The quality of the gravel was normally determined at a later date when they were exposed by low flows. The composition of the gravels were then analysed by digging into them and classifying them according to the table of standards.

The total amount of usable gravel available to salmon in the study area was computed after each series of measurements and plotted on a graph depicting the amount of usable gravel available in relation to streamflow. See Figs. 3 and 4 for the results of Warner's studies on the American and Feather Rivers. Note that usable spawning gravel in the American River increased until a flow of 500 ft^3/s was reached and then as the flow increased above this the usable gravels declined in the study section because the depth and velocities became too great in the low flow channel. This decline continued until a flow of 1 300 ft^3/s was reached when the flood plain or peripheral gravels started to be covered by water of suitable depth and velocity. The usable gravels increased with increase in flows from 1 300 ft^3/s up to approximately 2 700 ft^3/s. Above 2 700 ft^3/s the usable gravels declined, again because of excessive velocities and depths. This study revealed that more usable spawning gravels were available to salmon at a flow of 500 ft^3/s than at higher flows. It also gave indication that if higher controlled discharges were necessary during the spawning period it would be best to hold them to approximately 2 700 ft^3/s if possible. A second peak of usable gravels was not found at higher flows in the Feather River studies. (Note that later refinements and re-surveys of the American and Feather Rivers gave different results. These are discussed later in this section.)

Using similar criteria and methods, Westgate (1958) did not find the peak of usable spawning gravels at the flows he studied on the Cosumnes River (See Fig. 5). Unlike the studies reported by Warner, he measured velocities at a depth of 0.3 ft from the bottom.

As these studies were carried out it became increasingly apparent to those involved that depth was less of a factor than velocity in selection of spawning sites by chinook salmon. Savage (1962) also noted

TABLE 3

Table of Standards for Salmon Spawning Gravel Surveys, Feather River 1954
(From Warner, 1953)

Gravel Size	Good (G_1)	Fair (G_2)	Poor (G_3)
Large - 6-12 in	30% or less	31-39%	40% or more
Medium - 3-6 in	40% or more	21-39%	20% or less
Small - 1-3 in	50% or less	51-79%	80% or more
Fine - Up to 1 in	20% or less	21-39%	40% or more
Sand and Silt	10% or less	11-19%	20% or more
Velocity	(V_1)	(V_2)	(V_3)
Ft/s at Surface	1.5-2.5	1.0-1.4 and 2.6-3.0	0.5-0.99 and 3.1-3.5
Depth of Stream	(D_1) 10-24 in	(D_2) 8-9 in and 25-36 in	(D_3) 5-7 in and 37-48 in

Percent Usable Gravel	Combination	Percent	Combination	Percent
	$G_1V_1D_1$	98% (96-100)	$G_2V_2D_2$ or $G_2V_3D_2$ or $G_3V_2D_2$ or $G_1V_3D_3$ or $G_3V_1D_3$ or $G_3V_3D_1$ or	48% (41-55)
	$G_1V_1D_2$ or $G_1V_2D_1$ or $G_2V_1D_1$	91.5% (86-95)		
	$G_1V_2D_2$ or $G_2V_1D_2$ or $G_2V_2D_1$ or $G_1V_1D_3$ or $G_1V_3D_1$ or $G_3V_1D_1$	78% (71-85)	$G_2V_3D_3$ or $G_3V_2D_3$ or $G_3V_3D_2$	35.5% (31-40)
			$G_3V_3D_3$	Up to 30%
	$G_2V_2D_2$ or any 1-2-3 combination	63% (56-70)		

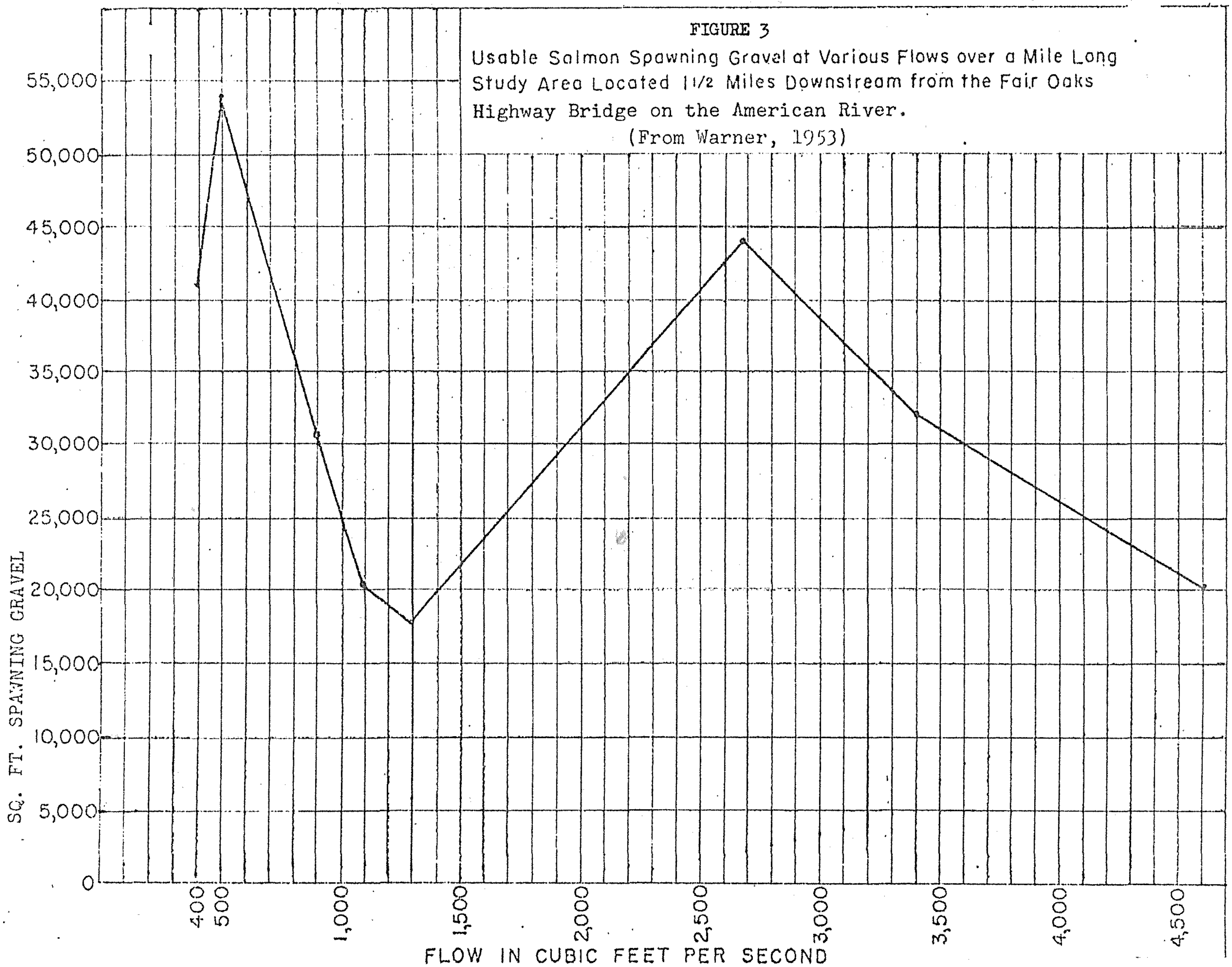


FIGURE 3

Usable Salmon Spawning Gravel at Various Flows over a Mile Long Study Area Located 1 1/2 Miles Downstream from the Fair Oaks Highway Bridge on the American River.

(From Warner, 1953)

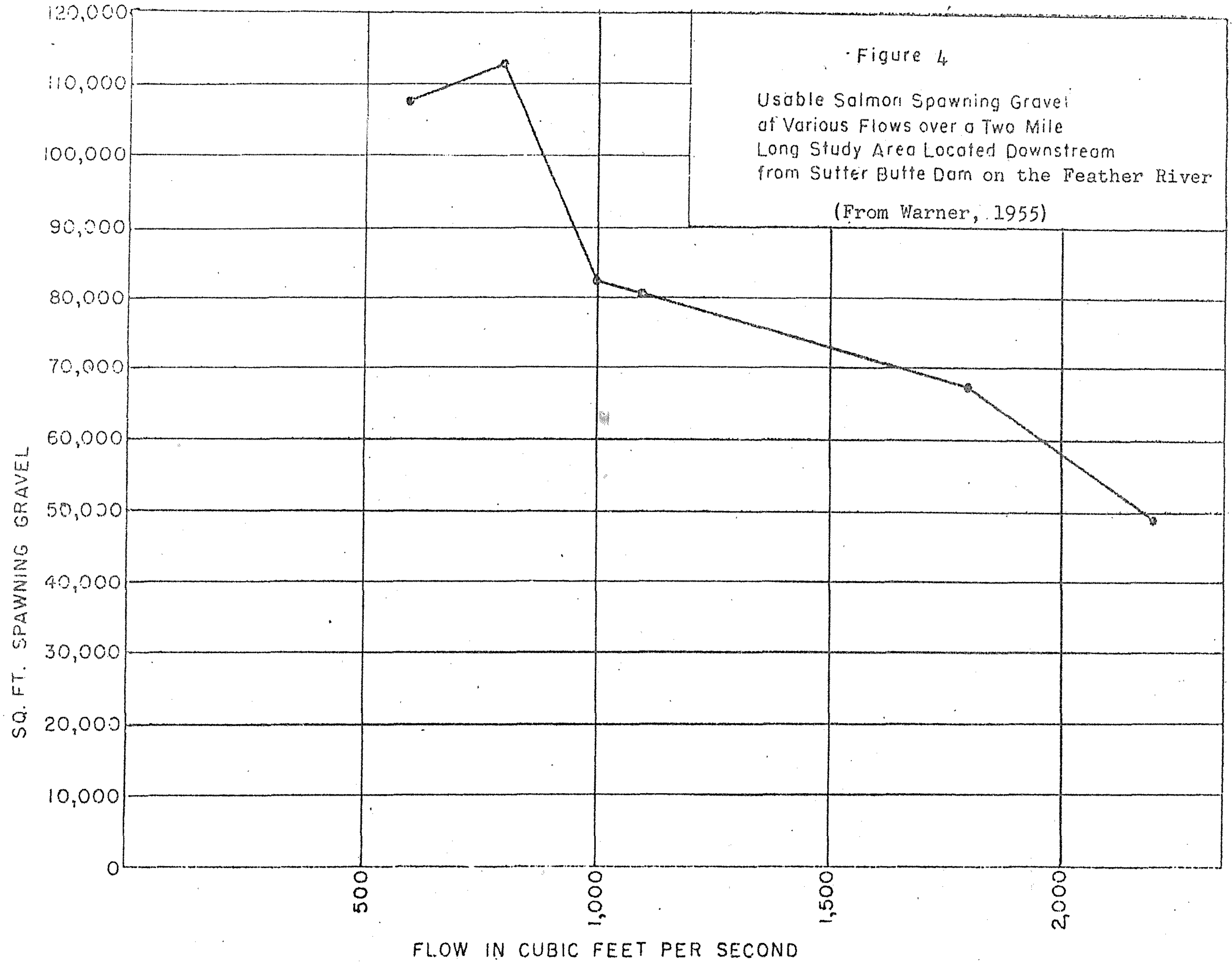


Figure 4

Usable Salmon Spawning Gravel at Various Flows over a Two Mile Long Study Area Located Downstream from Sutter Butte Dam on the Feather River

(From Warner, 1955)

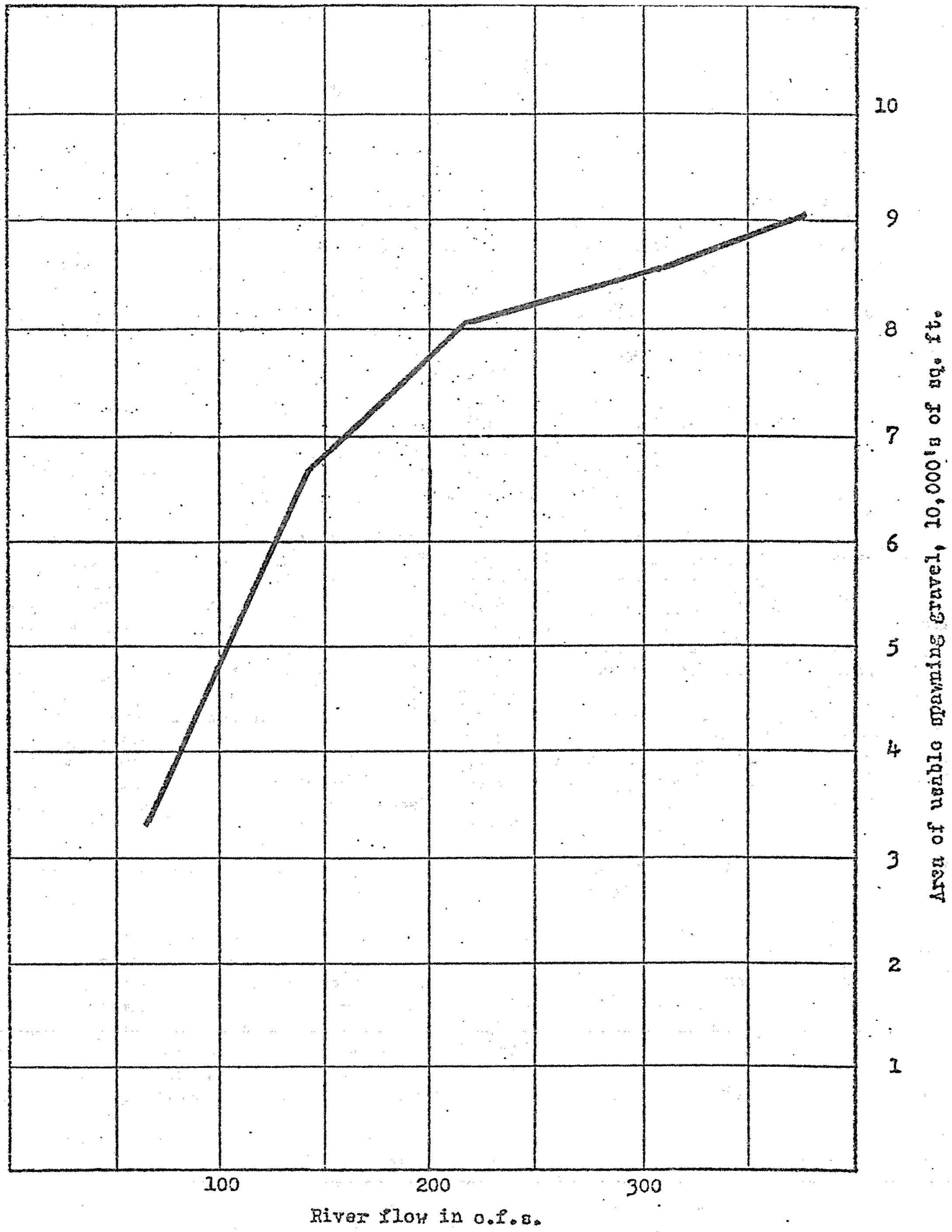


FIGURE 5. Relationship between usable spawning gravel and river flow, Cosumnes River, 1956.

(From Westgate, 1958)

that the proportion of fines in spawning beds play a more limiting role than does the range of size of gravels. These early studies did not consider the intra-gravel flows of water or the dissolved oxygen content of the water in the gravels. This resulted in early minimum discharge recommendations being based on the assumption that flows could be reduced during the incubation period from those required for the spawning period. This was done without an understanding of the effects of such reduced flows on the subsurface flows (underflow) and dissolved oxygen content and the effect of these factors on survival of eggs and fry in the gravel.

Although not directly a matter of concern in relation to regulated discharge it may be of interest to cite some approaches to calculating the number of salmon that can be accommodated on the spawning beds. In order to estimate the maximum number of chinook salmon that could spawn at a certain flow, the early studies in the fifties assumed that dividing the usable spawning gravel area by the average redd size (usually 40 ft^2) would give a reasonable approximation. This was then related to the average sex ratio of the salmon for the particular river and then adjusted by an arbitrary reduction (usually around 50 percent). Savage (1962) reported a different approach which is quoted from his paper in reference to studies on the Tuolumne River:

"Two basic assumptions were made:

(1) That an average of 10 days elapsed from the time the fish were counted until they commenced spawning.

(2) That on the average, salmon actively defend their respective spawning areas for a period of 10 days.

Daily spawning populations were computed by accumulating the daily counts of fish to the given day, then subtracting the accumulated daily counts of fish for all days more than 20 days prior to the given day. The calculated peak-day spawning population was then multiplied by the sex ratio factor (0.4) to obtain the given day's population of spawning females. These computations carried throughout the season identify the maximum daily population. The calculated total number of females for the season (0.4 x total count) was then divided into the calculated maximum daily number of females. This computation yields the fraction of the total number of females which were spawning during the peak-use day. This fraction is then multiplied by the territorial requirement of a female salmon to obtain the needed total spawning area requirement. The territorial requirement for autumn chinook salmon of 216 ft^2 developed by Burner was reduced to 200 ft^2 to allow for edges which, although not spawning gravel, were nevertheless useful for territorial needs. The product represents the average space required per female salmon during the season. The average space requirement per female for the five years of record was determined to be 64 square feet. About 1/3 of the females during the season were calculated to be spawning during the peak-day use."

The results of applying the foregoing procedure for the Tuolumne River is depicted in Table 4 which is taken from Savage's 1962 report.

During the period of 1961 to 1963, a follow-up study to those made earlier by Warner was made on the Feather River, and it revealed some needed revisions in procedures for determining streamflow - usable spawning area relationships (Kier, 1964). The principal refinement was to measure velocities at 0.3 ft from the streambed. The earlier studies by Warner and others in California used surface velocities corrected to average velocities by use of a constant factor. The earlier studies therefore tended to give higher velocity readings and therefore tended to eliminate more gravel areas with velocities over the prescribed maximum of 3.5 ft^3/s than would readings based on bottom velocities. This resulted in a favouring of lower flows for providing more usable gravels in the earlier studies.

Another refinement was in the criteria used to evaluate water depth. In the earlier studies, depths of less than 5 in or more than 48 in were considered poor for chinook salmon spawning. As noted by Slater and others (e.g., Chambers, 1956) salmon were observed spawning at greater depths. Thus the Federal and California biologists decided to discard the maximum-depth factor and limit unsuitable depth only to those areas less than 0.8 foot. Thus velocity became the dominant quality factor in relation to volume of streamflow.

Kier's report (op cit.) described the field techniques used; I repeat these here because they may be of interest to some readers of this report. Preliminary to the measurement programme, reconnaissance surveys were made by boat on 14 miles of the river. Characteristics of the 47 major riffles were noted including lengths, widths, gravel quality, gradient, and observed past spawning use. Aerial photographs of the reach were examined and three riffles were selected to represent the entire spawning area. On each test riffle, a staff gauge and base line along one bank were established. Steel fenceposts were

TABLE 4

Salmon Count and Spawning Area Relationship Based on Territorial Requirements of Spawning Female Salmon
Tuolumne River Salmon Spawning Area Survey Computed from Salmon Counts at Modesto, California

Year	Season Total No. of Salmon	No. of Females to Males	Total No. of Females	Maximum Day No. of Spawning Salmon		Territorial Requirement Per Female Salmon in ft^2	Maximum Area Required in ft^2	Area Per Female in ft^2
				No.	Fraction of Total			
1940	122 468	0.4	48 986	12 345	.252	200	2 469 000	50
1941	27 208	0.4	10 883	2 935	.270	200	587 000	54
1942	44 626	0.4	17 850	4 789	.268	200	957 800	54
1943	No Count							
1944	125 436	0.4	50 174	17 937	.357	200	3 587 400	71
1945	No Count							
1946	57 234	0.4	22 894	10 616	.464	200	2 123 000	93
Average	75 400	0.4	30 157	9 724	.323	200	1 944 840	64

(From Savage, 1962)

driven at 100-ft intervals along both banks. The combined length of the three sections was 1 900 feet.

The test riffles were divided into 100-ft squares from which gravels were sampled to determine their quality. (Quality assessment was in reference to essentially the same standards used by Warner, 1953, except that the "good" and "fair" classes were combined into a single "usable" category and all other gravels were considered "unusable".) Samples were collected initially by forcing a 2-ft section of 14-in well casing into the streambed to a depth of 1 ft and extracting its contents. Seven samples were screened in the field after visual grading of their quality had been noted. Good correlation of visual grading and screening results led to abandoning the screening in the interest of time.

Measurements of depth and velocity commenced at a flow of 792 ft^3/s. Measurements were made by wading and from a boat at 5-ft intervals along a cable tag line stretched across the stream between the paired fenceposts. Total water depth and velocity at 0.3 ft above the bottom, measured with Price current meters, were noted at each interval. A crew of eight men was required to complete the measurements at all sections during the short periods of equal flow. (A severe flood subsequently delayed further measurements and caused later measurements to be restricted to one remaining usable test site.) The later measurements on one test site were made at four different flows ranging from 800 to 3 400 ft^3/s.

A base map showing all suitable spawning gravels in the study section was prepared. Areas of suitable depths and bottom velocity, tabulated from the field records, were superimposed on the gravel map to indicate the total amount of usable spawning area at each flow. The relationship of usable spawning area to discharge was then plotted on a graph.

Fig. 6 illustrates the relationship of average bottom velocity to discharge at the 1963 study site. An average bottom velocity of 1.5 ft/s, the lower limit of preferred spawning velocities, was obtained at a flow of approximately 1 700 ft^3/s in the Feather River Studies. The usable spawning area at various flows in the study section is shown in Fig. 7 (from Kier, op cit.). Thus Kier obtained markedly different results from those of Warner (1955) in the same general area of the Feather River. Warner's study revealed an optimum spawning flow of 800 ft^3/s whereas, Kier concluded that a flow of approximately 1 700 ft^3/s gave the maximum usable spawning area.

Kier also made an analysis of historic flows in relation to the 1 700 ft^3/s optimum spawning flow and found that the average flows during a 38-year period for the chinook salmon spawning months of October, November and December were 1 602 ft^3/s, 2 585 ft^3/s, and 5 211 ft^3/s, respectively. Since chinook salmon do not usually begin to spawn in the lower Feather River until the second week in October, Kier concluded that his computed optimum spawning flow of 1 700 ft^3/s had been available historically throughout the spawning season.

The American River, originally surveyed in the studies reported by Warner (1953), was resurveyed in 1966 using the later techniques of measuring velocity 0.3 ft from the bottom and disregarding depth unless it was less than 0.8 ft. Water velocities (0.3 ft from the bottom) of 1.0 to 3.0 ft/s were considered satisfactory for chinook salmon spawning. These studies were conducted jointly by the California Department of Fish and Game and the U.S. Fish and Wildlife Service and reported by Gerstung (1971).

In the resurvey of the American River five representative test sections ranging from 400 to 2 000 ft in length were used. The total length of all five sections was 5 500 ft. On each section a staff gauge and base line were established along one bank. Steel fenceposts were driven at 100-ft intervals along both banks except in one section where a 200-ft interval was used.

Measurements of depth and velocity at 0.3 ft from the bottom at various test flows were made by wading or from a boat at 10-ft intervals along a cable stretched across the river between the paired fenceposts. The velocities were measured with Price current meters. Gravel samples were collected from each test section and graded according to the standards of Warner (1953) and Kier (1964).

The 1966 studies revealed that available spawning area increases substantially as streamflow increases from 500 to 1 500 ft^3/s in the American River; whereas, the early studies reported by Warner (1953) suggested a decline about 500 ft^3/s. The primary differences between the two studies were in measuring velocity and the elimination of depths over 48 in in the earlier studies. Both of these factors resulted in many usable spawning areas being eliminated in the earlier study at the higher flows because of high velocities or depths in excess of 48 inches.

As a result of these later studies the recommended flows for salmon spawning were revised from 500 to 1 250 ft^3/s (Gerstung, 1971).

Further studies along these same lines were carried out by Puckett (1969) and Horton and Rogers (1969). The data obtained by Horton and Rogers (op cit.) on the Van Duzen River further illustrate the usable spawning area technique. Tables 5 and 6 show the data for the two test sections and Fig. 8 is a graph of the data showing the relationship of flow to usable spawning area.

Figure 6: Relationship of Velocity (0.3 feet above streambed) to Discharge in the Feather River at 1963 Study Site (from Kier, 1964)

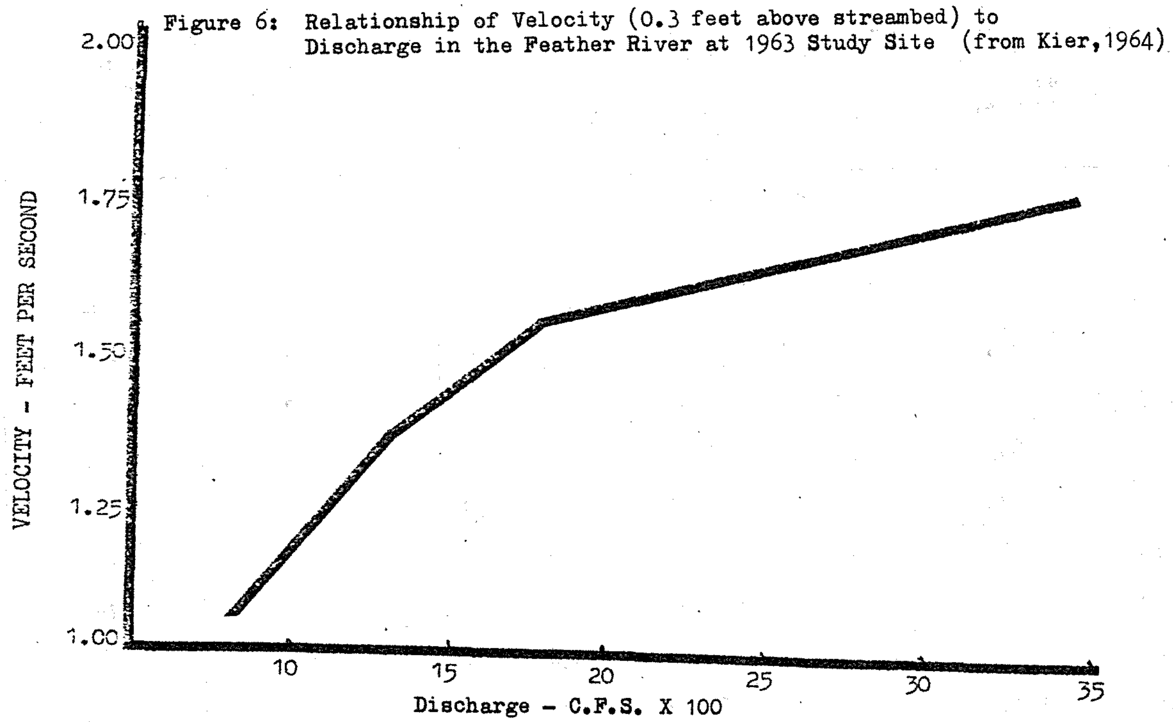


Figure 7: Relationship of Usable King (Chinook) Salmon Spawning Area to Discharge in The Feather River at 1963 Study Site (from Kier, 1964)

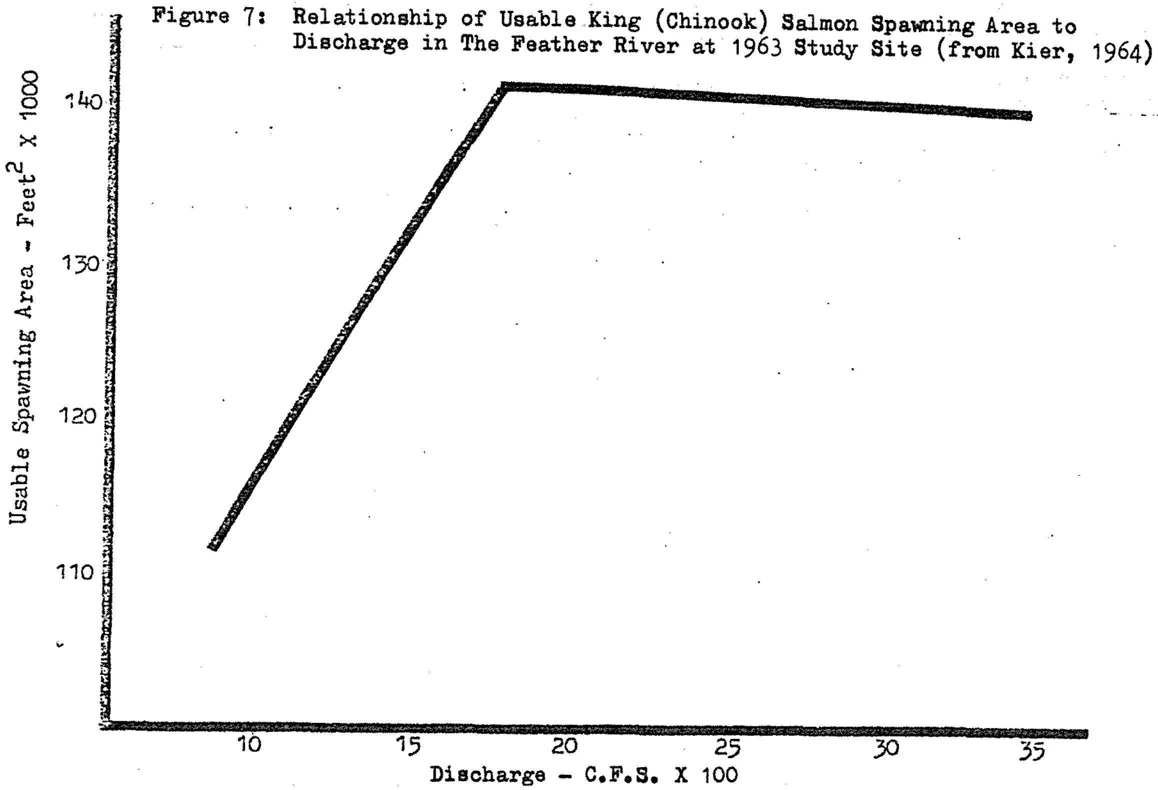


TABLE 5

Amount of Usable Spawning Area Available at Various Streamflows at Study Section 1 on the Van Duzen River, California

Date	Measured discharge at study site	Amount of usable spawning area at each subsection[1/] ft² Subsections 1	2	3	4	Total usable spawning area in section	Percent of potential spawning area
14. 6.68	56	784	-	-	-	784	0.01
26. 4.68	158	10 208	-	-	-	10 208	12.1
6. 1.68	262	11 360	-	1 600	2 528	15 488	18.3
16.12.67	293	13 120	-	4 112	2 400	19 632	23.2
13.12.67	494	14 496	11 904	23 232	5 920	55 552	65.6
3. 3.68	559	16 656	16 800	25 904	944	60 304	71.2
25. 1.68	622	20 400	8 992	26 176	1 504	57 072	67.4
11.12.68	699	17 088	14 560	23 616	6 640	61 904	73.1
29. 2.68	988	14 000	16 800	32 128	1 332	64 260	75.8
27. 3.68	1 090	19 296	16 800	29 056	1 312	66 464	78.4
9. 2.68	1 356	7 344	16 800	31 808	1 968	57 920	68.4
27. 2.68	1 465	11 910	16 400	32 346	1 648	62 304	73.5

1/ The amounts of potential spawning area for subsections 1-4 were 20 672, 16 800, 34 304, 12 960 ft², respectively.

(From Horton and Rogers, 1969)

TABLE 6

Amount of Usable Spawning Area Available at Various Streamflows at Study Section 2 on the Van Duzen River, California

Date	Measured discharge at study site	Amount of usable spawning area at each subsection 1/ ft² — Subsections 1	2	3	4	Total usable spawning area in section	Percent of potential spawning area
14. 5.68	103	-	-	11 072	320	11 392	10.5
25. 4.68	144	-	-	21 328	736	22 064	20.3
17.12.67	232	3 344	-	19 520	-	22 864	21.0
15.12.67	338	2 464	-	17 728	2 416	22 608	20.8
12.12.67	553	1 328	-	5 904	3 312	10 544	9.7
23. 1.68	689	-	2 128	33 664	4 528	40 320	37.0
10. 2.68	1 199	-	-	8 256	7 536	15 792	14.5

1/ **The amounts of potential spawning area for subsections 1-4 were** 4 608, 19 600, 43 680, 40 992 ft² **respectively.**

(**From Horton and Rogers,** 1969)

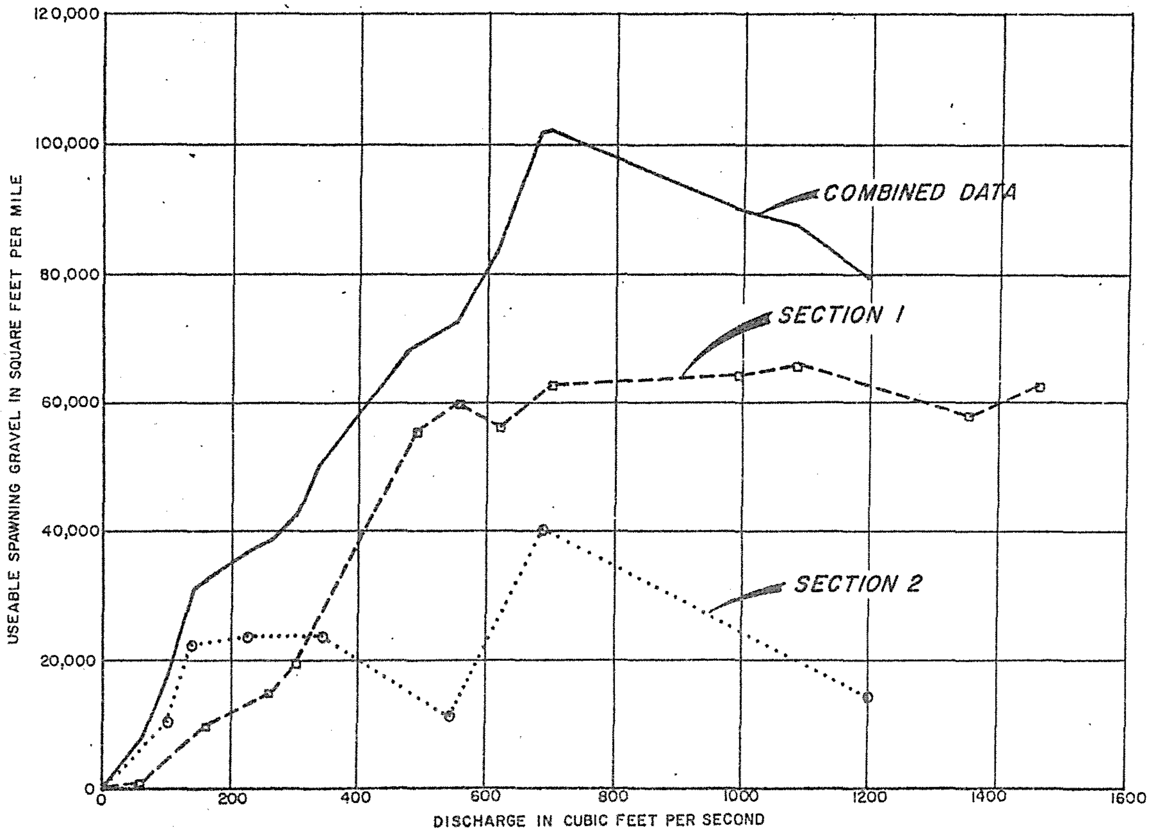


Figure 8: Relationship of Spawning Area with Flow in the Van Duzen River (from Horton and Rogers, 1969

THE OREGON BASIN INVESTIGATIONS

Commencing in 1961 (Hutchison, 1962), the Oregon State Game Commission embarked upon a series of river basin fish and wildlife surveys, including assessments of their water use requirements. (Fortune and Thompson, 1969; Hutchison 1962, 1965; Hutchison, Thompson and Fortune, 1966; Hutchison and Aney, 1964; Hutchison and Fortune, 1967; and Thompson, 1972.)

In relation to streamflows the studies were primarily aimed at determining the volumes needed for spawning, passage, rearing, food and shelter for anadromous and resident salmonids. In respect to spawning and passage, the studies were conducted whenever possible during periods of actual fish movement or spawning. Current meters were used to measure depths and velocities over available spawning gravels. Depths and spawning velocities were established for each species through measurements at numerous redds.

Through these measurements a series of flow recommendations were compiled for the streams studied. These flows were considered to be adequate for spawning and passage.

In relation to rearing flows during the summer months it was determined that a live stream with a minimum depth of one-tenth to two-tenths of a foot over a substantial portion of each riffle regardless of size was necessary. It was felt that these flows normally satisfied the requirements of food, shelter, a suitable medium, and passage between pools and for downstream migration of juvenile salmonids.

In the Clackamas River, spawning flow study on "average velocity analysis" (Sams and Pearson, 1963) was used to determine optimum spawning flows for spring chinook salmon (O. tshawytscha). Ten transects were established on representative gravel bars in 7.9 miles of the river. The average velocity method uses the formula:

$$V = \frac{F}{WD}$$

V = Average water velocity in feet per second over the entire transect at a given below

F = Total flow in cubic feet per second

W = Width of the transect in feet at a given flow

D = Average depth in feet of the transect at a given flow.

Stream width and average depth over each transect were measured under four different streamflow volumes. Average water velocities for each transect were then computed using the above formula. Then the means of the average velocities for all transects for each flow were plotted with the total flows to form a curve. (Fig. 9.) Table 7 shows the measurements of depths and velocities over 340 spring chinook salmon redds from which the curve is derived.

Careful selection of transect locations is important so that they are representative of the river's spawning and passage areas. If they are, then reliance may be placed on the projection of flows for suitable or optimum spawning and upstream passage.

In another spawning flow study on Gales Creek (Hutchison and Aney, 1964) a "usable width" criteria was applied. In two sections of the stream having different characteristics, 11 transects were established on spawning gravels. One section was narrow with fast water and the other, slower and wider. Depths and velocities were measured across each transect under four different flows. Areas considered unusable for coho salmon (Oncorhynchus kisutch) or steelhead trout (Salmo gairdneri) were those not covered by more than 0.6 ft of water at a velocity between 1.0 and 2.5 ft/s measured 0.4 ft from the stream bottom. From these measurements the widths of usable gravels were determined and plotted against total flows (see Fig. 10). The plotted curves depict the relationship between flow and usable spawning gravel in the two study sections. Reductions in usable gravel due to excessive velocities occurred in the narrower upper section at flows in excess of approximately 85 ft^3/s. This did not occur in the lower section until flows exceeded approximately 180 ft^3/s. Flows were satisfactory for spawning over a far greater range in the lower section than in the upper.

These Oregon survey reports usually contained species distribution maps which are helpful in orienting the reader to the species-location-flow situation. Examples are reproduced as Plates 2, 3, and 4.

SPAWNING FLOW DETERMINATION, UPPER CLACKAMAS RIVER
SPRING CHINOOK SALMON

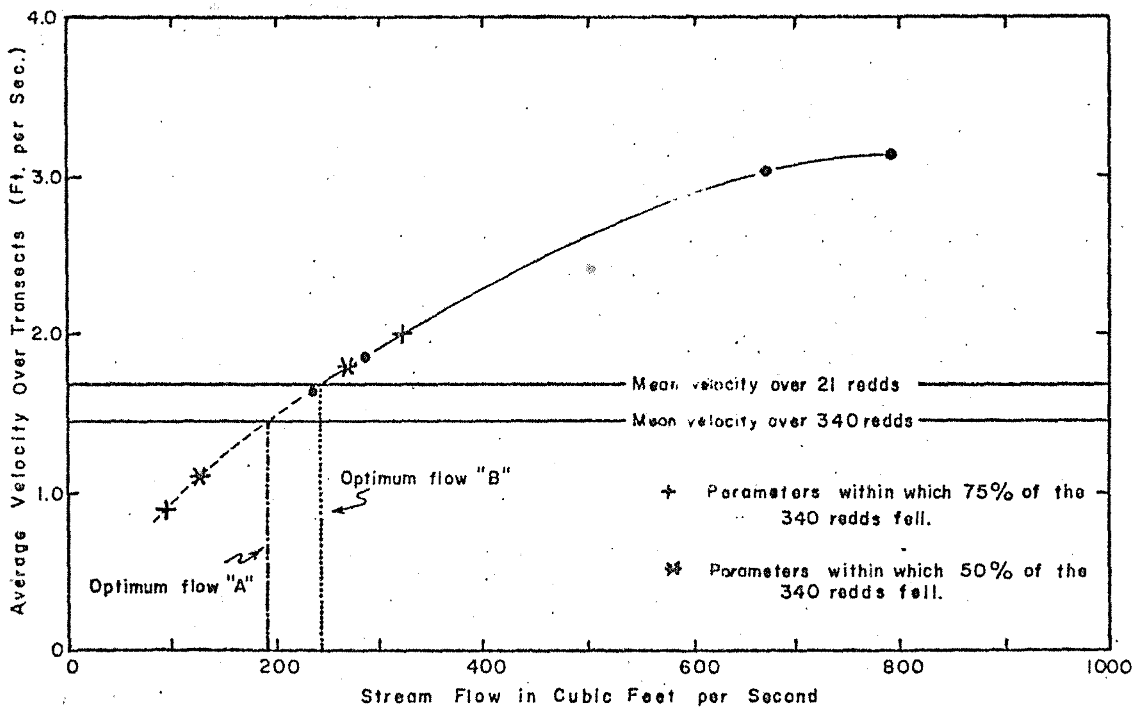


Figure 9 Spawning flow determination for spring chinook salmon in the upper Clackamas River using average velocity analysis. Optimum flows at U.S.G.S. gage 14-2080. Optimum flow "A" based upon measurement of 340 spring chinook redds in Willamette Valley streams. Optimum flow "B" based upon measurement of 21 spring chinook redds in the Clackamas River system

(From Hutchison and Aney, 1964)

PER CENT UTILIZABLE SPAWNING GRAVEL, GALES CREEK
STEELHEAD AND SILVER (COHO) SALMON

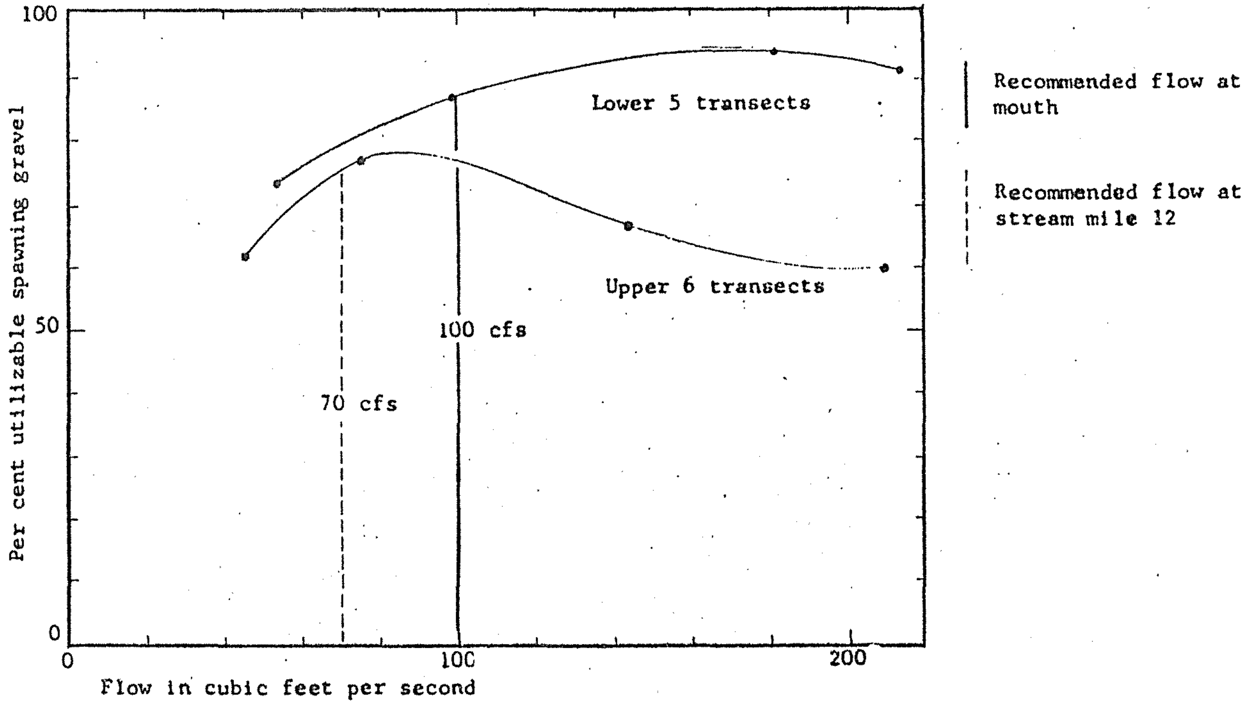


Figure 10. Per cent of gravel utilizable for steelhead trout and silver salmon spawning in Gales Creek as measured at 11 transects (usable width method).

(From Hutchison and Aney, 1964)

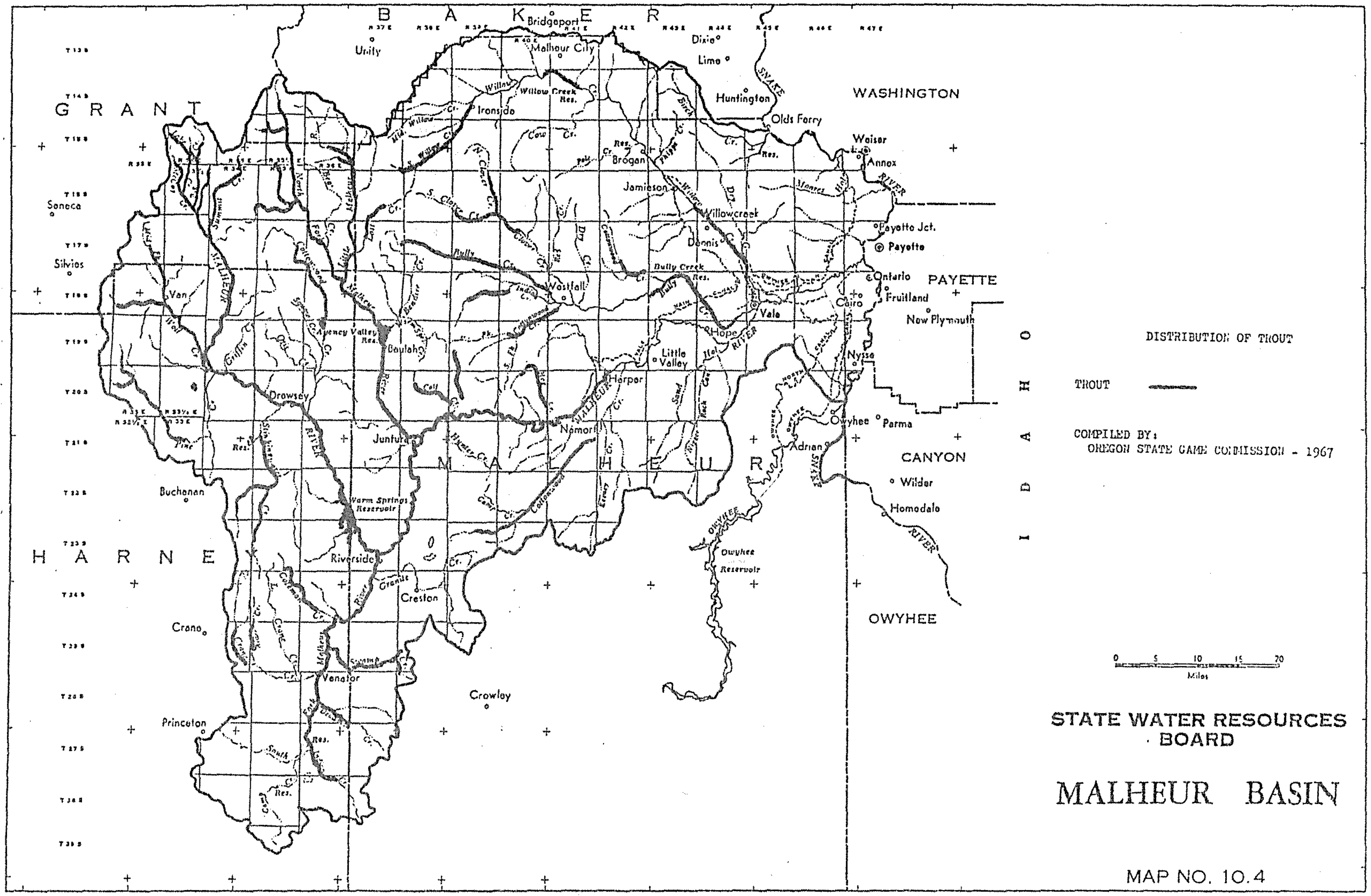


PLATE 2 - (From Thompson and Fortune, 1967)

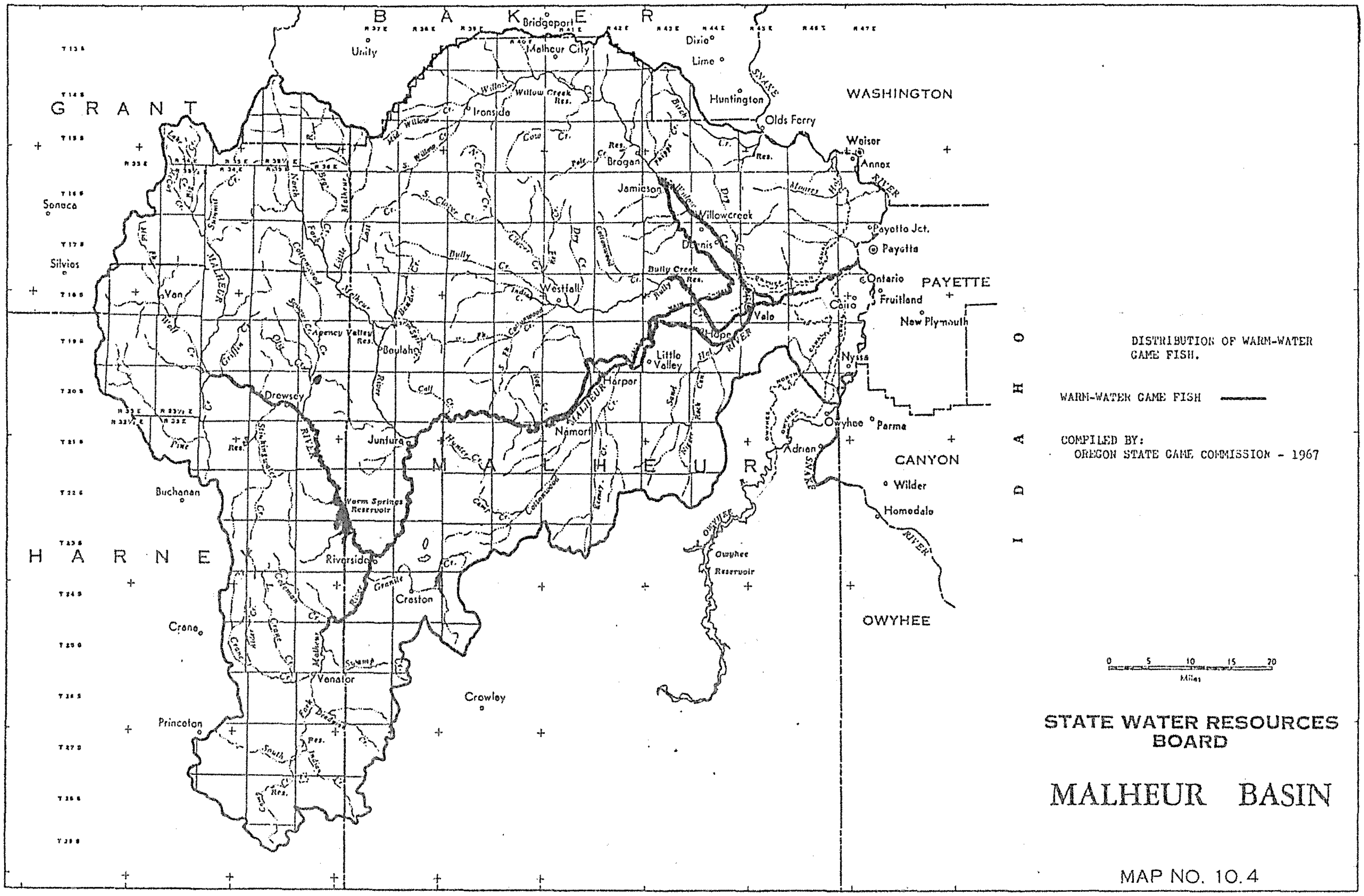


PLATE 3 - (From Thompson and Fortune, 1967)

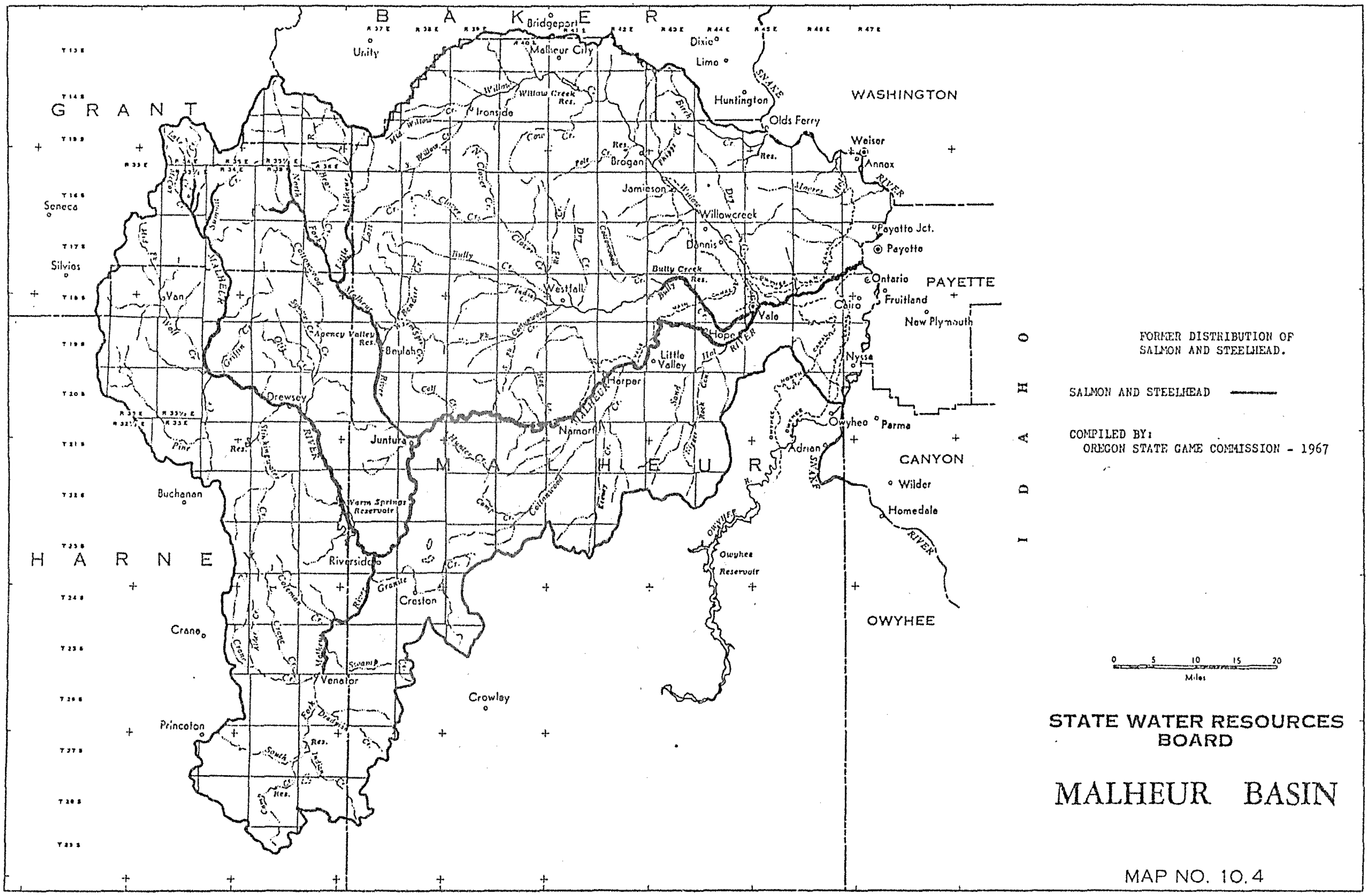


PLATE 4 - (From Thompson and Fortune, 1967)

TABLE 7

Water Depths and Velocities Measured over 340 Spring Chinook Salmon Redds in Willamette River System Streams, 1961-63[1/]

Water Depth[2/] (ft)	No. of Redds	Average Velocity[2/] (ft/s)	No. of Redds
0.3	7	0.45	3
0.4	9	0.5	1
0.5	11	0.6	4
0.6	26	0.7	10
0.7	32	0.8	15
0.8	30	0.9	21
0.9	47	1.0	23
1.0	45	1.1	25
1.1	29	1.2	25
1.2	24	1.3	29
1.3	9	1.4	24
1.4	22	1.5	15
1.5	10	1.6	24
1.6	8	1.7	27
1.7	8	1.8	23
1.8	8	1.9	20
1.9	7	2.0	14
2.0	5	2.1	5
2.1	0	2.2	14
2.2	0	2.3	3
2.3	1	2.4	5
2.4	1	2.5	3
2.5	1	2.6	3
		2.7	1
		2.8	1
		2.9	0
		3.0	1
		3.1	1
Means 1.03		1.46	

1/ Of the 340 total redds, Fish Commission personnel measured 270 and Game Commission personnel 70. Measurements were obtained from Clackamas, Little North Santiam, McKenzie, Molalla and South Santiam River systems.

2/ Measured 1 ft upstream from each redd.

(From Hutchison and Aney, 1964)

Pitney (1969) points out that there is a distinct difference in the curves of utilizable spawning gravel in relation to flow from stream to stream. Each stream must be studied. No slide rule formula has been developed as an alternate. Fig. 11 illustrates the difference for nine Willamette basin streams in Oregon. Particular attention is called to the last graph in this figure, the one for Mill Creek. From this graph it can be seen that the greatest amount of spawning gravel would be available at a flow of about 125 ft^3/s. However, Oregon law calls for the minimum flow "sufficient to support aquatic life". The Oregon workers have interpreted this to mean the flow sufficient to maintain a reasonable fish population in balance with other environmental factors. Thus the recommended minimum spawning flow on Mill Creek was set at 80 ft^3/s instead of 125 ft^3/s. By this process the water requirements for spawning was reduced by 36 percent while the available spawning area was reduced by 10 percent.

Out of these Oregon Game Commission studies have evolved criteria and methodology, which are perhaps the best yet devised for freshwater salmonids. Their developers are, however, quick to point out that they are only a beginning and that much more research and field work is needed. Thompson (1972) does an excellent job of summarizing the criteria and methodology which I will, in turn, paraphrase and summarize for the purposes of this report:

Fish Passage. To determine a recommended flow for passage of fish in a particular stream, the shallow bars most critical to passage of adult fish are located and a linear transect marked which follows the shallowest course from bank to bank. At each of several flows, the total width and longest continuous portion of the transect meeting minimum depth and maximum velocity criteria are measured. For each transect and each flow the total width of the stream, the width wetted (under water), the width usable for passage, and the longest continuous portion usable for passage are measured, tabulated and plotted on a graph of flows versus the longest continuous portion usable as a percent of the total. For each transect, the flow is selected which meets the criteria on at least 25 percent of the total transect width and a continuous portion equalling at least 10 percent of its total width. The results averaged from all transects is the minimum flow recommended for passage. (Thompson cautions that the relationship between flow conditions on the transect and the relative ability of fish to pass has not been evaluated.)

Spawning Flows. Three gravel bars are selected which represent the typical dimensions of those occurring in the study stream. On each gravel bar is marked a transect which coincides with the area where spawning is most likely to occur. At each of several flows, the total portion of the transect is measured where flow conditions meet predetermined depth and velocity criteria (See Appendix B). The mean relationship that discharge has with gravel area usable for spawning is then assessed from all transect measurements. An optimum spawning flow is that which provides suitable flow depth and velocity conditions over the most gravel. The discharge which created suitable flow conditions over 80 percent of the gravel available at an optimum spawning flow is recommended for minimum spawning. This generally coincides with the flow considered most efficient for spawning over the most gravel (the flow which makes available the most gravel per unit of flow).

Egg Incubation. Because of the complex relationship of surface flows and underflow in the intragravel environment, the Oregon workers resort to combining judgement with field observations to arrive at flow recommendations. At each of several flows, an estimate is made of the flow required to cover gravel areas used for spawning and to create an intra-gravel environment conducive to successful egg incubation and fry emergence. The flow recommended is based on the various observed estimates and is generally about two-thirds of the spawning flow.

Rearing. (The period when fish are not migrating, spawning or when eggs or fry are not in the gravel.) Based on evaluating several different flows, an estimate is made of the flow required to create a suitable stream environment for rearing using the following guidelines:

1. Adequate depth over riffles
2. Riffle-pool ratio near 50:50
3. Approximately 60 percent of the riffle area covered by water flow
4. Riffle velocities 1.0 to 1.5 ft/s
5. Pool velocities 0.3 to 0.8 ft/s
6. The most stream cover available as shelter for fish.

Summary Chart. With a flow recommendation for each of the four biological activities for each important species in the study stream, a chart is prepared depicting the life history phases and minimum flows for each study stream or stream section (Fig. 12). The flow selected for any month or two-week period is the highest flow required to accommodate any biological activity during that period.

The Report. The report prepared for each stream or a series of streams usually includes the following: flow recommendations for fish life by stream and month; fish species distribution and abundance; a description of the biological requirements of salmonids; limiting factors to fish in the study area; fish resource values; streamflow and temperature measurements, and a variety of photographs.

The reader is referred to Appendix C which contains a copy of the outline guide for the steps in determining streamflows for fish life developed by the Environmental Management Section of the Oregon State Game Commission.

Thompson (op cit.) states that two inviolable ground rules have evolved in this methodology: "Regardless of how tempting and how realistic it might be, flow recommendations are based on the biological requirements of fish and are not adjusted for seasonally natural flow deficiences. Second, we do not recommend flows for relatively unimportant species if the flow would be harmfully excessive to an important species."

Figure 11. Relationship between utilizable spawning gravel and stream flow on nine Willamette River Basin streams. (From Pitney, 1969)

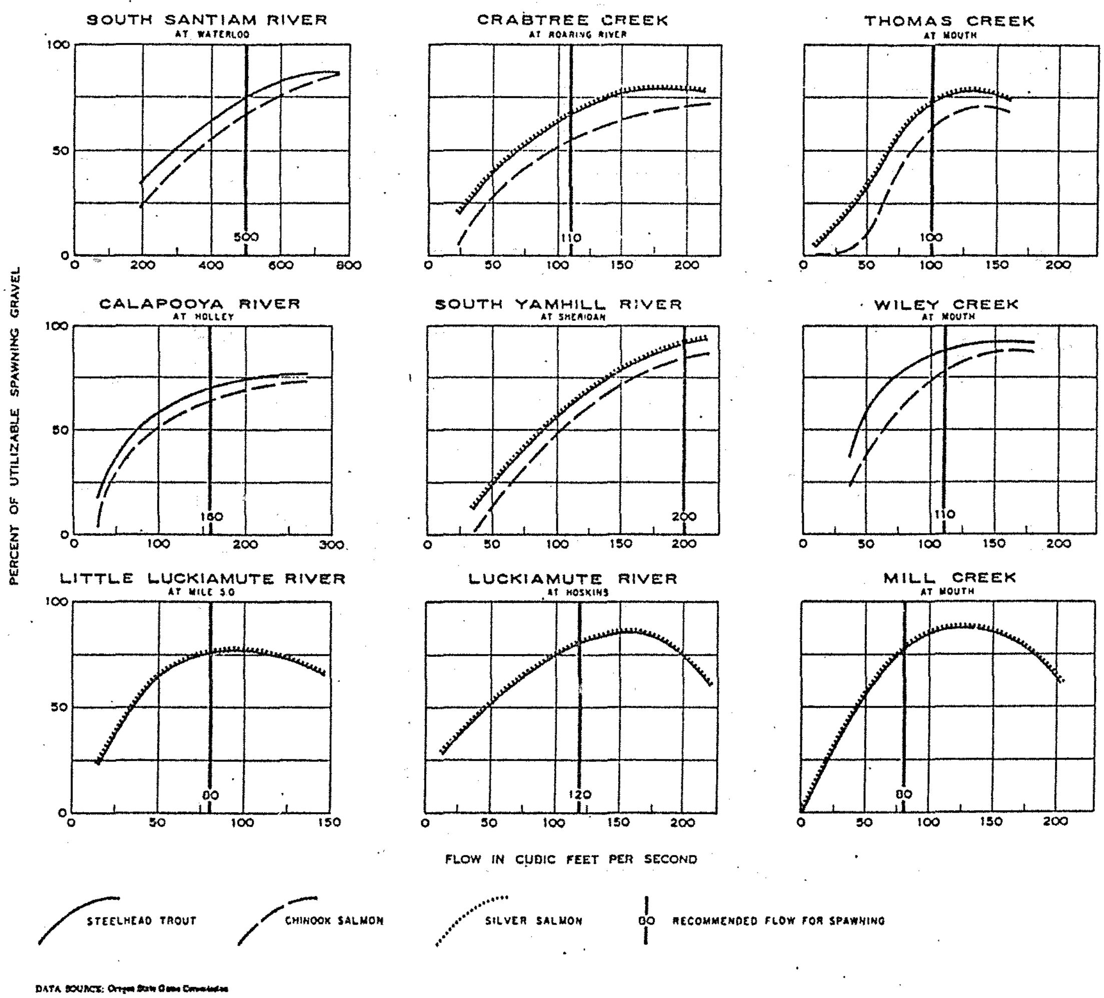
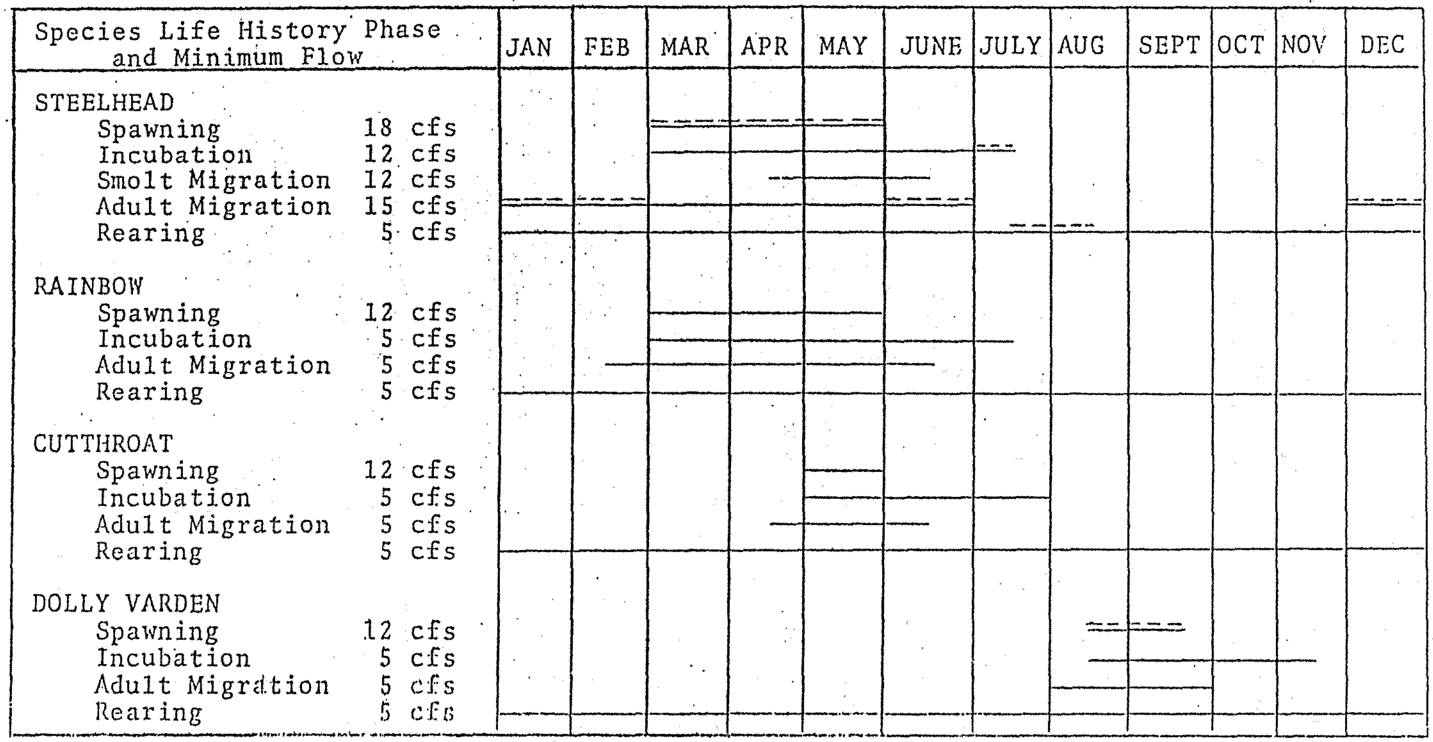


FIGURE 12

LIFE HISTORY PERIODICITY and MINIMUM FLOW
REGIMEN for EXISTING SALMONID POPULATIONS
in REYNOLDS CREEK, JOHN DAY BASIN

(From Thompson, 1972)



Recommended Minimum Flow Regimen	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
	15	15	18	18	18	15	12/5	5/12	12/5	5	5	15

WASHINGTON - McKINLEY's "MINIMUM ACCEPTABLE SPAWNING FLOW"

McKinley (1957) presented an approach to determining what he referred to as the "minimum acceptable flow" based on depth and velocity criteria and measurements in relation to spawning of salmon (species unspecified but probably chinook, O. tshawytscha). He states that the depth and velocity criteria are based on the optimum range for the salmon or, in other terms, the range which normally included (used by) 70 to 80 percent of the fish observed.

After a general biological study of a stream typical cross-sections are chosen as representative. Means are developed to measure the water stage at each cross-section. At various discharges the water stage is plotted on the cross-section, and a velocity distribution is plotted above it (see Fig. 13). The accepted criteria for depth and velocity are superimposed upon the two graphs and from this the available width of the cross-section having the acceptable ranges is recorded. The measurements and plottings are repeated for other flows to give a suitable range of data.

These data will show the flow at which the maximum of favourable spawning conditions occur (according to the selected criteria), but McKinley considered it more reasonable to select a "minimum acceptable discharge" by drawing a tangent from the curve to the origin. He states, "This system would assume a linear increase in width per unit discharge up to the point of intersection. Above this point there would be less gain in width per unit discharge or, in other words, a condition of diminishing return as regards water use only."

McKinley's paper cites the application of this "minimum acceptable discharge" concept to the Tolt River in Washington. Based on drawing a tangent to the curve of combined depth and velocity data, a recommended "minimum acceptable discharge" of 200 ft^3/s was derived (see Fig. 14).

Two possible shortcomings in McKinley's proposal appear in view of later work. First, assuming that the criteria used is appropriate and that the measurements and resulting data are truly representative of available spawning area in the cross-section, then a permanent reduction of flow below that which would provide maximum spawning area will inevitably have a depressing effect on spawning. If flows were normally available to provide the better conditions then an arbitrary reduction resulting from drawing a tangent on the curve must certainly be recognized as very probably resulting in a long-term reduction in the resource.

Secondly, if we eliminate depth as a factor and concentrate on velocity as do most later workers, and if we use the apex of the curve rather than the point of contact of the tangent, we can see that perhaps the more appropriate minimum flow recommendation for the Tolt River is 300 ft^3/s instead of 200 cubic feet per second.

In essence, McKinley's proposal suggests that a reduction in flow resulting in a small reduction in spawning area is acceptable, or in his terms "more reasonable." This concept may be acceptable or even desirable under some circumstances of compromising conflicting uses of water, but it should be recognized that it will not, in all probability, maintain the salmon resource at natural levels over a long period of years.

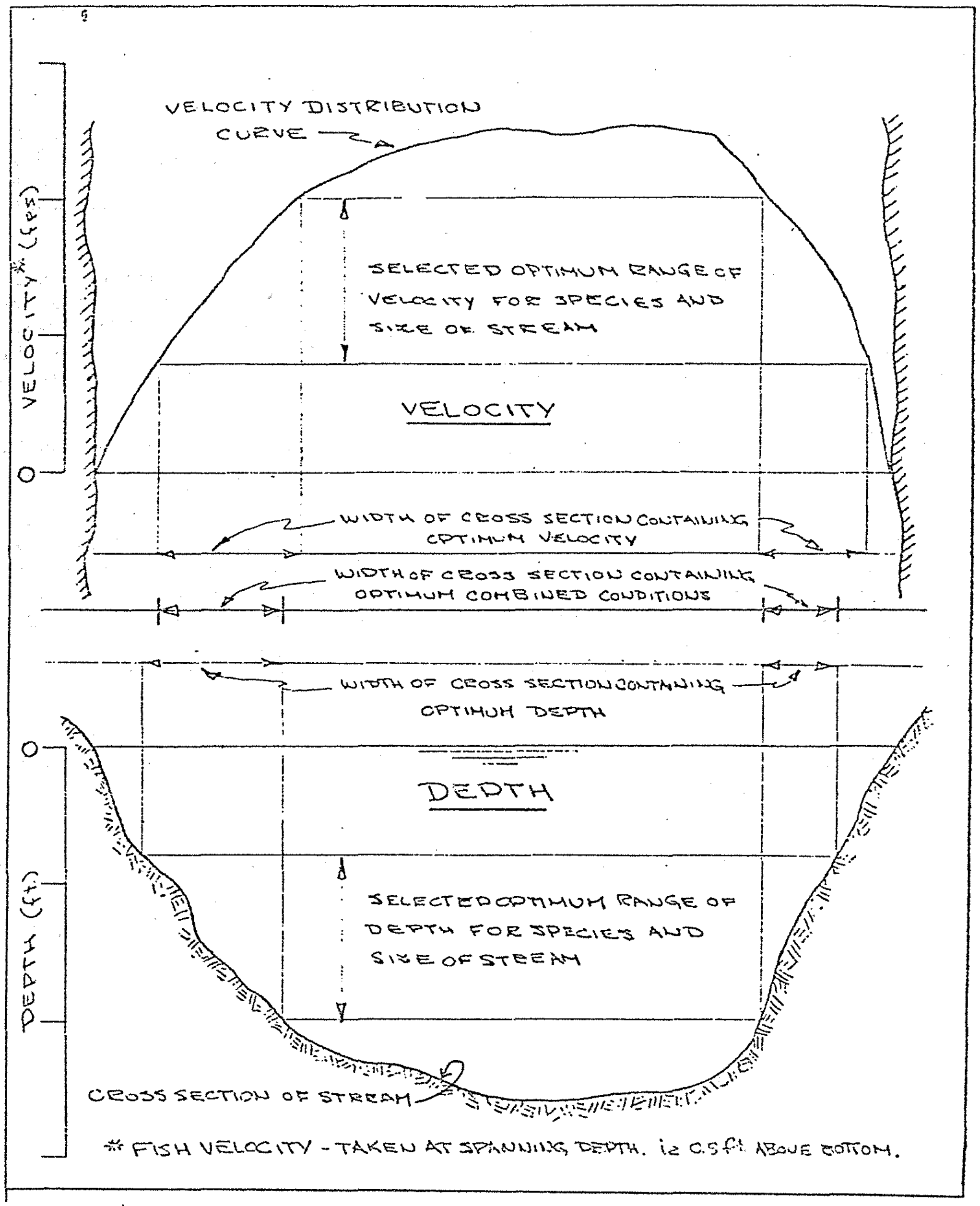


FIGURE 13. Method of Application of Optimum Criteria to a Particular Cross Section.

(From McKinley, 1957)

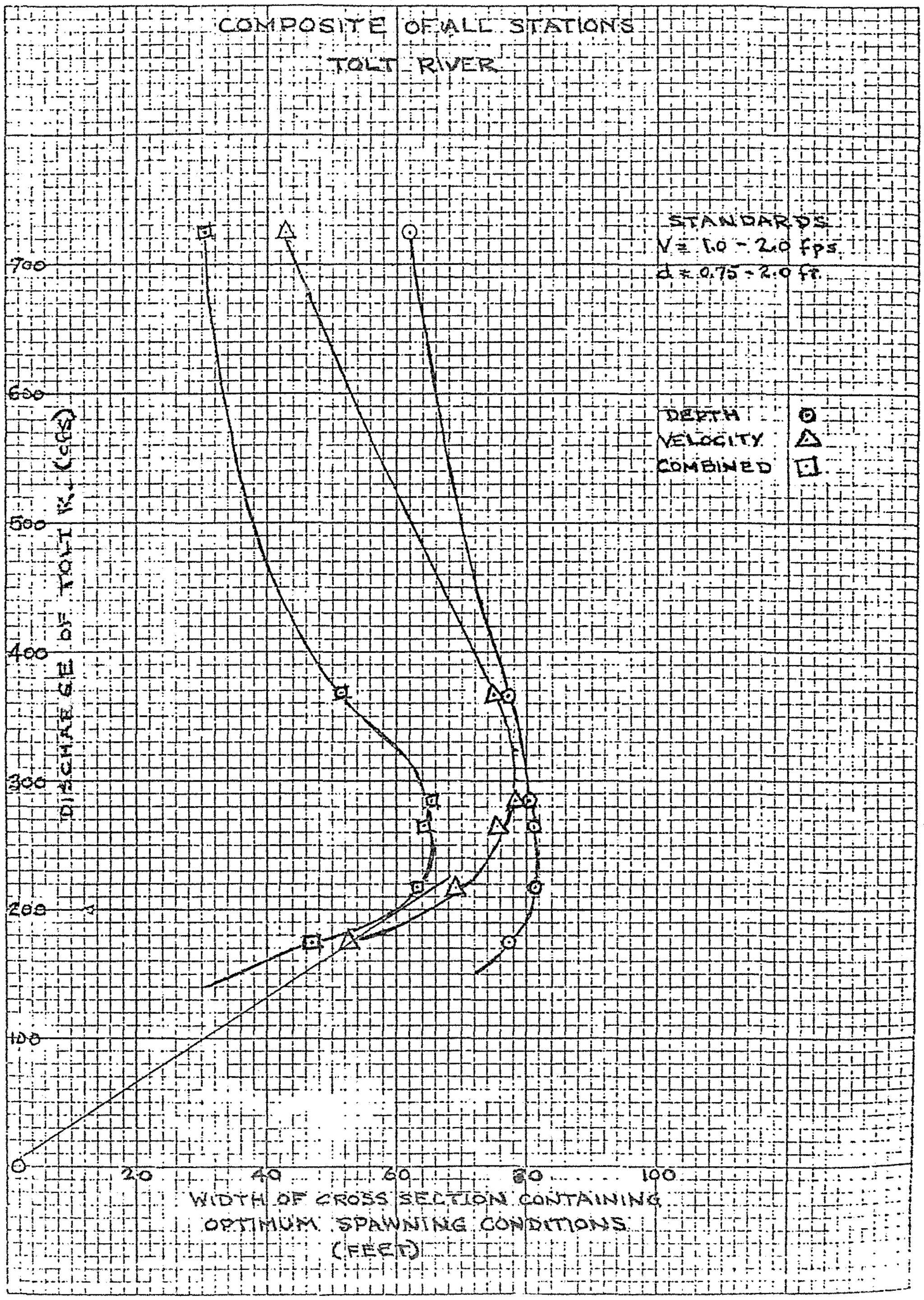


Figure 14.

Derivation of the "Minimum Acceptable Discharge"

(From McKinley, 1957)

THE IDAHO PROGRAMME

The Idaho Water Resource Board contracted with the Idaho Fish and Game Department to study the aquatic life water needs in a number of Idaho streams already influenced by storage, diversion, regulation or interstate water requirements (Idaho Fish and Game, 1969). As a result of the study, recommendations were made for minimum sustained flows which were described as merely preventing detrimental effects on populations "which are maintained at a lower level of abundance". The report states that this is in contrast to optimum flows which allow fish population increases to the fullest possible extent. (It is a little difficult for me to understand how the objective of maintaining a fish population at a lower level of abundance is equivalent to preventing detrimental effects on populations.)

In determining the recommendations for sustained minimum flows the biological requirements of the coldwater game fish populations were considered in the light of the following criteria:

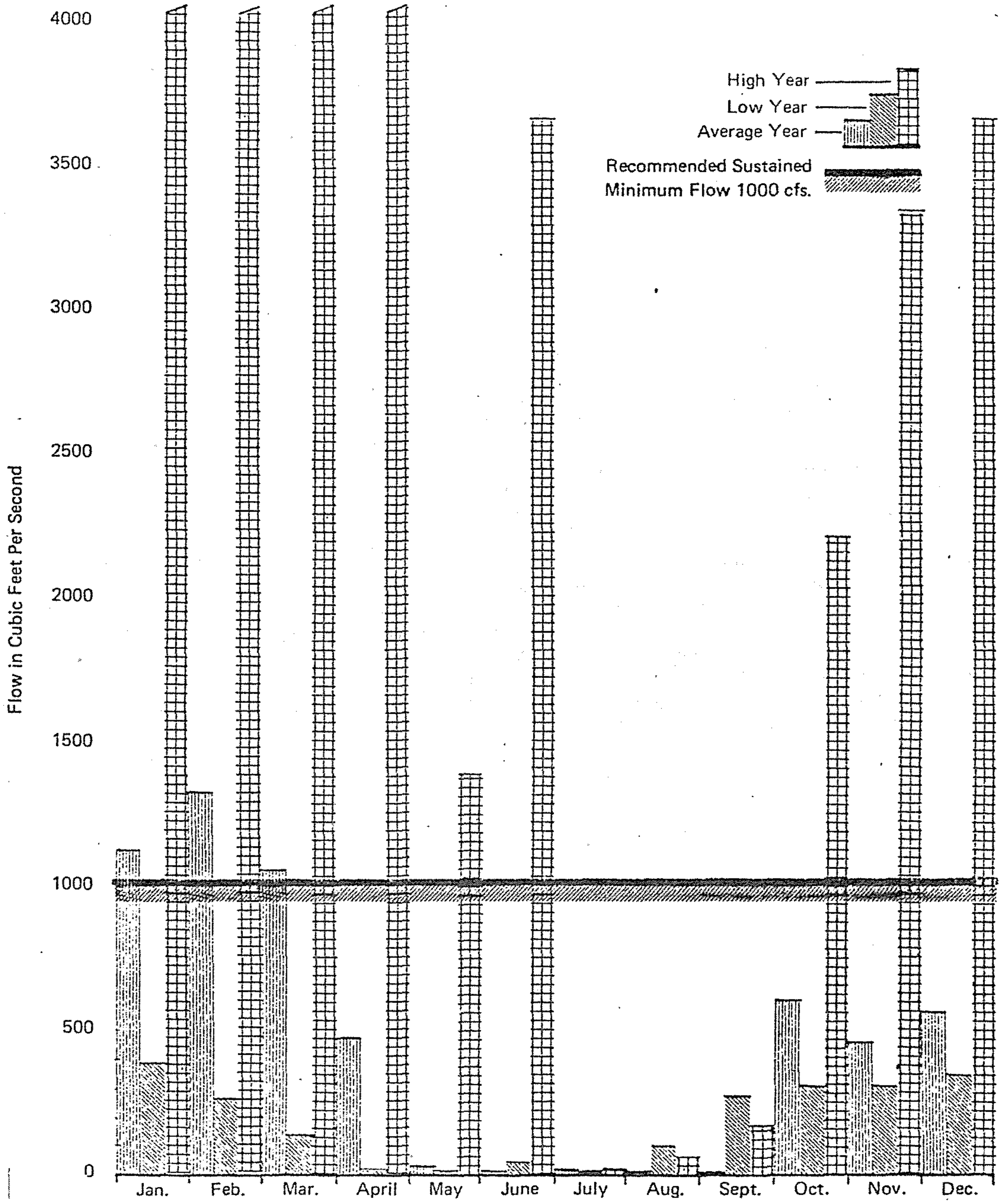
Water quality (primarily dissolved oxygen and temperature)
Food
Escape cover
Reproduction
Fish passage

The Oregon criteria for spawning flows were used in this study. Consideration was also given to stream-bottom configuration, composition and gradient, stream-side cover and several climatic conditions.

Stations were established on streams at state lines, below diversions and impoundments, and at other places where regulation of streamflows occurred. Past survey and study records were reviewed and fishery biologists consulted concerning past studies and observations. Where necessary, on-site investigations were made and preferably at the low-flow period of the year. On the larger streams, flow-habitat relationships were estimated using the nearest or a comparable known flow as reference. In the end the recommended flows were based on the judgement and experience of the regional fishery biologists.

Although the report does not describe the procedures used in any detail, it is assumed that they are similar to the transect studies used in Oregon and California. However, considerable reliance seems to be placed upon the judgement of the fishery biologist as a supplement or a substitute for in-stream or transect measurements. Another troublesome feature of these studies is that the recommendations are made as a single flow for the entire year. This does not consider seasonal variations in the needs of the fish and other aquatic resources. The report notes that the results of the study must be considered preliminary in nature. An example of the Idaho recommended sustained minimum flow in relation to high, low and average flows in the Snake River are shown in Fig. 15 taken from the 1969 report.

Figure 15— Average monthly flows for selected years, Snake River at Milner. (24-year average flow 1873 cfs)



(From: Idaho Fish and Game Department, 1969)

HYDROLOGICAL AND GEOMORPHOLOGICAL APPROACHES TO STREAMFLOW DETERMINATION

Several studies and proposals have been made to relate the hydrology and geomorphology of a stream or stream basin to the spawning or production of salmon. Such approaches have the obvious advantage of reducing or possibly eliminating costly and time consuming field measurements and surveys. They have an additional advantage in that they provide mathematical data and approaches which will help in the ultimate mathematical modelling of streamflow and aquatic resource dynamics. I shall briefly review some of the suggested approaches which have come to my attention.

The Flow Duration Curve

A method which has been used to estimate fish-flow recommendations in hydrologically and geologically similar drainages is the flow duration curve method. Applying it to spawning flows requires the calculation of mean monthly flows during the spawning months for a representative period of years tied in with at least one field-measured spawning flow for each drainage.

Hinton, Fisher and Mallette (1965) describe the following steps in utilizing this method to arrive at a spawning-flow recommendation:

"1. Construct a flow duration curve for a representative period of years for each of the spawning months on probability scale x 3 cycle logarithm paper (See Fig. 16). Denote Q in cubic feet per second along the ordinate, and the percentage of total years that mean monthly flow is less than that shown at any point on the curve, along the abscissa.

2. Introduce a field-measured fish maintenance spawning flow (flow required to maintain present average run) on to the individual flow duration curves from the point on the ordinate representing the appropriate flow (Fig. 16).

3. Read off the percentage probability figures (probable percentage of total years that the mean spawning flow would prevail) for individual months along the abscissa.

4. Introduce the percentage probability figures derived from step 3 to the abscissa of the graph of flow duration curves for any other stream in the same or similar drainages where mean monthly flows for similar time periods have been determined (Fig. 17).

5. Read off the estimated maintenance spawning flows for each month involved.

6. Average the flows thus derived. This figure is the estimated maintenance spawning flow for the particular stream.

7. Follow the same procedure to determine an enhancement (optimum) spawning flow."

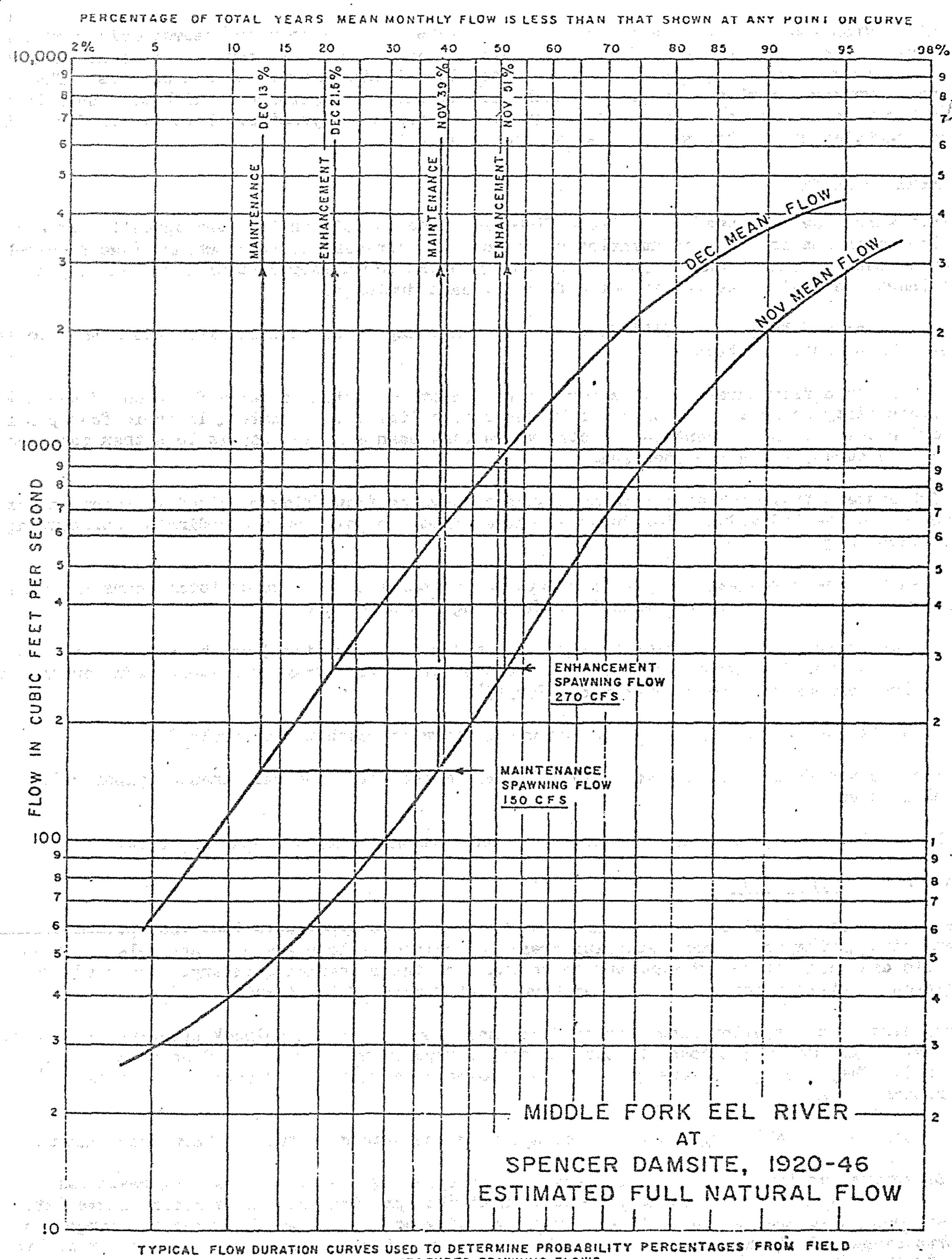
The Regression-Equation Method

Rantz (1964) carried out a reconnaissance study to test the hypothesis that the optimum discharges (the minimum flow giving the maximum spawning area) for chinook salmon spawning are related to some characteristic discharge of the streams and to an index of their channel geometry. The study was carried out in a region of similar geology in the northern Coast Ranges of California.

Optimum discharge was determined through field measurements at one chinook spawning area on each of nine streams using methods adopted by the California Department of Fish and Game (e.g., Kier, 1964, Puckett, 1969). These optimum discharges were then correlated with mean discharge and ratio of stream width to drainage area.

Rantz outlined the following procedure for applying the method to the northern Coast Ranges:

"1. Determine the long-term mean discharge at the spawning reach; the spawning reach has been gauged for 10 years or more. If the gauging station at the spawning reach is a recent installation, the long-term mean discharge may be obtained by correlating concurrent monthly mean discharges at the spawning-site gauge and at the nearest comparable gauging station for which the long-term mean discharge is known. If the spawning reach is ungauged, the first step is to make five or six discharge measurements over a wide range of discharge at the spawning reach. To obtain the desired mean, the measured flows are then correlated with concurrent discharges at the nearest comparable gauging station for which the long-term mean discharge is known.



TYPICAL FLOW DURATION CURVES USED TO DETERMINE PROBABILITY PERCENTAGES FROM FIELD MEASURED SPAWNING FLOWS

FIGURE 16

(From Hinton, Fisher and Mallette, 1965)

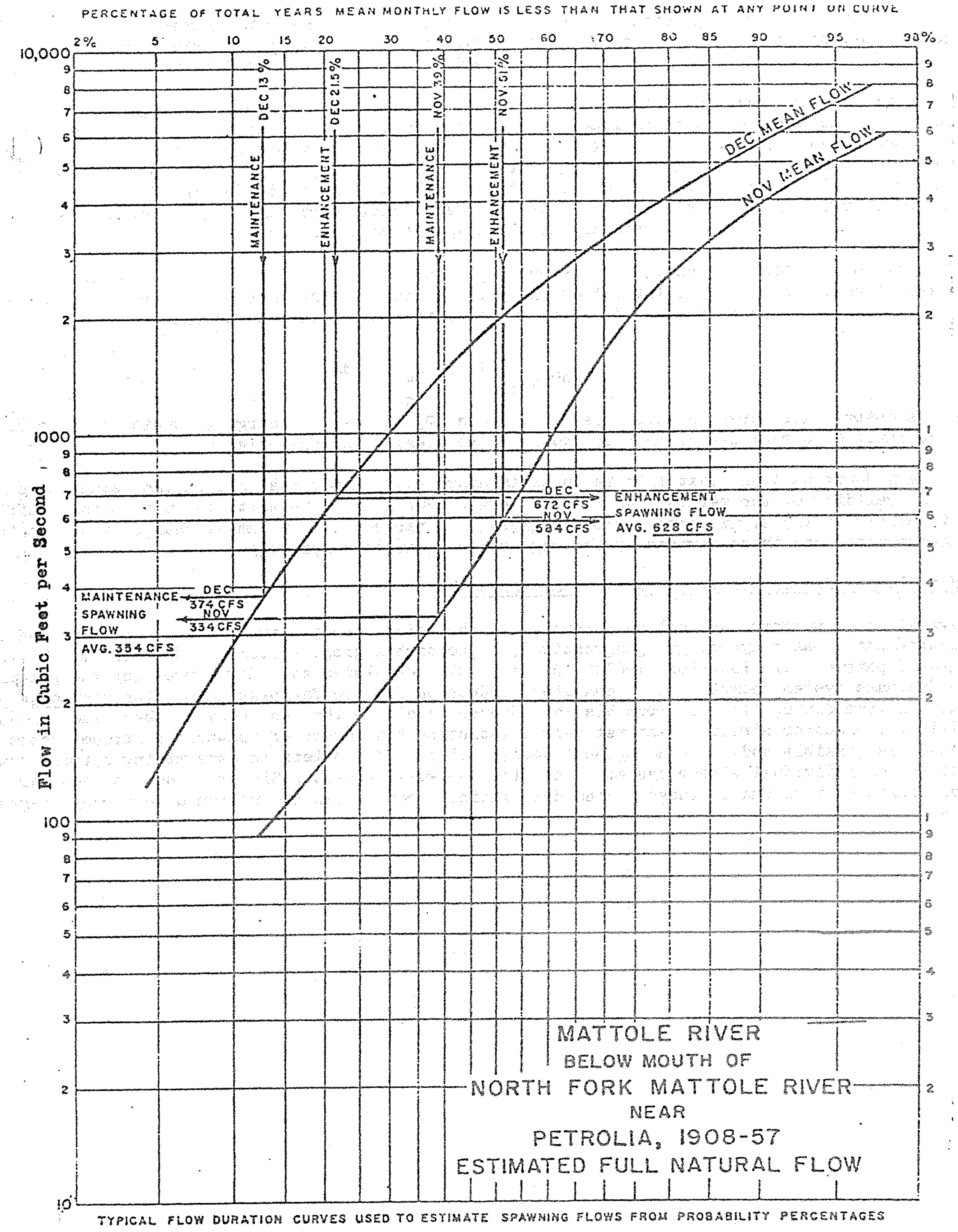


Figure 17

(From Hinton, Fisher and Mallette, 1965)

2. Determine the drainage area at the spawning reach: if the spawning reach is gauged, the drainage area may be obtained from streamflow publications. If ungauged, the drainage basin above the reach is first outlined on topographic maps. The desired drainage area is then measured by planimeter.

3. Determine the average stream width at the spawning reach when the discharge is at or near its mean value: if the spawning reach is gauged, the stage of the mean discharge will be known. If the spawning reach is ungauged, the stage corresponding to mean discharge can be deduced from the discharge measurements that had been made at the reach. Observations of stream width corresponding to the desired stage should be made in sufficient numbers to establish the average width for the full extent of the spawning reach or reaches. Commonly in the northern California Coast Ranges, the lowest line of vegetation on the stream banks is approximately at the stage of mean discharge.

4. Determine optimum discharge at the spawning reach by use of the regression equation or curves. The optimum discharge may be calculated from the data obtained in the three steps described above, by use of the regression curves on Fig. 18, or by substitution in the regression equation:

$$Q_o = 0.89\,(Q_m)^{1.09}\left(\frac{R_w}{da}\right)^{1.44},$$

where Q_o is optimum discharge in cubic feet per second, Q_m is mean discharge in cubic feet per second, $\frac{Rw}{da}$ is the ratio of stream width, in feet, to drainage area, in square miles."

Although Rantz cautions that this is an exploratory study and urges that further studies be made to test the validity of the method, the results were encouraging. The multiple correlation coefficient, 0.912, is statistically significant. Table 8 gives a comparison of optimum discharge figures based on field measurements and those derived by the regression-equation computation.

Other Hydrology - Geomorphology - Geographical Approaches

Several other workers have called attention to the relationship between salmon spawning and rearing flow requirements; basin hydrology, geographical or geomorphological factors, and basin area (e.g., Washington Department of Fisheries, 1967). Ziemer (1971) developed an index expressing the relationship between drainage system geometry and freshwater production factors for pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. From his work Ziemer concludes that an index of the salmon production potential of freshwater streams quantitatively forecasting the number of spawners a stream system can accommodate is possible and, as a management tool, will help biologists in determining optimum spawning escapements for individual stream systems. As with the work of Rantz, Ziemer notes the need for further study of finite channel and drainage system data against proper fish production data through regression analysis.

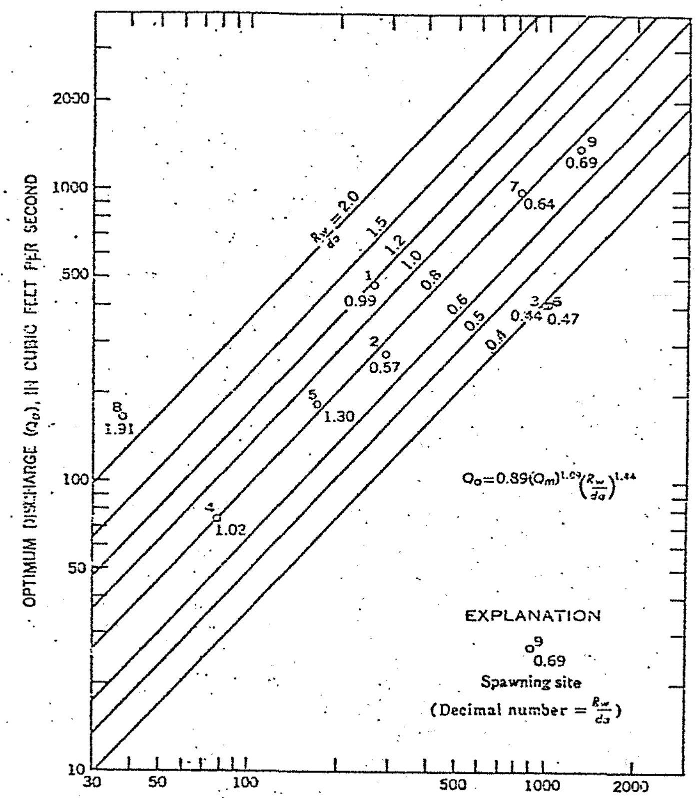


Figure 18

MEAN DISCHARGE (Q_m), IN CUBIC FEET PER SECOND
Graph showing the relation of optimum discharge to mean discharge and to ratio of stream width to drainage area.

(From Rantz, 1964)

TABLE 8

Comparison of Measured and Computed Optimum Discharge

Spawning site		Optimum discharge		
No.	Name and location	Measured (ft^3/s)	Computed (ft^3/s)	Percent difference referred to measured discharge
1	Outlet Creek near Arnold	480	379	− 21
2	Black Butte River near Covelo	280	189	− 32
3	Middle Fork Eel River near Covelo	400	481	+ 20
4	Williams Creek near Covelo	73	103	+ 41
5	South Fork Eel River near Branscomb	185	346	+ 87
6	South Fork Eel River near Leggett	400	533	+ 33
7	Van Duzen River near Carlotta	1 000	694	− 31
8	Canon Creek near Korbel	165	116	− 30
9	Mad River near Korbel	1 400	1 270	− 9

(From Rantz, 1964)

REARING FLOWS FOR SALMON

Much less work has been done on the flows needed for rearing of juvenile salmon than on the flows needed during the spawning period. It has been common practice to devote most attention to the spawning period and assume that juvenile salmon can survive in much reduced flows since in most salmon streams the summer flows are naturally lower. This assumption has unfortunately resulted in reducing summer controlled discharge rather drastically in many salmon streams. Recent studies have shown that summer discharge and water velocity have a significant relationship to the rearing capacity of coho salmon streams.

Pearson, Conover and Sams (unpublished draft, 1970?) carried out studies to develop field methods usable in determining adequate rearing flows for coho salmon (Oncorhynchus kisutch). They described two approaches as follows:

"Pool Velocity Method. This method is based on the fact that pool velocity seems to be an index of the factors that control the population of juvenile coho in a pool. The numbers of fish per pool area were found to be related to the average velocity through the pools.

With this method the assumption is made that conditions for rearing would improve with higher velocities in the pools. These conditions would improve until the current in parts of the pools becomes too fast and reduces the pool area available for coho rearing. Maximum velocities of about 0.7 ft/s at which coho were found in rearing could be used as a criterion for the optimum velocity in pools.

The method consists of getting measurements in the pools of the study stream that would enable the average pool velocity to be calculated for several streamflow levels. The optimum flow would be that flow in which the average velocity of the study pools matched the velocity criterion of 0.7 foot per second.

The Riffle Method. Food supply has been shown to be an important ingredient in the coho production of a stream. Therefore, an optimum flow for coho juvenile rearing would be that flow which provided the maximum amount of fish food while velocities through the pools are not excessive.

A large portion of the food supply originates on the riffles. The maximum amount of fish food is controlled by at least two factors related to flow. These two factors are water velocity through the riffle and the amount of riffle area. Results from our work indicate that peak insect production on the riffles occurred at velocities of about 2.0 feet per second. Therefore an optimum flow based on fish food production would be that flow which covered the greatest amount of the riffle and still provided large sections of the riffle with water velocities of about 2.0 feet per second.

This method would entail measuring the areas and velocities of an adequate sample of the riffles of the study stream. From the results of these measurements, it could be determined what was the best riffle area-velocity combination."

RELATING PAST FLOWS TO YEAR-CLASS SUCCESS

Flows for Downstream Migrant Juvenile Salmonids

Although considerable work has been done to quantify the waterflow requirements to the spawning activities of salmon, there are several other periods in the life cycle of salmon, any of which may be equally, if not more, critical in terms of their waterflow requirements. One of these, of course, is the period of downstream migration of juvenile salmon.

It has long been thought that the times of largest flow requirements were the periods of spawning and possibly upstream migration and at other times the flows could be greatly reduced without harm. It is becoming increasingly evident that this is not true.

A high correlation (r = 0.84) was found by Fry (unpublished manuscript, 1965, reported in California Department of Fish and Game, 1972) between the March-April flow (the downstream migration period of the juvenile chinook salmon) of the San Joaquin River and the size of the chinook salmon spawning population in the Tuolumne River (a tributary of the San Joaquin River) two and three years later.

Menchen (unpublished data reported in California Department of Fish and Game, 1972) updated Fry's work to include chinook salmon spawning stocks through 1971. These data had a correlation coefficient of 0.81; they are plotted in Fig. 19. He also correlated the number of females in the Tuolumne River runs with riverflows in March through June. This was done because in recent years most females returned as 3-year fish, and therefore the relationship between the females and flows 2½ years earlier is more direct than using total run data. The coefficient of correlation for this relationship was 0.79 (see Fig. 20).

These data and calculations by Fry and Menchen suggest that the size of a spawning population (as a reflection of juvenile survival) increases slowly at first in relation to riverflow (at time of downstream migration of juveniles), then increases rapidly with further increases in streamflow and then reaches a plateau beyond which the increases cease or are small in relation to increments in flow.

This information, coupled with the fact that there is far less correlation between flows at time of adult upstream migration and the adult spawning population, strongly suggests that streamflow at the time of downstream migration may be a major influence on chinook salmon populations. The California Department of Fish and Game report (1972) notes that high streamflows at the time of downstream migration create a more favourable environment for the survival of juvenile salmon by:

(1) providing more living space and shelter, thus reducing intra-specific competition, both in the broodstream and along the migration route;

(2) reducing vulnerability to predation;

(3) reducing losses in irrigation diversions (at higher flows the proportion of water diverted is smaller and losses would also be less).

The report does not mention another possible factor; with higher flows the orientation of downstream migrating juveniles would be greater, thus resulting in less straying.

Striped Bass Survival

Another example of comparing survival or strength-of-year classes with streamflow has been done in the delta and lower sections of the Sacramento and San Joaquin Rivers in California. This is an important area for striped bass (*Morone saxatilis*) which migrate upstream in the spring of the year from the bays or ocean to spawn in the rivers. With their semi-buoyancy and the currents of the river water keeping them suspended, the eggs develop as they move downstream. Spawning generally takes place in May and June. The larval fish spend their first summer in the delta at the confluence of the Sacramento and San Joaquin Rivers.

Most spawning occurs in fresh water. Because of low flows in the San Joaquin River and a high percentage of poor quality agriculture return water, a reverse salinity gradient occurs in some years. When these salinities of agricultural origin exceed 350 mg/l TDS, the adult striped bass generally refuse to spawn and must drop back downstream to areas of lower salinity (Radke and Turner, 1967).

A significant correlation (r = 0.89) between delta outflow during June and July and the survival of juvenile striped bass has been demonstrated by Chadwick (1969) and Turner and Chadwick (1972). These studies indicate that survival of young striped bass is relatable to outflow up to about 10 000 ft^3/s. Six flow-related factors have been suggested by Turner and Chadwick (1972) as the reason for this increased survival at higher flows. Figure 21 depicts the relation between the index of year class abundance of young striped bass and river outflow during June and July.

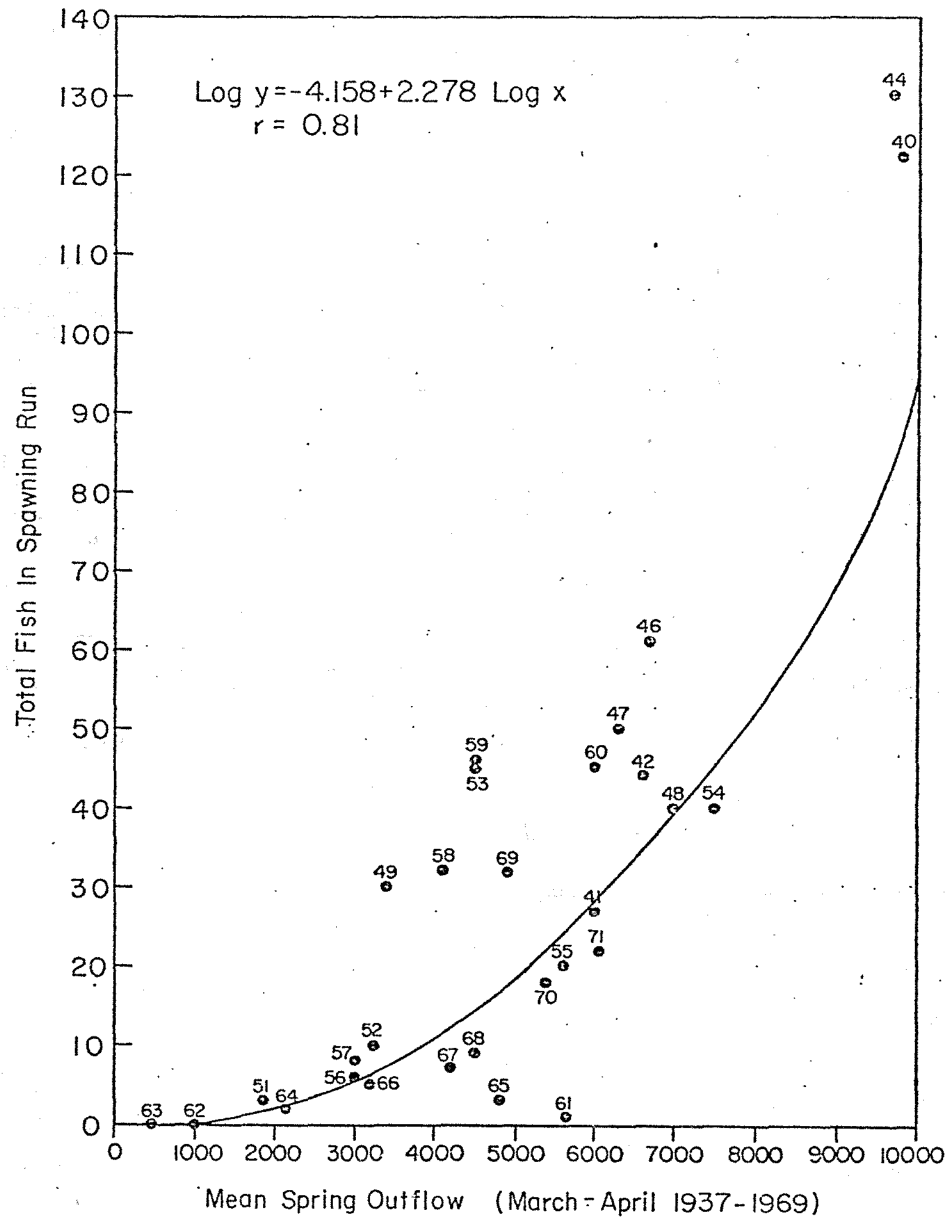


Figure 19. Relationship between spring outflow of San Joaquin River at Vernalis and salmon spawning run 2 and 3 calendar years later in the Tuolumne River (numbers indicate year of spawning).

(From California Department of Fish and Game, 1972)

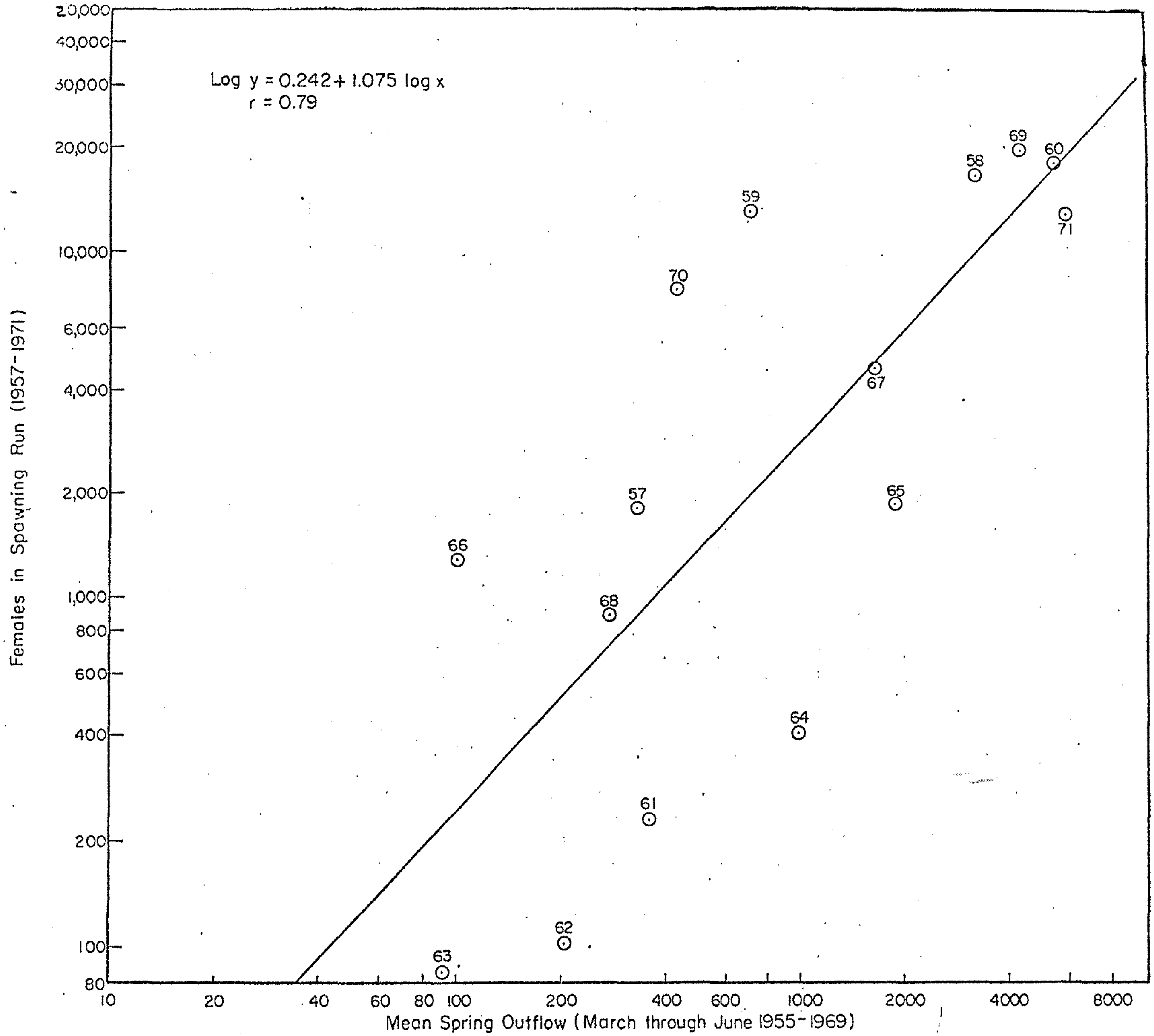


Figure 20. Relationship between spring outflow of Tuolumne River and number of spawning females 2½ years later (numbers indicate year of spawning).

(From California Fish and Game, 1972)

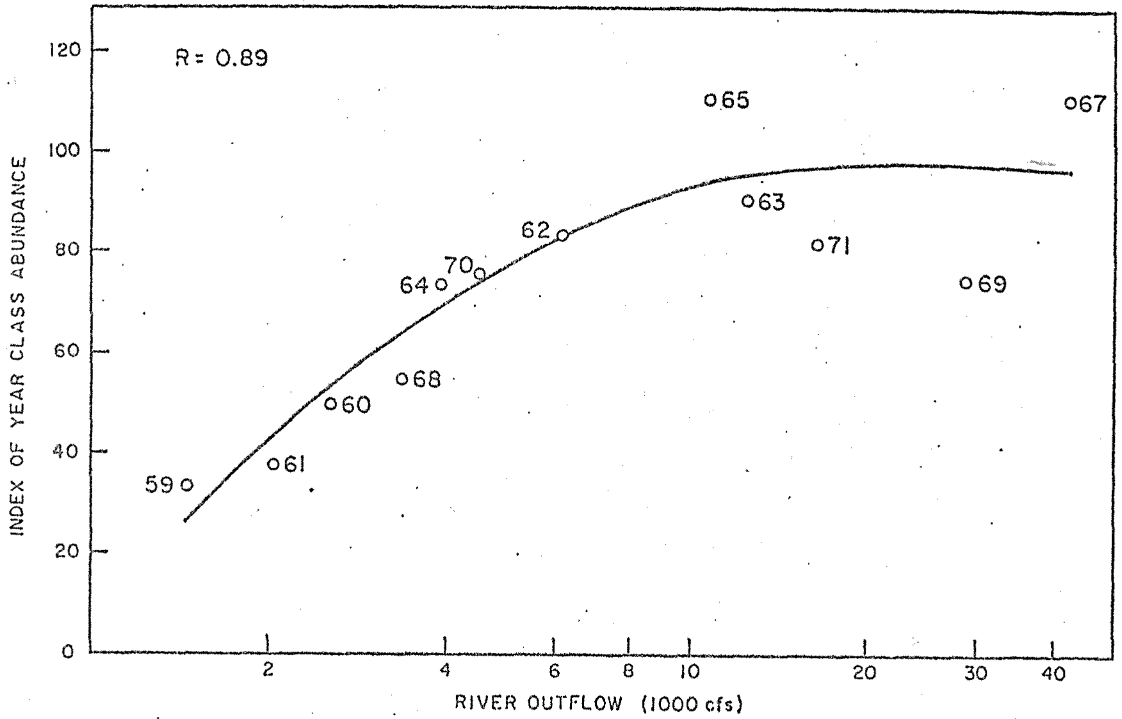


FIGURE 21. Relation between index of year class abundance of young striped bass and river outflow past Chipps Island during June and July. Numbers on figure designate years.

(From California Department of Fish and Game, 1972)

DETERMINING FLOWS FOR TROUT STREAMS

The science of determining adequate controlled discharge for trout streams is developing slowly. Actually, serious efforts to quantify the streamflow needs of trout populations have only taken place in the past 20 to 25 years. Earlier work on the biology of trout has, of course, provided data essential to these recent efforts.

Most attempts to quantify the flow requirements of trout have concentrated on: (1) food production, (2) spawning and (3) shelter. Many studies have depended largely upon the judgement of biologists (e.g., Idaho Fish and Game Department, 1969), comparison of photographs of a stream at various flows, calculations of wetted area at various flows or a combination of these, e.g., Kent (1963) and Petersen and Leik (1958). Others have measured the depth, velocity or volume of flow and related these data to trout food production, spawning and shelter. These are, for the most part, rather gross or limited evaluations of two or three parameters and certainly, at best, are probably only approximations of the total effects of various streamflows on the lotic environment of trout. However, they are significant steps in the direction of ultimate quantification of the many ecological factors which make for a trout population of certain size and composition.

Kelley, et al.(1960 and 1964) reviewed the problems of measuring and evaluating these parameters. Their first measurements were made on Frazier Creek, a small mountain trout stream where flows could be controlled within certain limits. Their study area consisted of an 81-ft long riffle and a 64-ft long pool. It was divided into small sections and measurements of food-producing, shelter and spawning areas were made with tapes and staffs marked off in feet. The measurements were made at six discharges ranging from 0.5 to 30.8 ft^3/s. Flows were measured with a Gurley current meter.

The criteria used by Kelley, et al.(1960 and 1963) were:

(1) for food producing areas - those areas with large gravel or rubble where surface velocities were estimated (or measured) to be above 0.5 ft^3/s;

(2) for shelter - the biologist's best estimate;

(3) for spawning - the area where velocities were from 0.5 to about 3.0 ft^3/s, with a depth of 0.25 to 3.0 ft over gravel of pea size to 2 in in diameter.

The Frazier Creek studies demonstrated that both food producing and shelter area increased as streamflow increases but that the rate of gain became less as the volume of flow filled the stream channel.

Delisle and Eliason (1961) gathered data from similar measurements on the Middle Fork Feather River. Table 9 shows the data gathered in this study and those on Frazier Creek.

Studies in 1963 by biologists of the California Department of Fish and Game were guided by the following criteria:

"1. Food supplying areas - defined as those areas of the stream bottom which have a velocity of between one-half and three feet per second, measured .2 foot from the bottom with a standard current meter.

2. Spawning areas - defined as those areas of the stream bottom which have (1) water velocities .2 foot from the bottom of one-half to three feet per second, (2) at least a 2-foot square section of bottom consisting of gravel from pea size to three inches in diameter and (3) a water depth of between three inches and three feet.

3. Shelter area - is defined as those more or less permanent local habitat conditions which tend to protect the adult trout from harmful factors (man, birds, snakes, fur-bearing mammals, solar radiation) in its environment. In measuring shelter area along a cross-sectional line in a natural stream environment, only gross lack or gross abundance of cover will be defined. Area of shelter will not be defined in units of less than one foot in width. If any one-foot interval has enough cover to more than provide shelter for one adult trout (six inches plus) it will be counted as cover area. If a one-foot area does not contain at least enough cover for one adult trout, it will not be counted as cover. All areas where, due to surface turbulence, the bottom cannot be seen will be initially counted as shelter-producing area. These same areas will be re-evaluated when the flow is lower to determine if the bottom substrata could provide shelter. Bedrock or smooth bottoms will not be considered as cover except in some pools where surface turbulence may provide cover even with a relatively smooth bottom."

TABLE 9

Area (in ft^2) of Food Producing, Shelter and Spawning Area Per Lineal Foot of Test Sections in the California Trout Streams

	Flow in ft^3/s	Food Producing Area	Shelter Area	Spawning Area
Frazier Creek	0.5	1.3	1.8	T
	2.6	7.0	2.4	T
	4.8	10.6	8.0	0.3
	9.0	12.6	9.0	0.3
	12.0	14.9	10.6	0.3
	30.8	18.5	14.4	0.3
Middle Fork Feather River	41	30.8	38.4	0
	58	35.4	39.2	0
	70	45.9	45.2	T
	94	47.4	48.5	T
	109	51.6	50.1	T
	212	58.4	58.1	0.03

(From Kelley et al., 1964, and Delisle and Eliason, 1961)
T = Trace

Kaweah River (California) Studies

In 1971 studies were conducted to evaluate the trout food production potential of several streamflows. The following is a description of the methods used in that study (Horton, 1972):

Trout Food Production Studies

Methods

In order to determine how flow reductions affect availability of trout habitat, a study to evaluate the trout food production potential of various streamflows was conducted in the summer of 1971.

Seven transect locations were chosen to represent typical riffle sections. Wetted width and depth and bottom velocity 0.3 ft above the bottom were measured at intervals across the permanent transect line at each site at various streamflows. Photos taken at each measurement provided a record of cover and general river habitat conditions.

In analysis of the collected data, a graph of flow versus wetted width was drawn. On the same graph, using the criteria of water depth greater than 0.3 ft and bottom velocities between 0.5 ft/s and 3.5 ft/s as good trout food producing area, the amount of wetted width rated good was also plotted against flow.

To further analyse the transect data, various velocities measured were assigned relative values for trout food production potential. These values were set following a normal curve distribution with 2.0 ft/s velocity as the optimum value. The relative value of trout food production decreased approaching 0 and 4 ft/s, respectively, at either end of the curve. Each velocity measurement across a transect line was used to determine the relative index of trout food production for that interval. The total of these indices was plotted against streamflow and labelled the "Relative Index of Trout Food Production". This method of analysis was used to evaluate the quality as well as the quantity of trout food producing area.

Results

The stream transect method assumes that water depth, and more importantly water velocity, are qualities that can be used in determining the value of an area as game fish habitat. Optimum velocities provide a maximum of aeration, cover, and distribution of the proper nektonic and benthic food organisms needed for game fish production.

Width Rated Good

As streamflow increases from some value at or near zero, the width rated good for trout food production increases rapidly at first and then tends to stabilize or increase more slowly with considerably higher flows. Flow changes on the lower end of the range generally result in greater increases in usable width than will the same changes on the upper end of the range. A well defined break, or the midpoint of maximum slope on the graph representing plotted transect data, can be said to be the "optimum flow".

The data curves for two combined transect sites on the East Fork Kaweah and five combined transect sites on the Middle Fork Kaweah show drastic decreases in "width rated good" and wetted width at flows below 25 ft^3/s. Measurements of width rated good for trout food production on the East Fork ranged from 16 ft at 5 ft^3/s to 64 ft at 94 ft^3/s. The combined width rated good for the five Middle Fork sites ranged from 100 ft at 15 ft^3/s to 195 ft at 60 ft^3/s.

Relative Index of Trout Food Production

It was found that the "relative index of trout food production" increased with streamflow in a manner graphically similar to the analysis of "width rated good". On the East Fork, the point where there was significant decrease in the index with decreases in streamflow again occurred at about 25 ft^3/s. Results at three Middle Fork Kaweah transect sites showed a linear pattern of index increase. Data points for the two remaining Middle Fork study sites were somewhat erratic, showing optimum streamflow values ranging from 25-40 ft^3/s.

Average Velocity

A study conducted on the Kern River comparing numbers of aquatic insects to various velocities 0.3 ft above the stream bottom showed that velocities around 2 ft/s were preferred by most of the genera present. Assuming that the types of aquatic insects and their value to gamefish were similar on the Kaweah, an analysis of average bottom velocities at the various streamflows was made.

The highest average bottom velocity on the East Fork Kaweah, a value of around 0.9 ft/s, occurred at about 30 ft^3/s. On the Middle Fork, an optimum value of approximately 0.7 ft/s occurred at about 40 ft^3/s discharge.

Pictorial Evaluation

Photos used for subjective evaluation of cover, fishability, turbulence and aesthetic qualities of the river at various discharges show that the quality of habitat increased greatly with increasing streamflows.

Transect Studies on Trout Streams

The following is an outline of the methods currently in use by the California Department of Fish and Game for transect studies on trout streams:

Transect Studies

The Transect procedure is patterned after king salmon studies on the Feather (Delisle and Eliason, 1961) and Cosumnes (Westgate, 1958) Rivers, with modifications to fit trout stream conditions such as smaller riffles, higher stream gradient, greater variation in bottom type, and importance of food production.

Because of manpower limitations, riffles are classified into four size groups, to allow reasonable time to take measurements on large riffles as well as an adequate sample of smaller riffles.

I. Select Transect Stations

A. Reconnaissance of entire stream section below diversion structure.

B. Selection of representative riffle sections for test stations, and establishment of a general range for test flow releases, based on observations. It is extremely important that the selected range of test flows be adequate to cover the stream size.

II. Measurements

A. Establish a straight-line parallel to the river flow at each test site along one bank above high-water mark (highest test flow).

B. Set stakes along this "reference bank" at the following intervals:

1. If test riffle is 30 ft long or under, set up four transects at equal intervals.

2. If riffle is 31 to 50 ft long, set up transects at 10-ft intervals.

3. If riffle is 51 to 75 ft long, set up transects at 15-ft intervals.

4. If riffle is over 75 ft long, set up transects at 20-ft intervals, to a maximum of six transects.

C. Set stake on far side of river opposite each stake on reference bank. The line between each pair of stakes should be perpendicular to the river flow. (An attempt should be made to select riffles which run in a relatively straight line.)

D. Stretch engineer's tape measure, divided at 0.1 ft intervals, across the river with "0" mark at reference stake.

E. At each test flow take the following measurements, starting at the "0" mark.

1. Location of water's edge, both sides of river.

2. Depth of water at the following intervals, based on highest test flow release (depth to nearest 0.1 ft on wading rod).

a. Six inches if stream width is less than 18 feet
b. One foot if stream width is 18 to 35 feet
c. Two feet if stream width is 36 to 53 feet
d. Three feet if stream width is 54 to 71 feet
e. Four feet if stream width is over 71 feet

3. Velocity of water, 0.25 ft from the bottom, at the same locations as depth measurements.

4. Bottom-type, at same locations as depths and velocities (should be evaluated only at lowest measured flow to facilitate observation). Bottom types include:

a. Clay
b. Silt
c. Sand
d. Gravel (1/8 in to 3 in diameter)
e. Rubble (3 in to 12 in diameter)
f. Boulder (over 12 in diameter)
g. Bedrock
h. Plant material and detritus

5. Locations of edges of emergent rocks, to nearest 0.1 ft.

F. Streamflow (ft^3/s) at time of transect measurement.

G. Incremental flows - tributaries, ground water, etc.

III. Evaluations

A. Depth - less than 0.25 ft considered too shallow for good trout habitat. Since depths were measured to the nearest tenth of a foot, all areas listed on data sheets as less than 0.3 ft are too shallow.

B. Velocity - less than 0.5 ft/s is too slow for good riffle habitat; over 3.5 ft/s is too fast.

C. Calculation of area - each measurement is assumed to be the average (depth, velocity, bottom type) for half of the distance to the next measurement, both across the stream and parallel to the direction of flow. The following is a simple formula for the calculation of each section area:

$$A = d\,(i - r)$$

A = area of individual section (square feet)

d = distance between transects (feet)

i = interval between measurements (feet)

r = length of interval which is not submerged (emergent rocks)

In actual practice it is not necessary to calculate the area of each section separately. Only sections with emergent rocks must be calculated individually (also edges).

RATE OF FLOW CHANGE (LIMITING FLUCTUATIONS)

Sudden changes in streamflow can have a number of adverse effects. Stranding of fish and fish food organisms, and the disruption of migration and spawning activities have been demonstrated in a number of studies made on quick reductions in flow. Sudden increases in flow can also cause disruption of spawning activities and scouring. Rapid changes in flow are a common occurrence in the operation of hydro-electric power plants. Rapidly fluctuating flows can be a problem at any dam, especially if the outlet structures are not designed to provide gradual changes in the flow releases. A very real danger to downstream fishermen can result from sudden increases in flows. In past years a number of anglers were drowned in the Klamath River in California due to sudden discharges from a hydro-electric power plant. This condition was ultimately rectified by construction of a re-regulating reservoir below the discharge to smooth out the flow.

It is becoming standard practice to require operational limitations designed to ensure that the rate of change of the discharge to the stream channel from a dam or hydro-electric power plant or other artificially controlled source is not damaging to the downstream resources. Most such limitations have been designed more by the biologists' or recreation specialists' judgement than by the results of specific scientific study.

A fairly recent limitation imposed on the operation of the Llyn Celyn Dam in the River Dee system in the U.K. called for a maximum allowable rate of reduction of 120 m.g.d. per hour to be achieved in uniformly spaced steps not greater than 10 m.g.d. each. This limitation applies during the winter months of December to February. During the remainder of the year when there is greater risk of stranding fish, the maximum allowable rate of reduction is 20 m.g.d. per hour for flows above 120 m.g.d. and 10 m.g.d. per hour for lesser flows, in uniformly spaced steps not greater than 5 m.g.d. each. To provide this protection for the salmon resources required the design of the generating plant and outlet structures to accommodate a wide range of flows (7 to 250 m.g.d.) under varying heads (Crann, 1968). It is suggested that these limitations are approximate simulations of the rate of recession of a natural river after a rain (Blezard, Crann and Jackson, 1970).

Another approach to limiting fluctuations is to restrict the change in river height as represented in the U.S. Federal Power Commission Order Issuing Licence No. 2299 on the Tuolumne River (U.S. Federal Power Commission, 1964) a chinook salmon (Oncorhynchus tshawytscha) spawning stream in California. A multi-purpose irrigation water supply, hydro-electric and flood-control dam would have fluctuating releases to satisfy peaking hydro-electric and flood-control objectives. Unrestricted operation for these purposes would have been detrimental to the spawning, rearing and passage of salmon.

Under the Federal Power Commission Order the flood-control releases could be made as necessary with the exception that during the 45-day salmon spawning period the flows would be increased to 4 500 ft^3/s within 24 hours and reduced as soon as possible after flood-control criteria are met. Apparently this was to keep the period of excessive flows to a minimum so that salmon would not start spawning in marginal areas of the higher flows only to have the redds de-watered when the flood releases were terminated. Discharges for salmon during this same period would range between 200 and 385 ft^3/s by the Federal Power Commission Order.

For purposes other than flood control the discharges were limited during the 45-day spawning period so as not to cause a daily increase of river height in excess of 10 in, provided that for a period not to exceed two hours per day, the increase could exceed 10 in but not more than a total of 18 in. During the incubation and downstream migration of the juveniles the river height could not be reduced by more than 4 in below the average height established in the 45-day period, excluding heights reached as a consequence of daily fluctuation in excess of 4 in during the 45-day period. Minimum fish release discharges would range between 135 and 280 ft^3/s during this period.

More restrictive fluctuation controls were recommended to the Federal Power Commission by the State biologists for the Tuolumne River. They recommended limiting fluctuations to not more than 0.2 ft in river depth during the spawning period and limiting reductions in flow to no more than 0.4 ft in river depth during the incubation period.

The British Study Group on the Fisheries Implications of Water Transfers Between Catchments made preliminary recommendations regarding operating procedure for initiation and cessation of seasonal inter-basin transfers as follows:

"(A) It is recommended that the sudden onset and sudden cessation of transferred flows should always be avoided, the "build-up" and "die-down" periods being of not less than 24-hours duration.

(B) It is recommended that where transfers produce enhanced flows which attract fish into small streams which they would not normally ascend, consideration should be given to the situation resulting when the transfer stops. Where stranding in inadequate flows and depths is likely to result, the transfer should be partially continued to safeguard them or at least until such time as the fish have been enabled to leave the stream (British Ministry of Agriculture, Fisheries and Food and Association of River Authorities, 1972)."

Abnormally high fluctuations resulting from controlled discharges could result in major changes in the characteristics of the stream channel. Channel configuration is basically the result of the more repetitive flow conditions rather than the occasional spate. If controlled discharge fluctuations are to be of a magnitude comparable to major flood conditions and repeated frequently, the channel will be subjected to forces which will probably cause configuration changes.

Similarly, if the rate of change or range of fluctuation is much less than natural conditions, this can result in channel changes. For example, the absence of high flows in many California salmon and trout streams after water development has resulted in extensive encroachment of terrestrial vegetation (especially willows) on the stream channel. This has reduced spawning and food producing areas. Fluctuating flows or flows of sufficient magnitude to deter vegetation encroachment is a necessary consideration in developing controlled-flow recommendations.

Fluctuating flows can have an important effect on the downstream fishability and navigability of a stream. In determining an allowable or recommended maximum rate of change of controlled flows or fluctuation range, consideration must always be given to the effect on channel configuration, velocity and depth changes, bank-erosion, sediment transport, spawning and food production, migration and passage of fish, navigation, fishing riparian vegetation, and vegetation encroachment on the stream channel.

NOTES ON METHODS IN OTHER AREAS

British Columbia

Hooper (1973) reports that the Fisheries Service of British Columbia is in the process of developing methods for determining discharge recommendations for salmonids stressing quantified descriptions of their habitats. He further indicates that they are experimenting with the Manning hydraulics equation with which water-surface profiles and velocities can be calculated from information gathered at a known flow.

United Kingdom

Faced with massive plans for inter-basin transfers of water involving many rivers, the British Ministry of Agriculture, Fisheries and Food and the Association of River Authorities jointly established the "Study Group on the Fisheries Implications of Large-Scale Water Transfers Between Catchments." The Study Group consists of 17 individuals including some of the leading authorities on stream biology and hydrology in England and Scotland. (See British Ministry of Agriculture, Fisheries and Food, 1972.)

Since May of 1971 the Study Group has been making a careful review of the information available and considering what further information or research is necessary, to enable the potential effects on fisheries to be accurately assessed. Early in its deliberations the group established the guidepost that the biological changes resulting from water transfers between one catchment and another are likely to be reflected at all trophic levels. The whole ecological situation, faunal and floral, is therefore likely to undergo change to some extent, even though the change may not be significant at the uppermost trophic level of fish production. The group therefore concluded that in examining the effects of water transfers it is necessary to consider not only the fish themselves, their eggs and progeny, but also their food supply - for without this a fishery cannot survive. Since the food organisms on which the fish depend are themselves dependent largely upon detritus, algae, and macrophytes for food, the group's attention is directed to the effects of water transfers on these levels of the biota as well.

Having sat in on one of the Study Group's meetings in late 1972 and having reviewed a number of the documents it is developing and considering, I am impressed with the in-depth treatment and expertise being applied to the problems. I am optimistic that this effort will result in many helpful techniques and criteria for application in other areas.

Wyoming

Two approaches are reported by Hooper (1973) as being used by the Wyoming Game and Fish Commission. One method involves the gathering of empirical data on the effect of various controlled discharges where this is possible. Where it is not possible, the Wyoming Commission is reported by Hooper to use the following "rule of thumb" for planning purposes:

".....instantaneous bypass flows at each structure to the tailwater and stream bed immediately below, should never be less than 10 percent of the mean annual flow of record at the location of the structure for a warm water fishery and not less than 33 percent of the mean annual flow of record for a cold water fishery."

Here again, I must point out the danger in using a "rule of thumb" geared to a percentage of the mean annual flow. If applied as a single flow throughout the year it will, in most cases, result in more water than may be needed in some months and in other months it will result in reduction of normal flows to the detriment of long-established fish populations. Application of this approach can usually be expected to result in a decline in fishery values as well as aesthetic and a number of other values of a stream. Unfortunately such "rules of thumb" are not uncommon, despite their acknowledged weaknesses. They tend to expedite decisions in the face of political or economic pressures.

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Appendix A

DEFINITIONS

Appendix A

Definitions

Abstraction. The taking of water from a stream or other body of water into a canal, pipe or other conduit or otherwise removing it from its natural course. Synonomous with "diversion".

Acre-foot. A unit for measuring the volume of water. It is equal to the quantity of water required to cover one acre to a depth of one foot and is equal to 43 560 cubic feet, or 325 851 gallons (U.S.), or 1233.49 cubic meters. It is commonly used in measuring volumes of water impounded, stored or used.

A.D.F. (a.d.f.). The average daily flow. The mean flow over a period of 24 hours. Synonomous with "Daily mean discharge". It is sometimes used in place of "average annual discharge" (e.g., Baxter, 1961) or "average discharge".

Annual flood. The highest peak discharge of a stream in a year (usually in a water year).

Annual mean discharge. The arithmetic mean of the daily mean discharges over the period of a water year.

Average annual discharge. The mean of a number of annual mean discharges (not necessarily consecutive).

Average discharge. The arithmetic average of all complete water years of record whether or not they are consecutive. The term "average" is generally reserved for average of record and "mean" is used for averages of shorter periods, namely, daily mean discharge. (Langbein and Isiri, 1960.)

Bank storage. The water absorbed into the banks of a stream channel, when the stages rise above the water table in the bank formations, then returns to the channel as effluent seepage when the stages fall below the water table. Langbein and Isiri, 1960 (After Houk, 1951).

Braiding (of river channels). Successive division and rejoining (of riverflow) with accompanying islands is the important characteristic denoted by the synonomous terms, braided or anastomising stream. A braided stream is composed of anabranches. (Langbein and Isiri, 1960.)

Cfs (c.f.s.). Abbreviation of cubic feet per second. (Commonly used in U.S.A. and Canada).

Cfs - day. The volume of water represented by a flow of 1 cubic foot per second for 24 hours. It equals 86 400 cubic feet, 1.983471 acre-feet or 646 317 gallons (U.S.).

Cfsm. Abbreviation of cubic feet per second per square mile. The average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area. (Langbein and Isiri, 1960.)

Cubic feet per second. A unit of measurement expressing rates of discharge. One cubic feet per second is equal to the discharge of a stream of rectangular cross section, one foot wide and one foot deep, flowing water at an average velocity of one foot per second. (After Langbein and Isiri, 1960.)

Cusec. The abbreviation for cubic foot per second commonly used in the British Commonwealth countries except Canada.

Daily mean discharge. The mean flow of a stream over a period of 24 hours (usually midnight to midnight). (Dalmer, 1972.)

Discharge. In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream or an ocean. The discharge of drainage basins is distinguished as follows:

Yield. The total water runout or crop; includes runoff plus underflow.
Runoff. That part of water yield that appears in streams.
Streamflow. The actual flow in streams, whether or not subject to regulation, or underflow.

(After Langbein and Isiri, 1960)

Diversion. The taking of water from a stream or other body of water into a canal, pipe, or other conduit. (Langbein and Isiri, 1960.) Synonomous with "abstraction".

Drainage area. The area, at a specified location, measured in a horizontal plane, which is enclosed by a drainage divide. (After Langbein and Isiri, 1960.)

Drainage basin. A part of the surface of the earth occupied by a drainage system consisting of a surface stream or a body of surface water together with all tributary surface streams and bodies of impounded surface water. (After Langbein and Isiri, 1960.)

Drought. A period of deficient precipitation, runoff or streamflow, extending over a period of time but without a specific standard against which to measure the deficiency or the period of time. (Usually accompanied by or resulting in desiccation or depressed growth rates in vegetation; a depression in animal and human activities or well-being, or a shortage of water for animals and crops.)

Flood. An overflow or inundation from a stream or other body of water and causing or threatening damage. Any high streamflow overtopping the natural or artificial banks in any reach of a stream. (After Langbein and Isiri, 1960.)

Flood peak. The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but since it connotes the top of the "flood wave", it is properly used only in referring to stage - thus, crest stage, but not crest discharge. (Langbein and Isiri, 1960.)

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equalled or exceeded. (Langbein and Isiri, 1960.)

Fords. The shallower and faster-running parts of a stream. Synonomous with riffle areas. (England and Scotland.)

H. O. Flow or Hands Off Flow. That natural flow below which no abstractions will be made from the stream without there first being an augmentation of the flow equivalent to the abstraction to be made. A term commonly used in England.

Hydrograph. A graph showing stage, flow, velocity, or other property of water with respect to time. (Langbein and Isiri, 1960.)

Impaired flow (or discharge or runoff). The flow of a stream as altered by regulation, control or abstraction.

Low-flow frequency curve. A graph showing the magnitude and frequency of minimum flows for a period of given length. Frequency is usually expressed as the average interval, in years, between recurrences of an annual minimum flow equal to or less than that shown by the magnitude scale. (Langbein and Isiri, 1960.)

Monthly mean discharge. The arithmetic mean of the daily mean discharges over a calendar month. (Dalmer, 1972.)

Optimum flow (or discharge). A level or volume of streamflow at which there is the most desirable combination of conditions for maximum production of a species or combination of species of aquatic organisms. Used also to denote the flow that will give the maximum satisfaction of a condition or conditions needed for a particular phase of an organism's life cycle, e.g., optimum spawning flow.

Pool. A reach of stream in which there is deep water usually of reduced velocity and lying between two riffles or two reaches with shallower depth and higher velocity. Natural streams often consist of a succession of pools and riffles. (After Langbein and Isiri, 1960, in part.)

Regimen (of a stream). The system or order characteristic of a stream; in other words, its habits with respect to velocity and volume, form of and changes in channel, capacity to transport sediment, and amount of material supplied for transportation. The term is also applied to a stream which has reached an equilibrium between corrosion and deposition or, in other words, to a graded stream. (After Langbein and Isiri, 1960.)

Regulation. The artificial manipulation or control of the flow of a stream.

Return flow (or return water). The part of water used on land (e.g., for irrigation) that is not consumed by evapotranspiration and returns to its source or another stream or body of water.

Riffle. A reach of stream in which the water flow is rapid and usually shallower than the reaches above and below. Natural streams often consist of a succession of pools and riffles.

Riparian. On or pertaining to the banks of a stream.

Runoff. That part of the precipitation that appears in surface streams. It is the same as "streamflow" unaffected by artificial diversions, storage, or other works of man in or on the stream channels. (Langbein and Isiri, 1960.)

Second-foot. Same as cfs. This term is an infrequently used shortened version of cubic foot per second.

Shelter. A place where a fish will seek when frightened or disturbed.

Stream. A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal. Streams in natural channels may be classified as follows:

Perennial. One which flows continuously.

Intermittent or seasonal. One which flows only at certain times of the year when it receives water from ground or surface sources.

Ephemeral. One that flows only in direct response to precipitation, and whose channel is at all times above the water table.

Continuous. One that does not have interruptions in space. In other words, without dry sections.

Interrupted. One which contains alternating reaches, that are either perennial, intermittent or ephemeral.

Gaining. A stream or reach of a stream that receives water from the zone of saturation.

Losing. A stream or reach of a stream that contributes water to the zone of saturation.

Insulated. A stream or reach of a stream that neither contributes water to the zone of saturation nor receives water from it. It is separated from the zones of saturation by an impermeable bed.

Perched. A perched stream is either a losing stream or an insulated stream that is separated from the underlying ground water by a zone of aeration.

(After Langbein and Isiri, 1960.)

Streamflow. The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff", as streamflow may be applied to discharge whether or not it is affected by diversion or regulation. (Langbein and Isiri, 1960.)

Underflow. The downstream flow of water through the permeable deposits that underlie a stream and that are more or less limited by rocks of low permeability. (Langbein and Isiri, 1960.)

Unimpaired flow (or discharge). The natural flow of a stream without regulation, control, or abstraction.

Usable area. It is that area of a stream which a particular species of fish or other aquatic organism effectively uses for shelter, spawning, rearing and which provides its food production. It is the area encompassing the major food producing, shelter and spawning areas. It is usually limited by excesses or deficiencies in depth, velocity, substrate, oxygen supply, temperature, shade or other physical or chemical factors in the stream environment.

Usable spawning gravel. The gravel of a size composition and quality suitable for spawning of a particular species of fish. (Warner, 1953.)

Watershed. The divide separating one drainage basin from another and in the past has been generally used to convey this meaning. However, over the years, use of the term to signify drainage basin or catchment area has come to predominate, although drainage basin is preferred. Used alone, the term "watershed" is ambiguous and should not be used unless the intended meaning is made clear. (In part, Langbein and Isiri, 1960.)

Wetted area. The total area submerged by the flow of a stream. The relationship of wetted area to flow is usually that it decreases at a much slower rate than volume. In most streams it far exceeds the "usable area" for a particular species of fish.

Zone of saturation. The zone in which the functional permeable rocks are saturated with water under hydrostatic pressure. Water in the zone of saturation will flow into a well, and is called ground water. (Langbein and Isiri, 1960.)

Appendix B

STREAM DEPTH AND VELOCITY CRITERIA FOR SALMON, STEELHEAD AND TROUT SPAWNING

Appendix B-1

Stream Depth and Velocity Criteria for Salmon Spawning

Author and Location	Year	Species	Minimum Depth (M)	Maximum Depth (M)	Average (single figure) or Range of Velocity in M/Sec	Point of Measurement for Velocity*
SALMON						
Warner – California	1953	Chinook	0.122	1.219	0.152–1.067	S
Chambers – Washington	1956	Chinook			0.677	
McKinley – Washington	1957	?	0.229	0.610	0.305–0.610	0.15
Andrew & Green – British Columbia	1960					0.09
Hutchison – Oregon	1962	Chinook	0.244		0.305–0.762	0.12
Sams & Pearson – Oregon	1963	Chinook (Spring)	0.183		0.247–0.625	
		Chinook (Autumn)	0.183		0.336–0.756	
		Coho	0.153		0.247–0.708	
Kier – California	1964	Chinook	0.244		0.305–0.914	0.09
Rantz – California	1964	Chinook	0.244		0.305–0.914	0.09
Deschamps *et al.* – Washington	1966	Chinook) Coho) Chum)	0.229	0.457	0.305–0.701	0.12
Washington Department of Fisheries	1967	Chinook (Spring)	0.457	0.533	0.533–0.686	0.12
		Chinook (Autumn)	0.305	0.457	0.305–0.686	0.12
		Coho	0.305	0.381	0.366–0.549	0.12
		Sockeye	0.305	0.457	0.533– ?	0.12
Baxter – England	1968	Atlantic	0.152	0.914	0.305–0.381	S
		(Preferred)	0.152	0.229		S
Puckett – California	1969	Chinook	0.213		0.366–1.067	0.15
Horton & Rogers – California	1969	Chinook	0.213		0.366–1.067	0.15
Gibbs & Fisk – California	?	Chinook			0.457–0.762	0.09
Thompson – Oregon	1972	Chinook (Autumn)	0.244		0.305–0.914	
		Chinook (Spring)	0.244		0.305–0.914	
		Coho	0.183		0.305–0.914	
		Chum	0.183		0.457–0.975	
Smith – Oregon	1973	Chinook (Spring)	0.183		0.217–0.644	0.12
		Chinook (Autumn)	0.305		0.186–0.805	0.12
		Coho	0.122		0.192–0.692	0.12
		Chum	0.183		0.451–1.003	0.12
		Kokanee	0.061		0.143–0.729	0.12

* Figures shown for point of measurement for velocity are distances in meters above streambed. "A" indicates an average of several velocities measured between the surface and the bottom. "S" indicates a surface measurement

Appendix B-2

Stream Depth and Velocity Criteria for Steelhead and Trout Spawning

Author and Location	Year	Species	Minimum Depth (M)	Maximum Depth (M)	Average (single figure) or Range of Velocity in M/Sec	Point of Measurement for Velocity*
STEELHEAD						
Sams & Pearson - Oregon	1963	Steelhead	0.347 0.387 ←	0.427 (Average)	0.597-0.695 0.646	A
Orcutt - Oregon	1968	Steelhead			0.853-1.067 0.701-0.762	S 0.12
Thompson - Oregon	1972	Steelhead	0.183		0.305-0.914	
Smith - Oregon	1973	Winter SH Summer SH	0.244 0.244		0.387-0.869 0.433-0.970	0.12 0.12
TROUT						
Kelley *et al.* - California	1960	"Trout"	0.076	0.914	0.152-0.914	
California Department of Fish and Game	1963	"Trout"	0.076	0.914	0.152-0.914	0.06
Johnson *et al.* - California	1966	Brown			0.396-0.518	0.08
Thompson & Fortune - Oregon	1967	"Trout"	0.122 ←	(Average)	0.305-0.762	0.12
Hooper	1973	Brown Cutthroat Brook Rainbow			0.305-0.814 0.305-0.914 0.061-0.914 0.427-0.823	
Thompson - Oregon	1972	Species (?) Species (?) "Other Trout"	0.244 0.122 0.122		0.213-0.640 0.244-0.640 0.305-0.914	
Smith - Oregon	1973	Rainbow Brown Brook	0.183 0.244 0.092		0.488-0.909 0.204-0.683 0.009-0.232	0.12 0.12 0.12

* Figures shown for point of measurement for velocity are distances in meters above streambed. "A" indicates an average of several velocities measured between the surface and the bottom. "S" indicates a surface measurement

Appendix C

OUTLINE GUIDE - DETERMINING STREAM FLOWS FOR FISH LIFE

(From Environmental Management Section,
Oregon State Game Commission -
Thompson, 1972)

Appendix C

DETERMINING STREAMFLOWS FOR FISH LIFE

Environmental Management Section
Oregon State Game Commission
15-16 March 1972

B. Planning
   1. Set study goals and objectives (broad)
   2. Recognize financing and deadlines
   3. Select types of flow recommendations needed
      a. Biological requirements of fish life (minimum or optimum)
      b. Others (minimum or optimum)
         (1) Wildlife water requirements
         (2) Angling considerations (bank and boat)
         (3) Recreational boating
         (4) Aesthetics
         (5) Water quality
   4. Determine existing flow protection and recommendations
   5. Gather basic study data
      a. Obtain maps showing stream systems and access
      b. Obtain USGS stream discharge annuals, rating tables and telephone gauges
      c. Interview local biologists
         (1) Formulate stream priority list by considering
            (a) Importance for fish production
            (b) Recreational use and potential
            (c) Potential for water developments
            (d) Access
         (2) Determine road access and routes
         (3) Inventory, abundance and distribution of fish and wildlife resources
         (4) Identify limiting factors
         (5) Determine fish life-history periodicities by species and stream or stream system
   6. Determine appropriate study procedures
   7. Determine number of streams or points of recommendation that time and financial limitations will permit
      a. 60-80 points of recommendation per man
         (1) If crew station close to study area
         (2) Prolonged work schedule
         (3) Limited travel between study stations
      b. 40-60 points of recommendation
         (1) Commuting to survey
         (2) Short work season
         (3) Considerable travel between study stations
   8. Obtain equipment
   9. Determine miscellaneous study activities
      a. Photographs
      b. Temperature studies
      c. Water quality analysis
      d. Others
   10. Appointing assisting personnel
   11. Chart stream run-off patterns to predict activity schedule
   12. Assign appropriate criteria to individual streams and stream reaches

C. Equipment
   1. Current meter (Gurley # 622)
   2. Steel tape
   3. Tape recorder (Norelco)
   4. Camera
   5. Thermometers (Normal and maximum-minimum)
   6. Data tabulation forms
      a. Flow-temperature-remarks
      b. Cross-section

7. Maps
   a. SWRB (Oregon)
   b. U.S. Forest Service
   c. Bureau of Land Management
   d. U.S. Geological Survey
8. Gauge records (USGS)
9. Calculator
10. Direct reading Gurley meter
11. Recording thermometers

D. Streamflow measurement procedures
1. Site selection
   a. Flow characteristics
      (1) Uniform depth (0.5-2.2 ft)
      (2) Uniform velocity (0.5-3.5 fps)
      (3) Pool tail-riffle head area generally best
   b. Stream channel characteristics
      (1) Shallow enough to wade
      (2) Smooth bottom
      (3) Free of meanders or obstructions which create eddies or flow surging
2. Procedure - where precision is required
   a. Measurement units (cubic feet per second)
      (1) Width (ft)
      (2) Depth (ft)
      (3) Velocity (fps)
   b. Width measurement
      (1) Tag line
      (2) Edge of current to edge of current
      (3) Perpendicular to flow or angular compensations
   c. Depth measurements
      (1) Taken along the imaginary transect of the width measurement
      (2) At least ten measurements each to represent no more than 10 percent of the total flow
      (3) Measured in feet and tenths of feet to simplify computations
   d. Velocity measurements
      (1) Taken along transect established by width measurement
      (2) Measurements taken at points along transect to represent mean velocity in each section created by depth measurements
      (3) Velocities taken at 0.2 and 0.8 of total depth if total depth is over 1.5 feet. Velocities measured at 0.6 of the total depth from the flow surface if total depth is 0.5-1.5 feet. Velocities measured at 0.5 of total depth if total depth is less than 0.5 feet
3. OSGC procedure (+ or - 10 percent error)
   a. Independent of flow requirement cross-sections
      (1) Site selection as described above (D,1)
      (2) Width measurement perpendicular to flow
      (3) Transect not segmented for depth and velocity measurements
      (4) Number of depth and velocity measurements variable, depending on stream size
      (5) Depth measurements evenly spaced
      (6) Velocity measurements spaced along transect to represent equal parts of total flow
      (7) Velocity measured at 0.6 of the total depth from the flow surface
   b. Discharge measured on cross-sections used to determine flow requirements of fish
      (1) Site normally similar to ideal flow measurement site
      (2) Only cross-sections perpendicular to flow are used as flow measurement sites
      (3) Nine evenly spaced depth measurements are averaged
      (4) Variable number of velocities measured, depending on stream size; but measurement points coincide with cross-section points
      (5) Discharge = product of width x mean depth x mean velocity

E. Criteria
1. Purposes
   a. Determine stream discharge required to create flow characteristics needed for various biological activities of fish life
   b. Lend continuity to recommended streamflow regimen
   c. Enhance the justification for flows recommended
2. Adult passage criteria (OSGC)
3. Spawning criteria (OSGC)

4. Incubation criteria
   a. 0.8 mg/l intragravel dissolved oxygen before hatching
   b. 0.5 mg/l intragravel dissolved oxygen from hatching to fry emergence
   c. No relationship to streamflow velocity established
   d. Criteria not used in OSGC conventional streamflow requirements study here described
   e. General guidelines for recommending incubation flows
      (1) Enough water to cover gravel made available by recommended spawning flow
      (2) Approximately equivalent to two thirds the spawning flow recommendation
5. Rearing criteria - tentative. Not used to date in OSGC streamflow requirements studies

Species	Preferred zone	Preferred stream depth (ft)	Preferred velocity (fps)
Chinook	Mid pool and pool head	1.0-4.0	0.2-0.8
Coho	Mid pool and pool head	1.0-4.0	0.2-0.8
Steelhead Rainbow	All zones	0.6-2.2	0.2-1.6
Cutthroat	Riffle tail and pool head	1.3-4.0	0.2-1.6

   a. Criteria above are only tentative
   b. General guidelines for recommending minimum rearing flows
      (1) Adequate depth over riffles
      (2) Riffle-pool ratio near 50:50
      (3) Approximately 60 percent of riffle area covered by flow
      (4) Riffle velocities 1.0-1.5 fps
      (5) Pool velocities 0.3-0.8 fps
      (6) Most stream cover available as shelter for fish

F. Streamflow requirement measurement procedures
1. Advantages (the use of criteria and standard procedures).
   a. Enhances the justification for flows recommended
   b. Lends continuity to recommended streamflow regimen
   c. Avoids bias inherent in individual judgement decisions
   d. Procedures may be more easily explained to a non-technician; hence, more likely to gain the confidence of those affected by the recommended flows
2. Disadvantages
   a. Not applicable to streams without uniform (symmetrical) cross-section sites
   b. Not applicable to even-flowing spring-fed streams or rivers with substantial minimum flows
   c. Most time consuming and expensive procedure
   d. Relationship recommended flows have with fish production levels is no more clearly understood nor demonstrated than flows recommended by other less sophisticated procedures
   e. Not applicable to fish species or biological activities where criteria have not been identified
3. Adult fish passage
   a. Purpose
      (1) Provide adequate water for physical movement through most critical reaches to spawning areas
      (2) Not to provide flows generally believed necessary to induce migration
      (3) Most important in streams used by anadromous fish
   b. Select the point on the stream or stream section where extreme width creates shallow flows most critical to passage of adult fish
   c. Measurements
      (1) Discharge
      (2) Transect length
         (a) Measured from edges of flow following the shallowest course
         (b) Measured once during a flow that covers all or most of the transect
      (3) Depth measurements
         (a) Evenly spaced along transect which follows shallowest course
         (b) Every two feet on small streams
         (c) Every four feet on medium sized streams
         (d) Every eight feet on large streams and rivers
      (4) Velocity measurements
         (a) 0.6 of the total depth from the flow surface
         (b) Only to verify that velocities are not excessive at any given point along the transect

(5) Frequency and number of measurements
(a) Six sets of depth measurements on each transect (six different flow levels)
(b) Measured often enough to ensure data on six evenly spaced flow levels

d. Data analyses
(1) Analysis of depth and velocity data at each flow
(a) Percent of total width meeting depth and velocity criteria
(b) Longest continuous segment of transect meeting depth and velocity criteria expressed as percent of total transect width
(2) Analysis of the usable width for passage-discharge relationships
(a) Prepare line graph of percent of total width meeting depth and velocity criteria versus discharge. Determine the flow which yields 25 percent of the total original width measurement passage
(b) Prepare line graph of longest continuous segment of transect meeting depth and velocity criteria versus discharge. Determine the flow which yields a continuous portion of the transect, equalling 10 percent of the total original width measurement, passable
(3) Derivation of the recommended flow
(a) Select the flow required to make passable at least 25 percent of the total width and a continuous portion of the transect of at least 10 percent of the total width
(b) If more than one transect is measured to determine the recommended minimum flow, select from the transects the highest flow requirement indicated
(c) Make certain that other obstructions to fish passage, such as falls and cascades do not require more flow to pass fish

4. Spawning
a. Purpose
(1) Provide adequate water for adult salmonids to spawn in their preferred stream areas
(2) Flow requirement determined for all important species of salmonids inhabiting the study stream or stream section

b. Transect locations
(1) For most species, establish the transect on a symmetrical gravel bar in the prime spawning area at the head of the riffle
(2) Select three transects for each flow recommendation to be developed
(3) Select gravel bars which approximate the size of those typically found in the study stream or stream section
(4) Straight line transect
(5) Not necessarily perpendicular to the flow

c. Measurements
(1) Discharge (if transect measurements not applicable)
(2) Transect length (stream width)
(a) Measured from edges of flow
(b) Measure each time depths and velocities are measured
(3) Depth measurements
(a) Nine evenly spaced measurements along transect, the first and last measurements being 1/10 of the transect length from the stream edge
(b) Spaced to divide the transect into 10 equal parts
(c) One section on each end of the transect, each equivalent to 1/20 of the total transect length, theoretically never meets spawning criteria and is automatically disregarded
(4) Velocity measurements
(a) Measured 0.4 foot from stream bottom
(b) Measured at same points on transect where depths are measured (nine measurements)
(c) Except where obtaining measurements to compute discharge, the velocities at each of the nine stations need only to be identified as they relate to parameters of velocity criteria
(5) Frequency and number of measurements
(a) Measurements at enough different flow levels to reliably identify the "discharge-usable width for spawning" relationship (approximately six different flow levels)
(b) The most intensive study period should coincide with the season of declining flows

d. Data Analysis
(1) Compute and graph stream width usable for spawning
(a) At each flow
(b) on each transect

(2) Summarize the relationships "stream width usable for spawning have with discharge" for the transects in each study stream or stream section:
  (a) Determine the average stream width usable for spawning on the transects at each of about six different flow levels
  (b) Regraph the relationship of "discharge with mean stream widths usable for spawning" for each study stream or stream section
    (1-1) Maximum gravel = optimum spawning
    (2-2) 80 percent of maximum gravel = optimum spawning

5. Spawning (usable-area procedure - see OSGC manual)

G. Streamflow requirement observation procedures

1. Advantages
   a. Applicable to all types of streams
   b. Less time consuming and less expensive than measurement procedures
2. Disadvantages
   a. Results subject to bias of individual observers
   b. Justification of results not as strong as for the measurement procedure; hence, less likely to gain the confidence of those affected by the recommended flows
   c. Less inherent continuity in the results than the measurement procedure
3. Adult fish passage
   a. Purpose
      (1) Provide adequate water for physical movement through the most critical reaches to spawning areas
      (2) Not to provide flows generally believed necessary to induce migration
      (3) Most important in streams used by anadromous fish
   b. Select the point on the stream or stream section where extreme width creates shallow flows most critical to passage of adult fish
   c. Observations
      (1) The estimated flow which would yield approximately 25 percent of the total width and a continuous section of the bar equalling approximately 10 percent of its total width passable according to the parameters of passage criteria are estimated at several different flow levels
      (2) Incidental observations of fish passing suspected critical spots and the flow at which they pass
   d. Discharge measurement during each observation
   e. Derivation of the recommended flow
      (1) Select the flow the various observed recommendations seem to indicate
      (2) Make certain that other obstructions to fish passage, such as falls, cascades, or cataracts, do not require more flow to pass fish
4. Spawning
   a. Purpose
      (1) Provide adequate water for adult salmonids to spawn in their preferred stream areas
      (2) Ensure recommended flows which will accommodate all important species of salmonids inhabiting the study stream or stream section
   b. Observation locations
      (1) For most species, observations are made on the portions of gravel bars where spawning is most likely to occur (the head of the riffle)
      (2) Select about three symmetrical gravel bars which approximate the size of those typically found in the study stream or stream section
   c. Discharge measurement during each observation
   d. Observations
      (1) At each of several flow levels, an estimate is made of the approximate flow required to provide a spawning flow (see criteria)
         (a) Optimum spawning flow is that which covers the maximum amount of gravel with flow depths and velocities specified by spawning flow criteria (excessive velocities will be the limiting factor)
         (b) Minimum spawning flow is that which covers 80 percent of the gravel available at an optimum spawning flow
      (2) The measurements taken to determine discharge are useful in estimating spawning flow requirements
   e. Derivation of the recommended flow
      (1) Select the flow the various observed estimates seem to indicate
      (2) Repeat the same procedure where different species have different spawning flow requirements

5. Incubation
   a. Purpose
      (1) Provide adequate water to ensure successful egg incubation and fry emergence
      (2) Ensure recommended flows which will accommodate all important species of salmonids inhabiting the study stream or stream section
   b. Observation locations
      (1) Spawning areas (for most salmonids, on gravel bars at the head of the riffle)
      (2) Same sites where the spawning flow observations are made is most convenient
      (3) On gravel bars which approximate the size of those typically found in the study stream or stream section
   c. Discharge measurement during each observation
   d. Observations
      (1) At each of two or three flow levels near that required for spawning, an estimate is made of the approximate flow required for incubation
      (2) Measurements taken to determine discharge are useful in estimating incubation flow requirements
   e. Derivation of the recommended flow
      (1) Select the flow the various observed estimates seem to indicate
      (2) Repeat the same procedure where different species have different spawning flow requirements

6. Rearing
   a. Purpose
      (1) Provide adequate streamflow conditions for salmonids when flows for passage, spawning, or incubation are not required
      (2) Ensure recommended flows which will accommodate all species of salmonids, both juvenile and adult, which inhabit the study stream or stream section
   b. Observation locations
      (1) Most conveniently those areas where other observed recommendations are made
      (2) On both riffles and pools which approximate the size of those typically found in the study stream or stream section
      (3) In some areas with stream-side shade cover
   c. Discharge measurement during each observation
   d. Observations
      (1) At each of several flow levels near that required for rearing (relatively low flows), an estimate is made of the approximate flow required for rearing (see rearing criteria and guidelines)
      (2) Measurements taken to determine discharge are useful to estimate flows required for rearing
   e. Derivation of the recommended flow
      (1) Select the flow the various observed estimates seem to indicate
      (2) Repeat the same procedure if different species have different rearing flow requirements

H. Streamflow requirement prediction technique
1. Advantages
   a. Least time consuming and least expensive technique
   b. Results not subject to biases of personnel using the technique
   c. Applicable to streams where the lack of symmetrical cross-sections preclude other techniques
   d. Results display high level of continuity
2. Disadvantages
   a. Least inherent justification for results of all techniques; hence, least likely to gain the confidence of those affected by the recommended flows
   b. Not applicable to spring-fed streams
3. Spawning and rearing
   a. Equipment
      (1) Maps
         (a) Isohyetal with streams prominent
         (b) Sectioned with streams prominent
      (2) Spawning and rearing constants
   b. Derivation of flow recommendations
      (1) Determine drainage area above point where flow is to be recommended
      (2) Determine mean annual precipitation in drainage above point where flow is to be recommended
      (3) Multiply drainage area (m^2) by mean annual precipitation
      (4) Select the appropriate constant value
      (5) The recommended flow is equivalent to the product of (m^2) x (in) x (constant value).

c. Adult passage and incubation
(1) Constants not available
(2) Use OSGC conversion factors

I. Streamflow requirement conversion factors
1. Advantages
a. Enables the derivation of flow recommendations not obtainable by any other procedure
(1) Angling flow requirements
(2) Aesthetic flow requirements
(3) Boating flow requirements
b. Enables the derivation of flow recommendations not obtained by measurement of observation procedures during the field survey
(1) Adult fish passage (minimum and optimum)
(2) Spawning (minimum and optimum)
(3) Incubation (minimum and optimum)
(4) Rearing (minimum and optimum)
c. One of least time consuming and least expensive procedures
d. Results not subject to biases of personnel using the technique
e. Flow recommendations proportional to flow recommendations upon which they are based, thus lending continuity to recommended flow regimen for any given location
2. Disadvantages
a. Little direct justification for flow recommendations; hence, it may be difficult to gain the confidence of those affected by the recommended flows
b. Existing flow recommendations required to which the conversion factors are applied
3. Conversion factors
a. Adult passage
(1) Optimum passage = minimum spawning
(2) Minimum passage = 0.67 x minimum spawning
b. Spawning
(1) Optimum spawning = 1.67 x minimum spawning
(2) Minimum spawning with 0.8 ft flow depth criteria = 1.2 x minimum spawning with 0.6 ft criteria
(3) Minimum spawning with 0.6 ft criteria = width of typical gravel bar (ft) x
1.0 (under 20 ft)
1.5 (under 100 ft)
2.0 (over 100 ft)
(4) Minimum spawning with 0.8 ft criteria = width of typical gravel bar (ft) x
1.5 (under 50 ft)
2.0 (over 50 ft)
2.5 (over 100 ft)
c. Incubation
(1) Optimum incubation = minimum spawning
(2) Minimum incubation = 0.67 x minimum spawning
d. Rearing
(1) Optimum rearing = 0.67 x minimum spawning
(2) Minimum rearing = 0.2 x minimum spawning
e. Bank angling = 0.5 x optimum spawning
f. Boat angling
(1) 2.0 x optimum spawning in eastern Oregon
(2) 4.0 x optimum spawning in western Oregon

J. Preparing recommended flow regimen
1. Information required
a. Recommended flows for
(1) Adult passage
(2) Spawning
(3) Incubation
(4) Rearing
b. Fish species distribution by stream
c. Life history periodicity
(1) Biological activity
(2) Fish species

2. Procedure
   a. Assign recommended flows
      (1) By month or 2-week periods
      (2) By stream or stream section
      (3) By species
      (4) By biological activity
         (a) Passage
         (b) Spawning
         (c) Incubation
         (d) Rearing
   b. Select highest flow required for any given period for each stream or stream section
   d. Precautions
      (1) Recommended flows are not adjusted to accommodate seasonally natural flow deficiencies or water right appropriations
      (2) Flows should not be recommended for a relatively insignificant species if the flow would be harmfully excessive for an important species
      (3) A flow recommendation derived by measurement procedures which is not similar to the flow recommended for the same location by the observation technique should be carefully evaluated for errors

K. OSGC streamflow requirement survey reports - contents
   1. Streamflow recommendations
      a. Minimums
      b. Optimums
      c. Other
   2. Fish species, abundance, and distribution
   3. Biological requirements of salmonids
   4. Limiting factors of fish life
   5. Fish resource values
   6. Streamflow and temperature measurements
   7. Photographs
      a. Streamflow comparisons
      b. Limiting factors
      c. Sport and commercial fisheries
      d. Study procedures

Appendix D

A LIST OF HUMAN USE AND EFFECT FACTORS
(Related to or Influenced by Streamflow)

Appendix D

A LIST OF HUMAN USE AND EFFECT FACTORS
(Related to or Influenced by Streamflow)

I. DRAINAGE BASIN - CATCHMENT FACTORS

A. Vegetation Cover

1. Forestation
2. Deforestation

B. Cultivation
C. Land Drainage
D. Urbanization
E. Mineral Extraction - Exposure
F. Soil Disturbance

II. IN- OR ON-STREAM ELEMENTS

A. Health and Safety Factors

1. Pollution
2. Disease vectors and pests
3. Toxicants
4. Drowning - water safety

B. Waste Transport and Disposal Factors

1. Domestic sewage
2. Agricultural wastes and return water
3. Industrial wastes
4. Radionucliides
5. Pesticides and herbicides

C. Recreation - Cultural Factors

1. Fishing (commercial, subsistence and sport)

a. Fishability
b. Fishing knowledge and effectiveness
c. Boats
d. Gear
e. Safety
f. Catch (qualitative and quantitative)
g. Economics
h. Effort

2. Boating

a. Transporation
b. Sport (e.g., river trips, etc.)

3. Swimming - water skiing
4. Aesthetics
5. Nature conservation

a. Wildlife watching
b. Educational
c. Rare species

6. Hunting

a. Subsistence
b. Commercial
c. Sport

D. Industrial - Commercial - Utilities

1. Navigation - boating

a. Transporation
b. Commercial - cargo

2. Water development

a. Storage
b. Abstraction - diversion
c. Power generation

(1) Mills
(2) Hydro-electric

III. OFF-STREAM (STREAM RELATED)

A. Recreation - Cultural Factors

1. Aesthetics - scenics
2. Housing - village sites - resorts
3. Camping - picnicking
4. Open space - wilderness
5. Parks and reserves
6. Historical and archaeological sites
7. Rare or unique geological, botanical or faunistic features
8. Cultural patterns - life styles
9. Population density
10. Economics - employment
11. Wildlife - riparian and flood plain habitat

B. Industrial - Commercial - Utilities

1. Transportation features - facilities and methods
2. Communications
3. Utilities

a. Electricity
b. Waste disposal

4. Structures (piers, etc.)
5. Economics
6. Agriculture - crop patterns
7. Forestry (riparian and floodplain)

C. Water Abstraction Use

1. Domestic
2. Industrial
3. Municipal
4. Agriculture
5. Recreational

Appendix E

STREAMFLOW CHECK CHART

Appendix E

STREAMFLOW CHECK CHART

This chart has been prepared and is included in this report for the purpose of providing a basic or initial system of checking on the effects of an altered streamflow situation. It is primarily intended as a check list of factors which may be influenced by controlled discharges but its use could be subjected to a number of sophisticated matrix-type analyses such as that proposed by Leopold *et al.* (1971) for evaluating the environmental impact of a proposed construction or development project.

Entry of streamflow data in the columns provided across the top of the chart forces the streamflow evaluator to consider the present flow regimen of the stream in relation to proposed changes. Most evaluations will require more detailed flow data than this chart provides but it will give an initial or screening analysis which is helpful.

For each flow the evaluator should decide whether or not the conditions and factors would be beneficially affected, adversely affected or unaffected. If the evaluator cannot make a decision, which will often be the case, he should enter a symbol or colour in the appropriate square to indicate this. For all such entries further review and possibly field studies would be advisable, if not necessary.

Although the evaluator should make every effort to complete the chart objectively, and based on the information and data already available to him, it will be an unusual stream where enough data are available to make more than a preliminary indication. Having made this preliminary analysis he will be in a better position to outline the additional data and fieldwork needed to thoroughly evaluate the many effects of a changed streamflow pattern.

This chart is not intended to be an alternative to the process of quantifying the needs of aquatic organisms or the human uses of fluvial resources. In the final analysis there is no substitute for the process of quantifying those needs.

The check chart will help to highlight those conditions and factors which are the more important and critical for the particular stream under consideration. Subsequent efforts can be concentrated on those items. The chart can also be revised and updated at intervals as the investigation progresses.

If possible, check charts should be completed by more than one evaluator and objectively checked or challenged by still other individuals.

Although the users of the chart are encouraged to develop their own set of symbols or numbers for its completion, the following can be used in the absence of a more sophisticated approach:

The flow will have:	Symbol
No effect	0
Major adverse effect	XX
Moderate adverse effect	X
Minor adverse effect	1
Major beneficial effect	≡
Moderate beneficial effect	=
Minor beneficial effect	-
Effect unknown	?

Colour coding may also be used to highlight the need for additional studies or the relative importance of the entries.

Editor's note: At the time of going to press the author called attention to several necessary corrections in the draft "Stream Flow Check Chart". These corrections could not be made but for the readers' reference they are:

C. Wildlife Habitat Functions

1. In-Stream Effect Factors

   a. Food Production
   b. Shelter
   c. Migration - travel
   d. Reproduction - rearing

2. Off-Stream Effect Factors

   a. Riparian habitat
   b. Flood plain habitat
   c. Food production
   d. Reproduction
   e. Migration - travel
   f. Shelter

STREAMFLOW CHECK CHART – DETERMINING DISCHARGES FOR FLUVIAL RESOURCES

CONDITIONS AND FACTORS INFLUENCED BY STREAMFLOW

Compiled by: ____________________
Title: ____________________
Organization: ____________________
Date: ____________________

B. HUMAN USE FACTORS

2. Off-Stream Effect Factors

- Water use (Existing)
  - Agricultural
  - Industrial
  - Domestic
- Structures (piers, etc.)
- Utilities
- Communications
- Transportation
- Economics – employment
- Population density
- Cultural patterns
- Rare – unique features
- Historical-archaeological sites
- Parks and reserves
- Camping – picnicking
- Housing
- Aesthetics

1. In-Stream Effect Factors

- Water use (Existing)
  - Agricultural
  - Industrial
  - Domestic
  - Power generation
  - Abstraction
  - Storage
- Water development
- Hunting
- Nature conservation
- Hunting
- Aesthetics
- Swimming
- Navigation
- Boating
- Sport
- Commercial
- Subsistence
- Fishing
- Waste disposal & transport
- Health and safety

A. FISH HABITAT FUNCTIONS

6. Miscellaneous

- f. Ecosystem disruption
- e. Interspecific competition
- d. Species composition
- c. Living space
- b. Disease
- (3) Sport
- (2) Commercial
- (1) Subsistence
- a. Catch

5. Rearing

- k. Invertebrates
- j. Microphytes
- i. Macrophytes
- h. Flood plain
- g. Substrate
- f. Territory space
- e. Predation
- d. Species composition
- c. Temperature
- b. Depth
- a. Velocity

4. Spawning

- l. Sedimentation
- k. Microphytes
- j. Macrophytes
- i. Flood plain
- h. Hydrochemistry
- (2) Underflow
- (1) Surface flow
- g. Dissolved oxygen
- f. Temperature
- e. Timing
- d. Substrate
- c. Fluctuation (flow)
- b. Depth
- a. Velocity

3. Migration

- h. Stranding
- g. Vegetation
- f. Diversions
- e. Timing (delays, etc.)
- d. Temperature
- c. Physical barriers
- b. Depth
- a. Velocity

2. Shelter

- h. Flood plain
- g. Bank Shelter
- f. Riparian vegetation
- e. Turbidity
- d. Macrophytes
- c. Substrate
- b. Depth
- a. Velocity

1. Food Production

- p. Turbidity
- o. Flood plain
- n. Temperature
- m. Vertebrates
- l. Invertebrates
- k. Microphytes
- j. Macrophytes
- i. Detritus
- h. Nutrients – enrichment
- g. Hydrochemistry
- f. Shoaling
- e. Scouring – erosion
- d. Sedimentation
- c. Substrate
- b. Depth
- a. Velocity

Streamflow in cfs or m^3/s

STREAMFLOW CATEGORY

Month	Streamflow category
JANUARY	Lowest known flow (any January)
	Mean of lowest flows (all Januarys)
	Mean of averages for all Januarys
	Mean of highest flow (all Januarys)
	Highest known flow (any January)
FEBRUARY	Lowest known flow (any February)
	Mean of lowest flows (all Februarys)
	Mean of averages for all Februarys
	Mean of highest flow (all Februarys)
	Highest known flow (any February)
MARCH	Lowest known flow (any March)
	Mean of lowest flows (all Marchs)
	Mean of averages for all Marchs
	Mean of highest flow (all Marchs)
	Highest known flow (any March)
APRIL	Lowest known flow (any April)
	Mean of lowest flows (all Aprils)
	Mean of averages for all Aprils
	Mean of highest flow (all Aprils)
	Highest known flow (any April)
MAY	Lowest known flow (any May)
	Mean of lowest flows (all Mays)
	Mean of averages for all Mays
	Mean of highest flow (all Mays)
	Highest known flow (any May)
JUNE	Lowest known flow (any June)
	Mean of lowest flows (all Junes)
	Mean of averages for all Junes
	Mean of highest flow (all Junes)
	Highest known flow (any June)
JULY	Lowest known flow (any July)
	Mean of lowest flows (all Julys)
	Mean of averages for all Julys
	Mean of highest flow (all Julys)
	Highest known flow (any July)
AUGUST	Lowest known flow (any August)
	Mean of lowest flows (all Augusts)
	Mean of averages for all Augusts
	Mean of highest flow (all Augusts)
	Highest known flow (any August)
SEPTEMBER	Lowest known flow (any September)
	Mean of lowest flows (all Septembers)
	Mean of averages for all Septembers
	Mean of highest flow (all Septembers)
	Highest known flow (any September)
OCTOBER	Lowest known flow (any October)
	Mean of lowest flows (all Octobers)
	Mean of averages for all Octobers
	Mean of highest flow (all Octobers)
	Highest known flow (any October)
NOVEMBER	Lowest known flow (any November)
	Mean of lowest flows (all Novembers)
	Mean of averages for all Novembers
	Mean of highest flow (all Novembers)
	Highest known flow (any November)
DECEMBER	Lowest known flow (any December)
	Mean of lowest flows (all Decembers)
	Mean of averages for all Decembers
	Mean of highest flow (all Decembers)
	Highest known flow (any December)
ANNUAL	Lowest flow on record
	Mean of annual low flows
	10% of Mean of average annual flows
	30% of " " " " "
	50% of " " " " "
	75% of " " " " "
	Mean of average annual flows
	150% of Mean of average annual flows
	Mean of highest annual flows
	Highest flow on record

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