# Standards for Instream Flows

Hal A. Beecher
*Habitat Management Division*
*Washington Department of Wildlife*
*600 Capitol Way North*
*Olympia, Washington 98501-1091*

*ABSTRACT:* Instream flow standards are not clearly defined in laws of most western states. An instream flow standard should imply a formula that would incorporate biological and hydrological information to assign a range of instream flows for a stream. Ambiguity in instream flow standards has led to unresolved controversy over water allocation in Washington. A clear instream flow policy would reduce costly delays in water resource planning. Five elements to an unambiguous instream flow standard are identified: goal, resources to be considered, unit of measurement, benchmark time period, and protection statistic. Future water management options and instream resource levels are influenced by choices pertaining to each of these elements. An instream flow standard for fish habitat protection is proposed as an example. If the standards recommended were implemented, future water appropriation would be restricted to large, high-gradient rivers.

*KEY WORDS:* Policy, streamflow standards, water allocation, water resource planning.

## INTRODUCTION

There is a dilemma in state instream flow programs. Many states have established programs dealing with instream uses of water, but few have achieved a consensus on what these programs are supposed to achieve. One solution to this problem is clear standards. At a minimum, the statutory language of a program should offer a clear, measurable goal. Instream flow programs that fail to meet this criterion will increase controversy and achieve vague results.

Although 15 states have laws that allow establishment and protection of instream flows (McKinney and Taylor 1988; Reiser et al. 1989), standards for instream flows are vaguely defined in law. If clearly defined, an instream flow standard would serve as a formula to prescribe, within relatively narrow limits, instream flows to be set in a given stream reach once specific information about the stream reach is considered in the formula. An instream flow standard should (1) define the goal of the instream use of water, (2) state the extent to which the goal is to be achieved, and (3) identify criteria for evaluating the achievement.

In several states (e.g., Colorado, Idaho, Kansas, Montana, Nebraska, Oregon, Washington, and Wyoming), the term "minimum" is associated with instream flows (McKinney and Taylor 1988). Specific hydrologic upper limits are placed upon instream flows in Oregon and Alaska. Oregon law specifies optimum levels for management of fish habitat, thus indirectly for instream flows for fish (Ore. Rev. Stat. 496.012, 496.435, and 506.109). Oregon's 1955 instream flow statute (Ore.

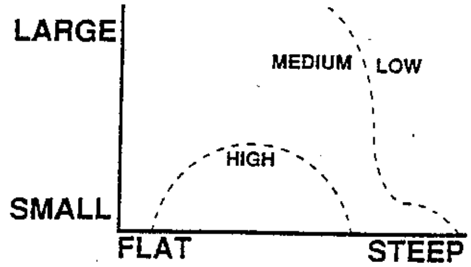


FIGURE 1. *Salmonid densities in Washington streams are greatest in small streams with moderate gradient and least in large, steep streams.*

Rev. Stat. 536.235) was for minimum flows, but a 1987 instream water rights law (Ore. Rev. Stat. 537), administered as incorporating minimum flows set under the earlier statute, recognizes broad instream uses but has no clear standards.

Increasing competition for finite water supplies has made establishment of instream flow protection a prolonged controversy (McKinney and Taylor 1988; Shupe and Sherk 1988), except in Alaska, where out-of-stream use has made few inroads into water supply (White 1982). For example, a Washington state program to establish instream flows stalled in 1985 as development and environmental interests clashed over the quantity of water to be reserved for instream uses. Each side's arguments were based on its interpretation of state water law and the instream flow standards perceived therein. The resulting review of the program included a year of inconclusive negotiations among members of a multi-interest Instream Flow and Water Allocation Advisory Committee. The Department of Ecology (Ecology), which administers water rights and instream flows, proposed optimum flows for fish as a standard. Challenges to that proposal led to creation of the state legislature's Joint Select Committee on Water Resource Policy in 1988 (Shupe and Sherk 1988; Joint Select Committee on Water Resource Policy 1989). Washington's experience has been costly in terms of effort, uncertainty, and delays. As of fall 1989, no resolution had been achieved.

Standards for instream flows are one key to resolving this dilemma. As long as they remain ambiguous, standards will be easily challenged. Attacking administrative standards can be a profitable exercise for anyone needing more water. As unallocated water decreases in availability, the challenges and counter-challenges are more likely to involve all available administrative, legal, and legislative processes. Standards that are unambiguously defined will greatly reduce delays and uncertainty, and minimize costs.

The Washington State Legislature has written three different statutes that allow establishment of instream flows (Rev. Code Wash. 75.20.050, Rev. Code Wash. chapter 90.22, and Rev. Code Wash. chapter 90.54). The oldest of these statutes (Rev. Code Wash. 75.20.050), first passed in 1949, declares "the policy of this state that a flow of water sufficient to support game fish and food fish populations be maintained at all times in the streams of this state." The criterion for refusing to issue a permit is the opinion of the Director of Game or Director of Fisheries that granting a water right would reduce flow to a level no longer sufficient to sustain fish populations. Ecology can place conditions, including minimum flows, on water rights, rather than deny applications. Under these laws, setting of minimum instream flows has been a negotiation process, which has become bogged down because of uncertainty over standards (Shupe and Sherk 1988).

Minimum flows (independent of a water right application) may be established in Washington to protect instream values, primarily fish and wildlife, at the request of the director of either the Department of Wildlife (WDW, formerly Department of Game) or the Department of Fisheries (WDF), according to Rev. Code Wash. 90.22. The legislature also mandated a program to establish base flows (Rev. Code Wash. 90.54) to preserve instream resources, including fish and wildlife. In both Rev. Code Wash. 90.22 and 90.54, two different and potentially conflicting standards have been implied. The terms "base" and "minimum" can be interpreted in a hydrological sense as prescribing relatively low instream flows, whereas the terms "protect" and "preserve" can be interpreted as requiring anything up to a very high quality habitat. In smaller streams, which contribute a disproportionately large fraction of total salmonid production in Washington streams (Figure 1), a relatively high instream flow is required to maintain high quality habitat. What level of protection is required by law?

In most statutes, it is difficult to either ascertain legislative intent or determine whether or not a proposed instream flow regime would satisfy the legislative purpose. To make this determination requires a clear standard in the statute and knowledge of the biological and regulatory consequences of implementation of the standard. The standard should be measurable, so that a reviewer could determine whether or not a recommended instream flow meets that standard.

## DEFINING LEVELS OF INSTREAM FLOW PROTECTION

Five elements must be considered in developing standards for instream flow protection: (1) the goal, such as nondegradation; (2) resources (i.e., the goal is to be considered in terms of certain resources); (3) the unit of measurement (is the goal achieved when the resource level equals the goal, when the flows that produced the goal are met, or when the flows that provide a specified combination of habitat indexes are met?); (4) the benchmark time period (a resource level varies over time, but the goal must be established in relation to a single resource level that has occurred at a specific time in order to determine whether that resource level has increased, decreased, or remained constant); and (5) the protection statistic.

### Goal

The goal of establishing an instream flow is to protect some level of a resource, use, or value. The goal guides the standard. Examples of goals could include (1) enhancement above pristine conditions, (2) nondegradation with restoration, (3) nondegradation, (4) no net loss, (5) set percentage of loss, (6) no loss of genetic diversity, and (7) population survival.

The goal with the highest level of protection is enhancement above pristine conditions. This is rarely a realistic goal when setting instream flows (exceptions discussed below). Furthermore, establishing instream flow standards usually addresses the effects of low flow conditions and not the effects of high flows. Stream reaches downstream from storage reservoirs are exceptions, because these storage projects can increase low flows and decrease high flows. However, in many cases, storage reservoirs are detrimental to the goal of enhancing a fishery resource.

Nondegradation with restoration normally is the highest possible goal for an instream flow standard. This is a goal that implies improvement over benchmark conditions. Examples of nondegradation include protecting resources that are in an acceptable condition at the time of the benchmark and restoring those resources that are below an acceptable level at the time of the benchmark. Decisions on acceptability of resource levels are based on knowledge of a stream's potential for production of fish or other instream resources.

The goal of nondegradation is a slightly lower objective than nondegradation with restoration for most fish. This goal suggests that presently reduced resources would be accepted instead of historic conditions. Streams that were previously barren of fish and have been stocked are a special case.

The next lower goal is "no net loss." Although the same in principle as nondegradation, "no net loss" implies that local, seasonal, or categorical losses will be permitted in exchange for local, seasonal, or categorical enhancements. If a goal of no net loss is used, a careful accounting of these trade-offs is necessary.

Yet another lower goal is a set percentage of loss compared to some benchmark. An example would be a 10% loss of habitat over current conditions. This goal allows some degradation while providing a finite amount of water to satisfy additional demand for out-of-stream uses. However, this goal only assures that, as demand continues to grow, the same dilemma of out-of-stream water uses versus instream resources will be faced at a later date when instream resources are further reduced. It may be better to face these decisions now rather than undertake hard public choices in the future when options may be fewer and more costly.

An alternative goal would be no loss of genetic diversity in biological instream resources. Allendorf and Leary (1986) reviewed examples of inbreeding depression resulting from loss of genetic diversity in reduced populations of a number of species of animals. Franklin (1980) suggested that the short-term minimum effective population size to maintain genetic diversity would be 50 adults, but that a long-term minimum population size would be 500.

The lowest goal is population survival. This is sometimes implied to be protection of habitat for one male and one female of the species of interest to survive and reproduce. The risks of a goal of one breeding pair probably ensure that it would not be met after a few generations. Gilpin and Soule (1986) discussed theoretical approaches to determining minimum viable population sizes. Life history characteristics such as fecundity, generation time, and frequency of reproduction all affect minimum viable population size estimates. Lande (1988) suggested that behavioral considerations make Franklin's (1980) estimate of 500 adults too small a population to maintain long-term viability. In practice, the goals of population survival and no loss of genetic diversity may be the same.

### Resources

Existing Washington state laws (Rev. Code Wash. 90.54.020 [1]) recognize the following instream uses, resources, and values as beneficial uses of water: stock watering, fish and wildlife maintenance and enhancement, recreation, preservation of environmental and aesthetic values, and all other uses compatible with the enjoyment of the public waters of the state. Navigation is also recognized as an instream resource to be considered in establishing instream flows (Rev. Code Wash. 90.54.020 [3][a]). If all of these resources are to be considered in setting and measuring instream flow standards, then each must be quantifiable. If protection is to meet the goal, then resource levels must be measurable at the benchmark and in the future.

Different resources may respond quite differently to changes in streamflow. For example, recreation includes both white water boating, which has some of the highest instream flow requirements, and swimming, which is favored when velocity is minimized. If resources respond to changes in streamflow differently and all responses are strong, then it might be impossible to protect all instream resources equally. An exception might be the nondegradation goal, where the instream flows equal those of the benchmark period.

On the other hand, some instream resources might be either more highly valued or more sensitive to flow changes than others. Fish and wildlife are the resources most frequently identified as the purpose for instream flows in western states (McKinney and Taylor 1988). Valued or sensitive resources might be chosen as the resources by which goal attainment is measured.

### Unit of Measurement

Three possible units of measurement are the resource itself, flow, or habitat. It is more difficult to measure some resources, such as fish and wildlife, than to measure flow. Even estimates of flow on ungauged streams may be easier than measuring gains and losses of fauna (Amerman and Orsborn 1987). Habitat is more difficult to quantify than flow, but indexes of habitat, such as weighted usable area (WUA), can be calculated as a function of flow (Bovee 1982).

If the resource is the unit of measurement, is enough known to prescribe an instream flow that will protect the chosen resource level? In the case of long-lived fishes with complex life histories, the answer is no. Fish can exhibit alternative reactions, such as differences in growth, reproduction, and behavior in response to a given influence.

This complex response to environmental variables means that care must be taken when relying on a single limiting factor in the instream flow prescription. Flow affects fish production both directly and indirectly, as shown in a diagram of steelhead trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) life cycle (Figure 2). Loar et al. (1985) concluded that habitat is important and that fish respond to habitat changes even when availability of other resources is low. The concept of a single limiting factor is most useful in simple ecosystems and simple life histories.

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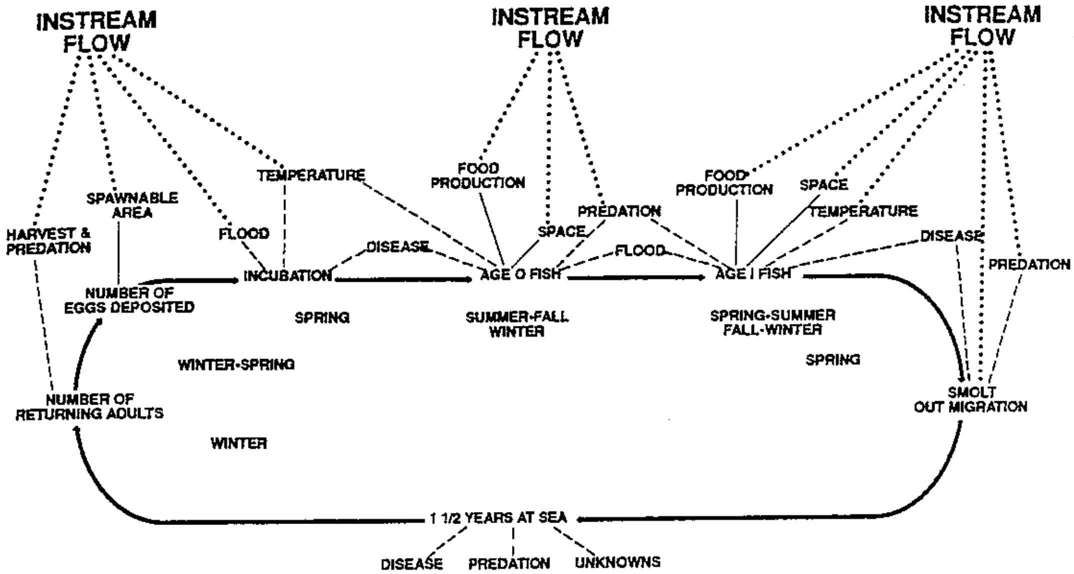


FIGURE 2. *Influence of instream flow, including floods, on life history of steelhead trout (*Oncorhynchus mykiss*). Solid lines indicate positive influence, dashed lines indicate negative influence, and dotted lines indicate influence by instream flow.*

of the Physical Habitat Simulation (PHABSIM) of the Instream Flow Incremental Method (IFIM), which is used to calculate WUA available at different flows, many studies have shown the importance of flow-influenced habitat components to fish production. Changes in fish populations, survival, or growth are correlated with flow changes and associated environmental factors, such as extreme temperatures, in many cases (Table 1). Cross and Moss (1987) attributed local extinctions and reductions of native fish populations in Kansas streams to reduced flows. Several habitat indexes that have been locally correlated with fish populations have incorporated flow statistics, flow indexes, or flow-influenced habitat components (Zillges 1977; Nickelson and Hafele 1978; Binns and Eiserman 1979; Orth and Maughan 1982; Loar et al. 1985; Bowlby and Roff 1986; Wesche et al. 1987). Easterbrooks (1981) found a strong relationship between rainbow trout density and depth in an artificial stream.

If fish respond to the habitat components used to calculate WUA in PHABSIM, then PHABSIM should predict fish distribution within a stream segment. Hardy et al. (1982) found positive correlations between predicted and observed distributions of several fishes in a Nevada stream.

At the same time, other factors, some of which may be independent of flow, also influence fish production. Flow changes can cause changes in other factors such as water temperature, food production and transport, intensity of competition, effectiveness of predation or harvest, or migration, any of which could influence fish populations independently from any changes in those aspects of habitat indexed by WUA (Figure 2); change in fish populations with a change in flow could be a response to one of these other flow-dependent factors. Many flow-related and flow-independent factors can interact to affect fish populations. Considering the diversity of potential influences upon fish populations, it is remarkable that the influence of flow upon fish populations is detectable (Nelson 1984; Orth 1987); it is not surprising that in many situations no significant influence of flow is readily apparent (Scott and Shirvell 1987; Platts and Nelson 1988). Thus, resource level in a benchmark period or in some later time may only partially reflect the flows that occurred during the formative time for that resource.

Using flow as the unit of measurement in an instream flow standard does not ensure a consistent level of resource protection. Neither a flow nor an exceedence flow has a consistent relationship to habitat or production across a range of stream types

**TABLE 1**

*Variations in fish populations related to flow or associated environmental parameters.*

| Fish | Biological response | Flow-related factor | References |
|---|---|---|---|
| 1. adult coho salmon (*Oncorhynchus kisutch*) | numbers of fish in commercial catch | rearing summer low flow in British Columbia, Oregon, and Washington | Neave 1949; McKernan et al. 1950; Smoker 1955; Mathews and Olson 1980 |
| 2. adult coho salmon | harvest management model to predict total number of fish | rearing summer low flow in Washington | Zillges 1977 |
| 3. adult steelhead (*O. mykiss*) | numbers of fish in sport catch | rearing summer low flows in western Washington streams | Beecher 1981 |
| 4. juvenile steelhead | biomass (weight/area) | habitat models incorporating depth, velocity, and cover in western Oregon | Nickelson and Hafele 1978 |
| 5. adult Yellowstone cutthroat trout (*O. clarki bouvieri*) | numbers of fish | numbers of Yellowstone River (Montana) tributaries not severely dewatered | Clancy 1988 |
| 6. brown trout (*Salmo trutta*) adults | numbers of fish | indexes of low flow and cover in Wyoming streams | Wesche et al. 1987 |
| 7. brown trout all ages | abundance and biomass (weight/area) | index of habitat based on depth and velocity in southern Appalachian streams | Loar et al. 1985 |
| 8. brown trout adult and juvenile | numbers of fish, distribution of fish | weighted usable area in Michigan stream | Gowan 1984 |
| 9. juvenile landlocked Atlantic salmon (*Salmo salar*) | numbers of fish | summer rainfall in Maine | Havey and Davis 1970 |
| 10. Atlantic salmon smolts | numbers of fish | low flows in rivers in Quebec and Norway | Frenette et al. 1984; Hvidsten and Ugedal in press |
| 11. brook trout (*Salvelinus fontinalis*) all ages | decrease in numbers of fish | drought in southern Appalachian streams | LaRoche and Pardue 1980 |
| 12. adult rainbow (*O. mykiss*) and cutthroat (*O. clarki*) trout | density, biomass, and numbers of fish | depth in artificial stream channel | Easterbrooks 1981 |
| 13. trout (*Salmo trutta, O. mykiss,* and *Salvelinus fontinalis*) all ages | numbers, biomass (weight/area), growth, and survival of fish | annual streamflow in Wisconsin streams | White 1975 |
| 14. trout (brown and rainbow) all ages | numbers of fish or biomass (weight/area) of populations or age classes | low flows in Montana streams | Nelson 1984 |
| 15. trout (brook, brown, and rainbow) all ages | biomass (weight/area) | model including low flows in Ontario streams | Bowlby and Roff 1986 |

**TABLE 1**
*Continued.*

| Fish | Biological response | Flow-related factor | References |
|---|---|---|---|
| 16. trout (brown, brook, cutthroat, and rainbow) young-of-the-year | reduced numbers of fish in year class | spring runoff in Colorado streams | Nehring and Anderson 1984; Anderson and Nehring 1985 |
| 17. trout (brown and rainbow) all ages | numbers of fish and survival | weighted usable area (WUA) in Colorado | Bovee 1988 |
| 18. trout (brook, brown, cutthroat, and rainbow) all ages | biomass (weight/area) | habitat quality index (HQI) including late summer flow and annual flow variation | Binns and Eiserman 1979 |
| 19. rainbow trout, whitefish (*Prosopium williamsoni*), bass (*Micropterus* spp.), and crappie (*Pomoxis* spp.) all ages | numbers of fish | low flows during preceding 5 years in Yakima River, Washington | Mongillo and Faulconer 1980 |
| 20. larval river-spawning fishes: goldeye (*Hiodon alosoides*), minnows (*Hybognathus hankinsoni* and *H. nuchalis*), walleye (*Stizostedion vitreum*), and sauger (*S. canadense*) | numbers of fish | river flows during spawning season in South Dakota reservoir | Nelson 1980 |
| 21. young-of-the-year striped bass (*Morone saxatilis*) | numbers of fish | river flow in delta of Sacramento–San Joaquin rivers, California | Turner and Chadwick 1972; Stevens 1977 |
| 22. smallmouth bass (*Micropterus dolomieui*) ages 1–4 | declines in growth rate | deviations from optimum flow | Paragamian and Wiley 1987 |
| 23. freckled madtom (*Noturus nocturnus*), central stoneroller (*Campostoma anomalum*), and orange-belly darter (*Etheostoma radiosum*) all ages | biomass (weight/area) | WUA index of habitat based on depth and velocity | Orth and Maughan 1982 |

and sizes. It is possible that the same stream channel could produce the same quantity of habitat or fish at two different flows (Figure 3). In such a situation, using the higher of the two flows might preclude further out-of-stream uses of the water.

Habitat is an intermediate step between flow and resource. Habitat indexes, such as WUA, are not susceptible to external non-flow-related influences, such as El Niño (Mysak 1986) or harvest and predation. Habitat indexes can also account for differing incremental values of water to resource production. However, it would be necessary to standardize units of a habitat index; one unit of WUA in one instream flow study is seldom equivalent to one unit of WUA in another study, even at the same site. WUA generally does not address channel maintenance flows or flows to

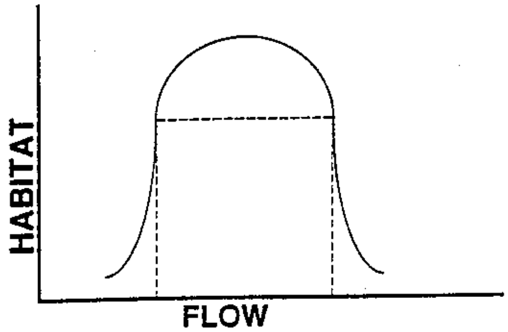


FIGURE 3. *Two different flows may provide the same amount of habitat. If the same resources can be produced by protecting the lower flow as by protecting the higher flow, protection of the lower flow leaves more water available for other uses.*

transport smolts of anadromous fish seaward. Despite these considerations, a habitat index similar to WUA holds considerable promise as the unit of measurement.

### Benchmark Time Period

An instream flow should protect a resource level related to a specific time period, the benchmark. The benchmark time period may be a time when pristine conditions existed, some period of cultural significance (such as statehood), recent past, or the present. This decision can greatly influence the level of protection provided by an instream flow. For example, if the instream use being considered is navigation, then the standard would be much higher in Washington with a benchmark of the present than with a benchmark of 1889, the year of statehood. Higher instream flows will be required in navigable waters to maintain present navigation than to maintain the amount of navigation that occurred a century ago. However, because of the locks and dams that aid in navigation, as well as other environmental changes and harvest, a benchmark period of 1889 would provide a higher standard for anadromous salmonids than would a benchmark of the present (Chapman 1986; Li et al. 1987).

The duration of the benchmark time period can also affect the standard. Resources and flow vary in response to many factors. Some of the variation appears to be cyclical; some does not. If the benchmark time period brackets only an extreme of the cycle or a significant noncyclical event, then the standard could be modified accordingly.

### Protection Statistic

Both the mean and median are functions of the full range of data from which they are generated. However, using a mean or median as the protection statistic may not maintain the resource at its historic mean or median level. The upper extremes of a distribution are important to maintaining an "average." If the data are levels of commercial fish, then upper extremes contribute disproportionately to harvest because a large part of a fish population is allocated for spawning escapement. If an instream flow is set to protect average conditions, but higher than average conditions are eliminated, then the average will decline. Thus a standard set to protect an average may fail to do so. It may be necessary to protect an upper extreme in order to maintain an average condition. Thus, if fish population, quantity of habitat, or flow is the unit of measurement, and if the goal is nondegradation, then an infrequently exceeded amount of that unit of measurement must be the standard.

Other hydrological statistics are often proposed as protection statistics. However, hydrological statistics will yield inconsistent results relative to the goal because habitat is a function of flow and channel shape, not frequency of flow.

## AN EXAMPLE: STANDARD FOR WASHINGTON

Existing Washington statutes suggest or imply a nondegradation or no net loss goal for fish and other instream resources. Examples are statutory language such as "sufficient to support" (Rev. Code Wash. 75.20.050), "protect" (Rev. Code Wash. 90.22), and "preserve" (Rev. Code Wash. 90.54).

Although the exact relation between flow and fish was not understood quantitatively when these laws were enacted, it was apparent then, as now, that fish need water. Water to be reserved in the stream was for the fish and fisheries themselves (Rev. Code Wash. 75.20.050, 90.22, and 90.54). Rather than use all fish (or all instream resources) as the resource to be measured, the standard should focus on a few larger, culturally important, flow-sensitive fishes. Larger fishes generally inhabit deeper, faster water and are, therefore, more flow-sensitive than smaller fishes (Hanson 1977). With the exception of some threatened or endangered fishes, culturally important fishes are generally large enough to be valued for food or sport. Because larger fishes are generally less numerous than smaller fishes, population losses due to habitat losses might also be more significant to population survival and genetic diversity in larger fishes.

A habitat index, unlike a resource level—such as a fish population—can be tied quantitatively to a known past or future flow. Thus, to meet the goals of the Washington statutes, an instream flow standard might be nondegradation of fish habitat as measured by a flow-related habitat index, such as WUA.

A 22-year benchmark period would incorporate a large amount of the variation recorded in fish populations and flows. This length of time would cover a complete cycle of solar activity (Howard 1981). A recent benchmark covering 1960–1982 would ensure reasonable availability of records of flows and fish production.

In order to achieve the goal of nondegradation, an appropriate protection statistic would be an infrequently exceeded amount of habitat. An example might be the 5% exceedence WUA. With this protection statistic as part of the standard, extraordinarily favorable conditions permitting unusually high production would not be precluded. Occasional high levels of production contribute to maintenance of an average and significantly increase harvest of fish.

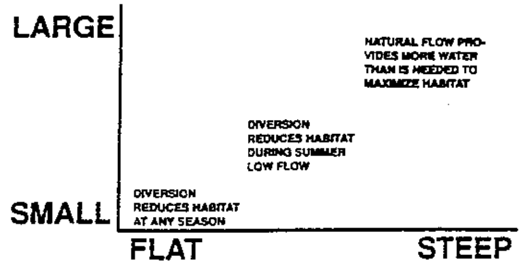


FIGURE 4. *In single-channel streams, duration of availability of at least a given quantity of habitat is most limited in small, low-gradient streams.*

A statistic of percent exceedence WUA would be calculated in much the same way as percent exceedence flows are calculated. Given a set of daily, weekly, or monthly flows over the benchmark period, a WUA value would be paired with each flow; then WUA values would be ordered from low to high for the day, week, or month in question, and the WUA value at or just below the highest 5% of the values would be the 5% exceedence WUA.

In this recommended standard, goal is nondegradation; resource is culturally important, flow-sensitive fishes; unit of measurement is WUA for those fishes; benchmark is a recent 22-year period beginning after 1960; and protection statistic is 5% exceedence WUA. This recommendation illustrates how considering each of the elements discussed will increase the chance that the choice is based upon a good understanding of the options, their significance, and consequences.

## REGULATORY CONSEQUENCES

Adherence to the suggested standard would limit future diversion to large or high-gradient streams. In numerous IFIM studies in Washington, I have observed frequent water availability above what is needed to maximize WUA in large or high-gradient streams and very infrequent water availability above what is needed to maximize WUA in small, low-gradient streams (Figure 4). Thus, in large streams, a 5% exceedence WUA may correspond to a frequently exceeded flow, but in small, low-gradient streams the exceedence frequency for WUA and flow are correlated.

In large or high-gradient streams, high velocities frequently limit habitat usability for most fish in large areas of the stream channel. Flow reduction often reduces velocities into a usable range in these streams. In low-gradient streams, velocities are seldom unusably high except during infrequent floods. Despite some published sal-

**TABLE 2**
*Use of deep water by Washington salmonids. Incidental observations by author.*

| Species | Stream |
|---|---|
| cutthroat trout (*Oncorhynchus clarki clarki*) adult | Snoqualmie River above falls |
| steelhead (*O. mykiss*) parr | below falls |
| chinook salmon (*O. tshawytscha*) smolt | below falls |
| pink salmon (*O. gorbuscha*) adult | Skagit River |
| mountain whitefish (*Prosopium williamsoni*) adult | Kettle, Yakima, Skagit, and Snoqualmie rivers |

monid depth preference curves indicating reduced suitability of deep water (Bovee 1978; Wilson et al. 1981; Sheppard and Johnson 1985; DeGraaf and Bain 1986; Campbell and Eddy 1988), I have observed high densities of salmonids in parts of some streams where depth was 5–10 m but where velocity was suitable (Table 2). Therefore, it appears that increasing depth does not reduce suitability unless accompanied by unsuitable velocity (or unless depth avoidance serves to reduce predation or risk of redd scouring). In small streams, channel roughness constrains velocity so that it does not exceed suitability except at infrequent high flows, and depth in small streams is often made more suitable as depth increases with flow.

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