WATER RESOURCES BULLETIN
VOL. 22, NO. 3 AMERICAN WATER RESOURCES ASSOCIATION JUNE 1986

REVIEW AND ANALYSIS OF METHODS FOR QUANTIFYING INSTREAM FLOW REQUIREMENTS[1]

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ABSTRACT: Present guidelines for selecting a method to determine instream flow requirements and evaluating the validity of the results from a particular method are insufficient. This paper contributes to the efforts of researchers to develop a guide and critique for instream flow methods.

A review of instream flow methods and recommendations for their application is supplemented by a summary of a comparison of four independent analyses. The four analyses: the Physical Habitat Simulation System approach of the Instream Flow Incremental Methodology by the U.S. Fish and Wildlife Service, the Montana Method by Tennant, and two methods by Orsborn (Maximum Spawning Area Flow and Maximum Spawning Area) represent resource intensive and simplistic data collection and analysis methods. Each analysis was used to independently determine flows to support spawning by chinook salmon (*Oncorhynchus tshawytscha*) in Willow Creek, Alaska.

Results of these analyses indicate that each method can be used independently or collectively to generate instream flow recommendations, if calibrated to the site or area studied. Once adjusted to the species and basin of interest, methods similar to the Montana and two Orsborn methods should be used to determine flow recommendations for areas where competition for water is minimal. The Instream Flow Incremental Methodology or similar methods should be applied when competition for water is keen or when detailed evaluations of the responses of species/life phases to flow variations are required.
(KEY TERMS: instream flow; spawning habitat; chinook salmon.)

INTRODUCTION

This paper compares the results of the application of four instream flow methods to estimate the availability of spawning habitat for chinook salmon (*Oncorhynchus tshawytscha*) as a function of flow variation in Willow Creek, Alaska (Figures 1 and 2). This information is intended to serve as a contribution towards establishing the need to develop standards for conducting instream flow evaluations required to support applications for instream flow reservations.

An instream flow is the amount of flowing water in a channel, as measured at a given place and time. An instream flow reservation is a legal water right for instream uses. Instream flows are essential determinants of channel morphology, riparian and aquatic flora and fauna, water quality, estuarine inflow, and streamload transport (Stalnaker and Arnette, 1976; Reiser, *et al.*, 1985). As a result, maintenance of natural seasonal instream flow patterns is essential for the protection of these valued ecosystems.

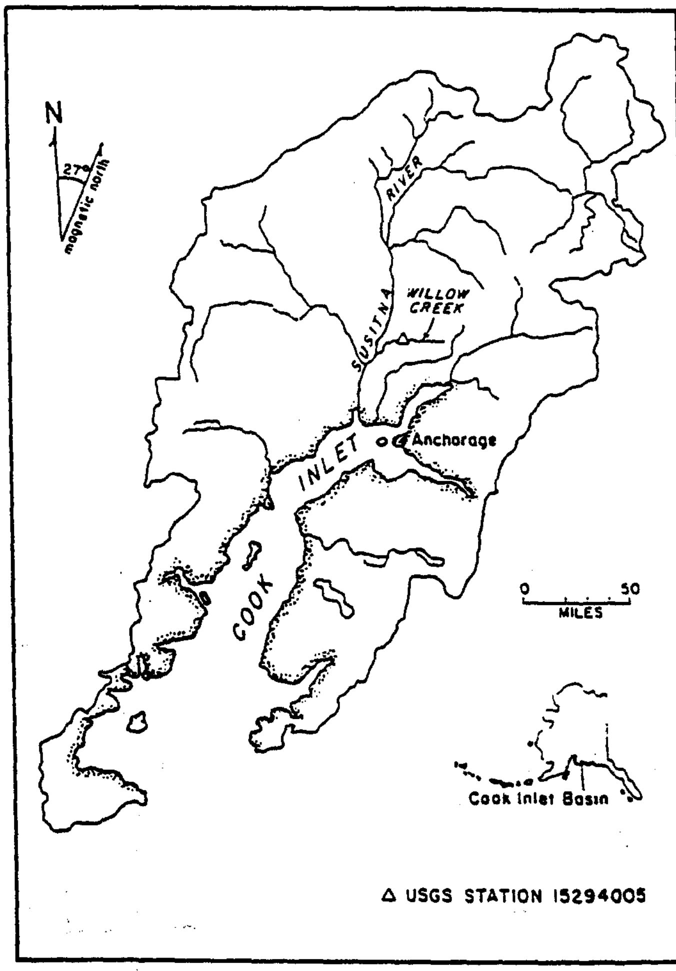

Figure 1. Cook Inlet Basin.

[1]Paper No. 86008 of the *Water Resources Bulletin*. Discussions are open until February 1, 1987.
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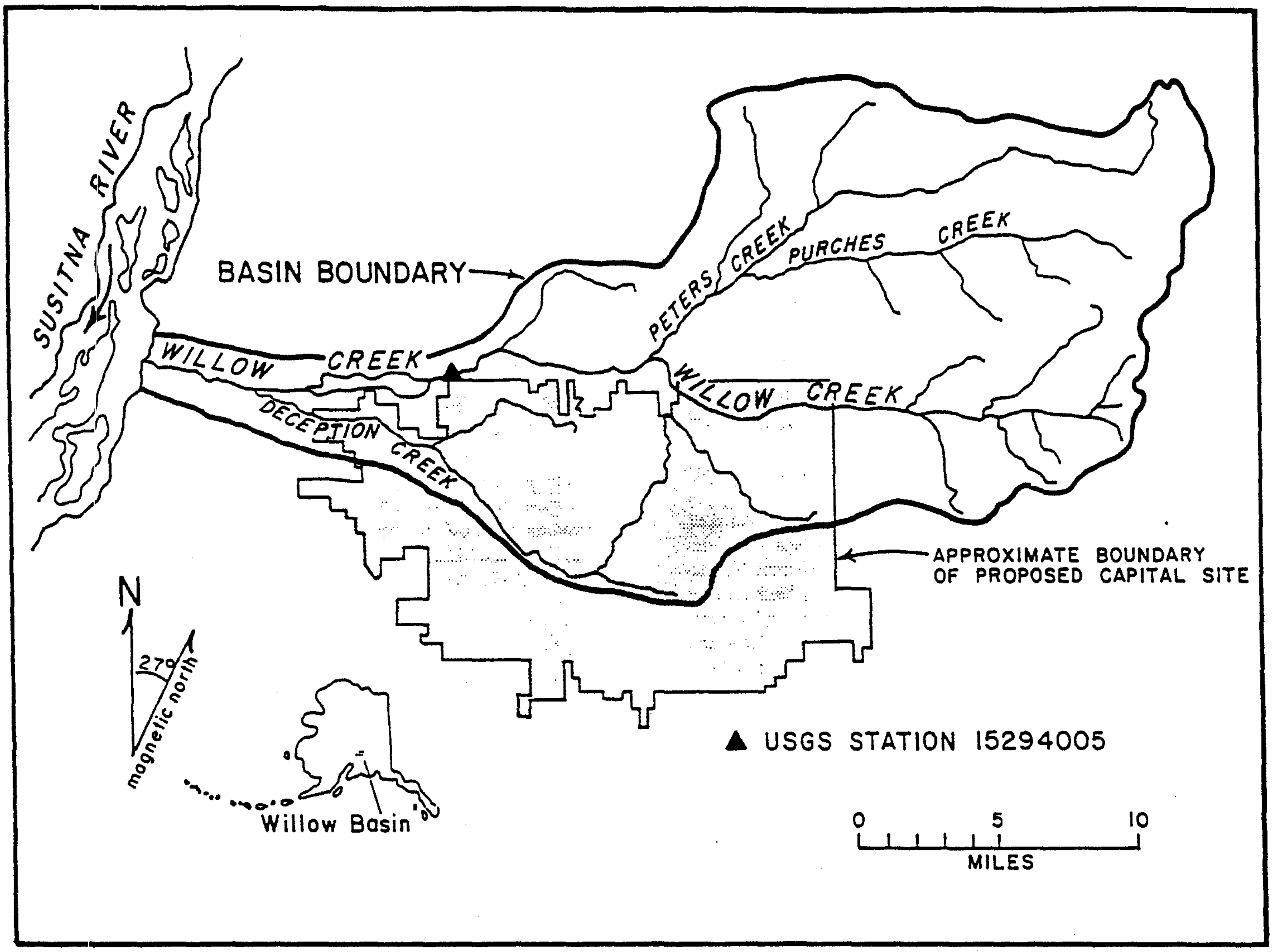

Figure 2. Study Area.

A variety of beneficial human uses can be derived from instream flows and the associated aquatic, riparian, and terrestrial flora and fauna. Uses of instream flow-related environments include: fishing, navigation, hunting, swimming, aesthetic enjoyment, and scientific and educational study.

Instream flow evaluations of fish habitat define the availability (area) and/or quality of a stream for supporting spawning, incubation, rearing, and passage of fish as a function of flow variation. Instream flow analyses are based on the theory that changes in riverine habitat conditions can be estimated from a field or synthetic data base. Collectively, instream flow methods are generally based on three principal components:

1. *Physical Projections* – the collection and assessment of geomorphic and/or hydraulic data to forecast or summarize a range of hydraulic and related conditions (e.g., channel shape, water depth and velocity, channel width, wetted perimeter, substrate composition, fish cover, and upwelling) as a function of flow;

2. *Fish Habitat Criteria Analysis* – the determination of the behavioral responses of fish to channel morphology or flow related variables (e.g., channel shape, water depth and velocity, substrate composition, and upwelling); and

3. *Fish Habitat Projections* – the combination of the first two components to project the availability (area) and/or quality of habitat for the species/life phase under investigation within study sites as a function of flow.

Accordingly, instream flow evaluations are intended for use in those situations where the flow regime and channel structure are the major factors influencing riverine habitat conditions. Furthermore, the physical and biological aspects of field conditions must be compatible with the underlying theories and assumptions of the techniques applied. Water chemistry, temperature, light, and other variables known to influence habitat quality (Krueger, 1981; Hale, 1981) are assumed not to change significantly or limit the species/life phases under study in the analyses summarized in this paper. Additional methodological approaches would have to be considered if it were determined that these variables would vary significantly with flow.

Instream flow methods are commonly grouped as "office" or "field/office" methods (Wesche and Rechard, 1980). These two classifications are based on the level of field effort required by the methodology. Often the level of field effort will be determined by the requirements of the methodology, existing data bases, and the availability of resources to collect and analyze data. Most methods, regardless of whether they are classified as office or field, were originally derived from analyses of extensive field data bases that were collected empirically.

During the past 30 years, an assortment of methods have been developed and applied for quantifying the relationship of flow variation to the suitability of fish habitat for various life phases (passage, spawning, incubation and rearing) and to other instream flow uses. The majority of these methods are described in Chambers, *et al.* (1955); Rantz (1964); Ziemer (1973); Hunter (1973); Collings (1974); Platts (1974); Fraser (1975); White (1975); Orsborn and Deane (1976); Stalnaker and Arnette (1976); Ott and Tarbox (1977); Swanston, *et al.* (1977); Cuplin, *et al.* (1979); Wesche (1980); Wesche and Rechard (1980); Newcombe (1981); Orsborn (1982); Baldridge and Amos (1982); Bovee (1982); ADF&G (1983); Estes and Vincent-Lang (1984); Rosgen (1985); Reiser, *et al.* (1985); Trihey and Baldridge (1985); Trihey and Stalnaker (1985); and Bovee (1985).

Several states do not provide a legal mechanism for reserving instream flows for instream uses. Of those which do, the burden of proof for providing hydrological and biological data required to support an application for an instream flow reservation is often placed upon the applicant. The application of a specific method for providing these data is not always designated or required. Accordingly, the myriad of methods for determining and defending an instream flow request can create a dilemna for potential users. This is further aggravated because existing literature does not provide a comprehensive methodological approach for selecting instream flow methods or substantiating the results produced by those following specified methods.

The American Fisheries Society (Peters, 1982) emphasized this problem in 1982:

> "Much of the present confusion, misunderstanding, and operational inefficiency with respect to present instream flow methods is caused by the lack of a single, recognized reference containing available, accurate descriptions and evaluations of instream flow methodologies for aquatic resources and guidelines for selecting the most appropriate method for a given situation."

Accordingly, resource managers and the applicant do not have a standard to measure the results of an analysis or determine its validity.

Four instream flow evaluation techniques (one field and three office), requiring different levels of effort, were selected for this evaluation. Results of these four methods are evaluated individually and collectively.

STUDY AREA

Willow Creek is 70 miles by road to the north of Anchorage, the major population center of Alaska. It is 30 miles in length and located within the 166-square mile Willow Creek drainage (Figures 1 and 2) in the southwestern foothills of the Talkeetna Mountains. Elevations in this area range from approximately 5,500 feet above mean sea level (MSL) in the upper portion of the watershed to 100 feet above MSL at the confluence of Willow Creek with the Susitna River.

A continuous gaging station (USGS Gage No. 15294005) was installed on Willow Creek in June 1978. Estimates of selected long-term flow characteristics for Willow Creek are summarized (Estes, 1984) in Table 1. Low winter flows occur from mid-November to mid-April with high flows occurring between May and August.

TABLE 1. Estimates of Selected Long-Term Flow Characteristics for Willow Creek (adapted from Estes, 1984).

Description	Flow (cfs)
High Average Annual Flow	550
Mean Average Annual Flow	350
Low Average Annual Flow	150
July Mean Monthly Maximum Flow	1040
July Mean Monthly Flow	820
July Mean Monthly Minimum Flow	410
August Mean Monthly Maximum Flow	1500
August Mean Monthly Flow	620
August Mean Monthly Minimum Flow	200
Mean Flood Flow	3300

Approximately 25 percent of the study area is within a 100-square mile site selected by Alaskan voters as the location for a new state capital. The remainder of the study area adjoins Willow Creek both upstream and downstream of its confluence with Deception Creek. The portion of the study area that is contained within the proposed Capital site is owned almost entirely by the State of Alaska and is virtually undeveloped. Lands adjacent to Willow Creek, however, are in private or Borough ownership and have been developed to a limited extent.

In recent years, the Willow Creek drainage has become a focal point for increasing recreational activities (e.g., fishing, hunting, boating, hiking, cross-country skiing, and snowmobiling) primarily because of the aesthetic qualities of the area and its proximity to Anchorage. The high productivity and variety of fish species make it one of the most important sport fisheries in the lower Susitna River basin. Willow Creek also serves as an access corridor to other fishing and hunting areas within the Susitna River drainage and is used extensively by boaters for this purpose.

FISHERY RESOURCES

Four of the five species of Pacific salmon (chinook, pink (*O. gorbuscha*), coho (*O. kisutch*), and chum (*O. keta*)) are known to utilize Willow Creek. In addition, adult sockeye salmon (*O. nerka*) are known to mill at the mouth of Willow Creek. Important resident fish species that utilize the system include Dolly Varden (*Salvelinus malma*), rainbow trout (*Salmo gairdneri*), Arctic grayling (*Thymallus arcticus*), and burbot (*Lota lota*). Timing of life phase activities of these species in Willow Creek is illustrated in Figure 3.

Resources were not available to evaluate more than one species and life phase. Therefore, chinook salmon were selected because of the importance of this species to the sport fishery. The spawning life phase was studied because it is usually the simplest to evaluate. Spawning by chinook salmon in Willow Creek occurs during mid-July through August

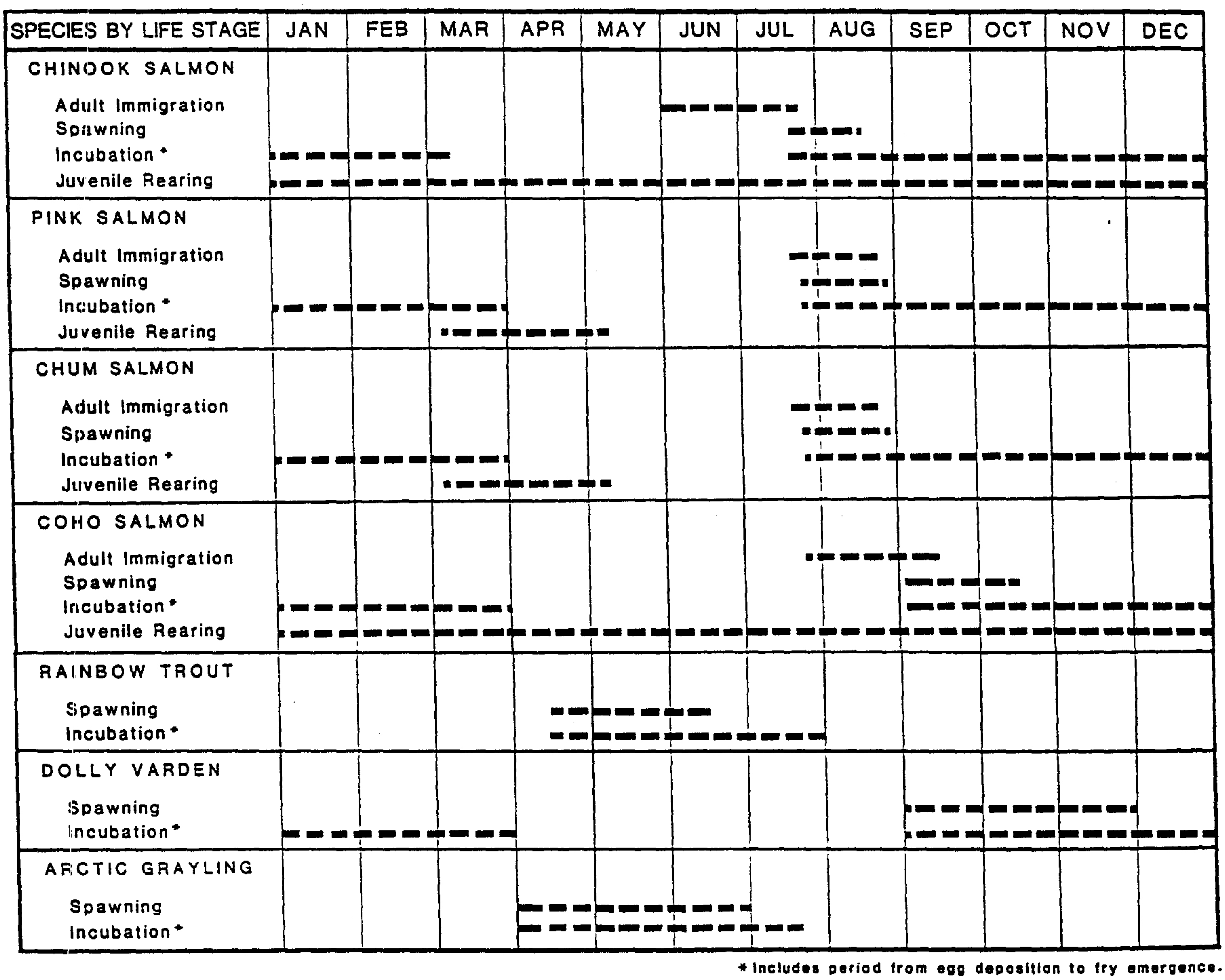

Figure 3. Fish Species (burbot data unavailable) Periodicity Chart.

(Figure 3). Accordingly, the relationship of July and August flows to the spawning phase of chinook salmon was the focus of this investigation.

METHODS

Four instream flow methods were applied both individually and collectively to Willow Creek, Alaska (Figure 1) to estimate instream flow requirements to support spawning by chinook salmon:

1. Instream Flow Incremental Methodology (IFIM), Physi-Habitat Simulation (PHABSIM) System Approach;
2. Montana Method;
3. Maximum Spawning Area Flow Method; and
4. Maximum Spawning Area Method.

Four methods were applied in order to provide a means of identifying whether a common standard could be established for evaluating the results generated by different methodologies. The methods were selected to represent a range of resource intensive and simplistic data collection and analysis techniques. Specific details of the data collection and analysis procedures for each method are presented in Estes (1984). Brief summaries of each method follow.

The PHABSIM system modeling approach of the IFIM (Bovee, 1982), a field/office method, was developed by the Instream Flow Group of the U.S. Fish and Wildlife Service. It is the most resource intensive of the four methodologies examined. The IFIM allows for the quantification of habitat that is capable of supporting a targeted species/life phase or combination of species/life phases as a function of selected flows. The ability to evaluate a series of specified flows with this method makes it the most versatile method of those examined for making water allocation decisions.

The PHABSIM system is a collection of computer programs that combine open channel hydraulics and behavioral responses of fish to hydraulic characteristics (Milhous, *et al.*, 1984). The combination of these programs translates flow variations into an index of the availability of fish habitat (weighted usable area, WUA) at a site. The PHABSIM models require extensive hydraulic data (e.g., water velocity and depth) collection and analyses to simulate available physical (hydraulic) conditions (a physical model). Fish habitat criteria (e.g., water velocity and depth, and substrate characteristics associated with the water column utilized by fish) are required to develop fish habitat criteria files. The fish habitat criteria files are used to determine, through weighting, the percentage of total wetted surface area at a given flow which provides fish habitat based on physical characteristics simulated by the physical model. The resulting product is designated as WUA and is an index of the capacity of a site to support the species and life stage being considered (spawning habitat for chinook salmon in this study). WUA is expressed as square feet (ft^2) or percentage (%) of wetted surface habitat area estimated to be available per 1000 linear feet of stream reach at a given flow. The range of flows for which WUA can be calculated is determined by the calibration range of the hydraulic models. WUA is *not* a measure of the number of fish at a site.

The second method, the "Montana Method" (Tennant, 1972; 1976), is an office method. It is considered one of the simplest techniques for selecting or qualitatively evaluating instream flows for fish and wildlife. Eight flow classifications were established by Tennant by analyzing a series of field measurements and observations. Each is assigned a percentage or percentage range of the average annual flow (QAA). Seven of the classifications characterize habitat quality for fish and wildlife and the eighth provides for a flushing flow. The percentages of QAA for habitat quality range from < 10 percent (Severe Degradation) to 60-100 percent (Optimum Range). The flushing flow classification equals 200 percent of the QAA.

The Montana Method requires that a QAA be calculated from an existing or synthesized data base. A flow recommendation is established by selecting the desired classification and multiplying the QAA by the corresponding percentage or percentage range.

The method is simple to apply. Thus, it has the potential for inadvertent misuse because it does not account for specific species/life phase habitat requirements. Also, QAA alone does not describe short- or long-term changes in flow rates, seasonal variability, or channel geometry. Accordingly, Tennant cautions that site evaluations should be conducted to determine if the percentages of QAA assigned to classifications require modification. These adjustments are not applied to this analysis as a demonstration of what can happen if the Montana method is performed without field evaluations.

The third, Maximum Spawning Area Flow (Method A), and fourth, Maximum Spawning Area (Method B), methods were developed by Orsborn (1982). Both are office methods and have a limited capability for assessing flow recommendations because they only evaluate one flow condition.

Method A is based on estimating the discharge (cfs) at which the maximum spawning area (QMSA) occurs as a function of velocity and depth criteria as determined from existing information on basin and streamflow characteristics. It is a simple tool for estimating the flow which should provide the best spawning habitat characteristics in terms of quality and quantity.

Method B provides for the estimation of maximum spawning area (MSA) as a function of bankfull discharge and requires one field trip to obtain measurements of channel geometry. It is expressed as (ft^2) per 100 linear feet of stream reach. Although this method provides a means of estimating the maximum area available for spawning, it does not, however, account for the quality of habitat for spawning.

Methods A and B were both developed from models of streams located in western Washington.

The premises of the two Orsborn techniques are:

1. streams flowing within comparable bed and bank materials exhibit consistent relationships among width, depth, and velocity as functions of discharge; and

2. basin characteristics are related to channel and flow characteristics that can be related to spawning preference.

Equations were developed by Orsborn (1982) for estimating QMSA and MSA by analyzing existing hydrological, basin and channel characteristics, and spawning habitat criteria (velocity and depth) for steelhead (*Salmo gairdneri*) collected at sites in western Washington. These equations were used to calculate the QMSA and MSA values for this study by deriving basin characteristics for Willow Creek from 1:63,360 topographic maps (Estes, 1984). The MSA equation also required a field measurement of the bankfull wetted perimeter that was representative of the study site. To adjust the Method A and B equations for chinook salmon criteria, a coefficient was developed based on calculating the ratio of differences in the ranges of velocity and depth criteria for steelhead and chinook salmon. The resulting coefficient was multiplied times the QMSA and MSA calculations to adjust the results accordingly.

After performing the individual analyses for the four instream flow methods, it was determined that the long-term QAA, two year peak or mean flood flow (QF2P), seven day average two-year (Q7L2) and 20-year (Q7L20) low flows (or long-term average 30-day minimum flow) during the salmon spawning months could be selected as a standard for comparing the validity of each instream flow analysis. These flows were selected as a standard because they provide a good indication of the flow variation that occurs naturally during the periods of interest for this evaluation. It was assumed that the successful production of the fish species that existed in Willow Creek was related to the long-term flow conditions represented by these flow characteristics. Accordingly, it was assumed that an acceptable flow recommendation would have to fall within the range of these natural conditions.

RESULTS

Results of the IFIM, Montana (MT), and the two Orsborn (A and B) analyses were reviewed to select flows which provide optimal habitat for spawning by chinook salmon in Willow Creek during the July and August period. Optimal habitat represents the most preferred habitat based on its quantity and/or quality. Table 2 summarizes the flow and habitat area estimates derived by each of the four methods. The first three columns of the table represent the IFIM evaluations; the next, the Montana Method, and the last two, the Orsborn A and B methods. Values within the table should not be compared without first reviewing this and the "Comparisons" sections, because all of the methods are not directly comparable. Specific results of each analysis and a detailed discussion of those findings are presented in Estes (1984).

Instream Flow Incremental Methodology

The IFIM data summary (Table 2) has two listings of WUA values (ft^2) in the second and third columns for six flows ranging from 50 cfs to 2000 cfs (column one). The second column represents WUA values calculated with velocity, depth, and substrate as spawning habitat variables. The third column lists WUA values calculated with velocity and depth habitat variables by deleting the influence of substrate. This modification was required to allow for a comparison of the IFIM and Orsborn Method B analyses in the "Comparisons" section below. Substrate characteristics are not considered in the Method B Analysis.

A flow of 598 cfs provided the maximum amount of WUA (1,941 ft^2/1000 ft.) for IFIM calculations in the second column. Without substrate criteria, a flow of 175 cfs in the third column provides the maximum WUA (15,420 ft^2/1000 ft.).

Long-term estimates of the range of monthly flows are 410 cfs to 1040 cfs for July and 200 cfs to 1500 cfs in August (Table 1). Monthly averages are 820 cfs in July and 620 cfs in August. These flow estimates indicate that the 598 cfs IFIM value listed in the second column is within the expected range of flows, whereas the 175 cfs value calculated without the substrate variable is less than that expected during these two months. The estimate of WUA without substrate at a flow of 598 cfs (14,088 ft^2/1000 ft.) is also only 9 percent less than that projected for 175 cfs. Thus, 598 cfs is not an unreasonable spawning flow request if one assumes all aspects of the IFIM analyses as being valid.

Montana Method

The fourth column in Table 2 lists the percentages of average annual flow (QAA) and their qualitative values of fish habitat as defined by Tennant (1976). The next column summarizes the flow values which are calculated by multiplying the Tennant percentage and QAA value. Flows range from 210 cfs to 350 cfs in the optimum range category, are 210 cfs in the outstanding category, 175 cfs in the excellent category, and 140 cfs in the good category. Flow calculations equal to or less than 105 cfs are considered of minimal or no value for fish. It is interesting that the optimum flow values are less than the long-term flow average monthly estimates for July (820 cfs) and August (620 cfs). Instead, these flows approximate the range of mean low monthly flows for these two months (410 cfs and 200 cfs, respectively).

On this basis alone, one should be suspicious of using the percentages of QAA recommended by Tennant without field investigation and a more detailed hydrological analysis, such as the development of monthly flow duration curves for July and August.

Orsborn's Methods

Method A. The sixth column of Table 2 lists the estimated flow (QMSA) which should provide the maximum spawning

TABLE 2. Summary of Results from Instream Flow Analysis of Spawning Habitat in Willow Creek for Chinook Salmon with the Instream Flow Incremental Methodology, Montana, and Two Orsborn Methods (demonstration analysis).

Instream Flow Incremental Methodology			Montana Method		Orsborn Methods	
Flow (cfs)	V, D, S Area (ft^2/1000 ft.)	V, D Area (ft^2/1000 ft.)	Percentage of QAA	Flow (cfs)	Method A QMSA (cfs)	Method B MSA (ft^2/1000 ft.)
2000	463	5495	100%	350	402	133,600
1500	538	8424	60-100% (optimum range)	210-350		(Bankfull area equals 182,000 ft^2/1000 ft)
991	897	9923	60% (outstanding)	210		
598	1941	14088	50% (excellent)	175		
175	1552	15420	40% (good)	140		
50	255	2631	30% (fair or degrading)	105		
			10% (poor)	35		
			<10% (severe degradation)	<35		

NOTES: V = velocity; D = depth; S = substrate; QAA = average annual flow; QMSA = maximum spawning area flow; MSA = maximum spawning area

area for chinook salmon in Willow Creek based on the relationships derived from basin, channel, and flow characteristics in Washington. The QMSA value of 402 cfs is representative of the July (410 cfs) long-term mean monthly low flow and is in between the long-term mean low (200 cfs) and average (610 cfs) monthly flows for August for Willow Creek. Thus it is suspected that 402 cfs is too low for supporting optimal spawning for chinook salmon in Willow Creek. This indicates Method A may require calibration to this system.

Method B. The last column of Table 2 lists the maximum spawning area (MSA) estimate (133,600 ft^2) for chinook salmon in Willow Creek. This amount of wetted area is projected to be available at flows greater than 1,400 cfs (Estes, 1984) and approximates the August mean monthly high maximum flow (1,500 cfs). The bankfull area for the middle reach of Willow Creek is estimated to be 182,000 ft^2/1000 ft. (Estes, 1984). Thus, from a hydrological perspective, the MSA value, in itself, does not appear unreasonable.

COMPARISONS

The above discussions provide summaries of more detailed analyses of the individual instream flow methods provided in Estes (1984). A review of Table 2, with its complete summary of results, suggests one must differentiate between the results based on an understanding of the methods selected. Thus, the four methods can best be compared by evaluating the results from the IFIM analyses listed in column three, the results for the Montana Method analyses listed in column five, and the results from the Method A Orsborn method listed in column six. The results from the IFIM analyses in column three can be compared with the results from the Orsborn Method B analysis in column seven.

The IFIM provides a quantitative estimate of usable habitat area (WUA) at different increments of flow selected by the investigator. It is limited by the calibration range of the hydraulic model from which it is based. Fish criteria used in the IFIM analysis must be representative of the species/physical relationships for the study area. The Montana Method is an assessment of percentages of the QAA based on qualitative terminology assigned to each percentage of flow. Without actually conducting a field investigation, it is not possible to translate the true value of Tennant's ratings to the specific resources to which it is being applied. Method A of the Orsborn methods generates one quantitative flow representing the optimum spawning condition. Method B provides a quantitative estimate of the upper limit of spawning habitat that could physically be available in a stream based on depth and velocity criteria.

Each method is based on a completely different level of data and analysis. Comparisons that are made among the results of these analyses can be made only if the individual elements of each analysis is kept in perspective. For example, based on the Montana Method, a flow in the range of 210 to 350 cfs is considered within the "optimum range." The IFIM analyses (Table 2) project optimum flows of 598 cfs (column two) and 175 cfs (column three); and Method A estimates 402 cfs as an optimum condition. The range of Tennant projections for excellent to optimum habitat conditions (175 cfs to 350 cfs) fall within the lower end of the highest range of the IFIM flow values.

Comparing the flow recommendations from three (IFIM, Montana, and Method A) of the four methods with average monthly flows for July and August, favors the 598 cfs IFIM flow projection. This comparison also indicates the 402 cfs flow projection with Method A and the highest values projected with the optimum flow range of the Montana Method are acceptable. A flow duration analysis for July and August flows would probably help select which of these values is preferred by better estimating the frequency of flows that could be expected during these months. This would provide a basis for not requesting more water than actually exists in the system.

The Method B estimate for MSA must be compared with the WUA estimates calculated without substrate, because substrate is not considered in the Method B analysis. Accordingly, an area of 133,600 ft^2/1000 ft. is projected by Method B. The optimum WUA value for the IFIM analysis for a flow of 175 cfs listed in column three of Table 2 is 15,420 ft^2/1000 ft. The comparison of the value projected by Method B with the 175 cfs and other IFIM flow values suggests that the MSA analysis is sensitive to channel geometry and will require calibration (which was not possible within the scope of this study) and/or that the WUA calculations of optimal habitat conditions cannot be compared with the Method B type of analysis. Of these analyses, this one probably has the least practical use for reservations of instream flows.

CONCLUSIONS

This paper contributes to the development of standards for conducting an instream flow evaluation. The IFIM, Montana, QMSA, and MSA methods were examined. A description of each and its application for estimating spawning flows for chinook salmon in Willow Creek was evaluated.

Individual results varied, suggesting that a closer examination of the recommendations derived from each method is required. By comparing the results of the IFIM, Montana, and QMSA methods to support spawning by chinook salmon, a flow of 600 cfs can be recommended. This value is based upon comparisons of the output from each method and an evaluation of hydrological conditions for Willow Creek for the period of interest. Biological criteria used in these analyses were not examined in this paper and could modify these recommendations.

The validity of any analysis depends on how well the assumptions are met. The IFIM is based upon the assumption that the physical model represents the range of physical conditions pertaining to the seasonal utilization of the stream reach by a species. It is assumed that the fish criteria reflect the species/physical relationships of the study area. By applying the Montana Method without adjusting percentages of QAA, it must be assumed that the percentages of QAA recommended by Tennant have universal application. The QMSA and MSA methods assume that regional basin and channel characteristics can be applied to project flow requirements and characteristics.

Regardless of these assumptions, an investigator should review basic hydrological characteristics for the study area as a standard for determining whether the hydrological components of an instream flow analysis fall within the expected range of natural hydrological conditions. Biological criteria must be representative of the species and system evaluated (Hunter, 1973). Accordingly, these evaluations should be conducted on an interdisciplinary basis by both a biologist and hydrologist (or hydraulic engineer).

It appears as though each of the methods evaluated can be used independently to generate valid instream flow recommendations if calibrated to the hydrological and biological conditions of the site or area studied. The IFIM, unlike the other methods considered, allows for incremental evaluations of any flow within the calibration range of the hydraulic model developed for a site. The Montana, QMSA, and MSA methods will provide limited evaluations of average conditions and can also be used for comparison with the IFIM.

Once adjusted to the species and basins of interest, the QMSA and Montana methods should be used to develop flow recommendations for areas where competition for water is minimal. When competition for water is high, an IFIM or similar approach is recommended for supporting a complete evaluation of all flow options and responses to the various species/life phases emphasized. The selection of a specific methodology will depend upon the quality and availability of hydrological and biological data and the resources for conducting the investigation. A level One to Four approach for selecting instream flow techniques, as summarized in Smith (1979), combined with the recommendations presented in Wesche and Rechard (1980), is a good starting point for determining the applicability of a technique.

It is recommended that additional efforts should be made to further improve the knowledge of instream flow investigators for selecting a method. Studies are also required to better define standards for evaluating the validity of the resulting output from an instream flow analysis.

ACKNOWLEDGMENTS

This research was supported by Washington State University, the Alaska Departments of Fish and Game and Natural Resources, the USDA Soil Conservation Service, and the U.S. Geological Survey.

The authors thank A. Hoffmann, K. Hepler, and N. Newcome, Alaska Department of Fish and Game, for their support in the data collection and for assisting with portions of the analyses in this paper. Special appreciation is extended to D. Vincent-Lang, Alaska Department of Fish and Game, and D. Reiser, Bechtel, for their editorial review of this paper. A. Armstrong and A. Sales, Alaska Department of Fish and Game, are acknowledged for their typing support. C. Hepler, Alaska Department of Fish and Game, is acknowledged for the illustration of figures.

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