

## Standards for Instream Flows

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**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

**T**here 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.

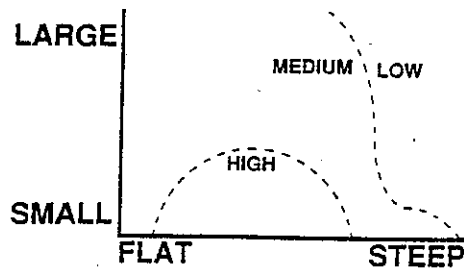


FIGURE 1. Salmonid densities in Washington streams are greatest in small streams with moderate gradient and least in large, steep streams.

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 any-

one 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

water. As unallocated availability, the challenges are more available administrative processes. Stagnantly defined will and uncertainty, and

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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 nor-

mally 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 re-

sources. 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.

Although Mathur et al. (1985) and Scott and Shirvell (1987) have criticized the use

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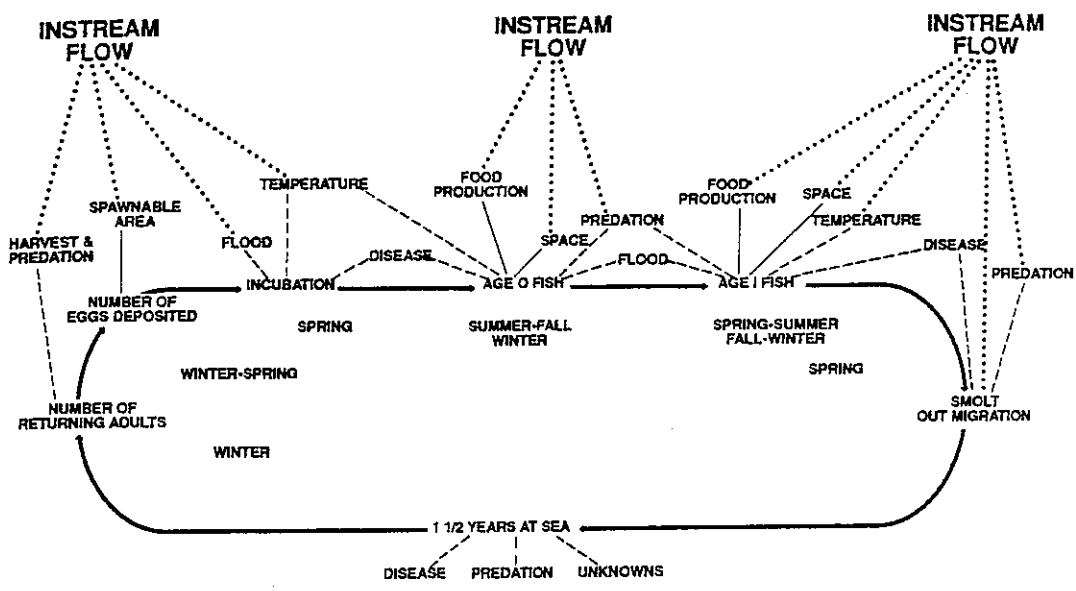


FIGURE 2. Influence of instream flow, including floods, on life history of steelhead trout (*Oncorhynchus mykiss*). Solid lines indicate positive influence, dashed lines indicate negative influence, and dotted lines indicate influence by instream flow.

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 ( <i>Oncorhynchus kisutch</i> )	numbers of fish in commercial catch	rearing summer low flow in British Columbia, Oregon, and Washington	Neave 1949; McKernan et al. 1950; Smoker 1955; Matthews 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 ( <i>O. mykiss</i> )	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 ( <i>O. clarki bouvieri</i> )	numbers of fish	numbers of Yellowstone River (Montana) tributaries not severely dewatered	Clancy 1988
6. brown trout ( <i>Salmo trutta</i> ) 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 ( <i>Salmo salar</i> )	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 ( <i>Salvelinus fontinalis</i> ) all ages	decrease in numbers of fish	drought in southern Appalachian streams	LaRoche and Pardue 1980
12. adult rainbow ( <i>O. mykiss</i> ) and cutthroat ( <i>O. clarki</i> ) trout	density, biomass, and numbers of fish	depth in artificial stream channel	Easterbrooks 1981
13. trout ( <i>Salmo trutta</i> , <i>O. mykiss</i> , and <i>Salvelinus fontinalis</i> ) 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

References  
 Leave 1949; Mc-Kernan et al. 1950; Smoker 1955; Matthews and Olson 1980  
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TABLE 1  
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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 ( <i>Prosopium williamsoni</i> ), bass ( <i>Micropterus</i> spp.), and crappie ( <i>Pomoxis</i> 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 ( <i>Hiodon alosoides</i> ), minnows ( <i>Hybognathus hankinsoni</i> and <i>H. nuchalis</i> ), walleye ( <i>Stizostedion vitreum</i> ), and sauger ( <i>S. canadense</i> )	numbers of fish	river flows during spawning season in South Dakota reservoir	Nelson 1980
21. young-of-the-year striped bass ( <i>Morone saxatilis</i> )	numbers of fish	river flow in delta of Sacramento-San Joaquin rivers, California	Turner and Chadwick 1972; Stevens 1977
22. smallmouth bass ( <i>Micropterus dolomieu</i> ) ages 1-4	declines in growth rate	deviations from optimum flow	Paragamian and Wiley 1987
23. freckled madtom ( <i>Noturus nocturnus</i> ), central stoneroller ( <i>Campostoma anomalum</i> ), and orange-belly darter ( <i>Etheostoma radiosum</i> ) 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



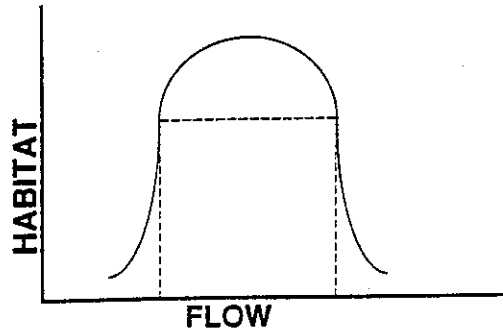


FIGURE 3. Two different flows may provide the same amount of habitat. If the same resources can be produced by protecting the lower flow as by protecting the higher flow, protection of the lower flow leaves more water available for other uses.

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)



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dard should focus on a few larger, cultur-  
ally important, flow-sensitive fishes. Larg-  
er fishes generally inhabit deeper, faster  
water and are, therefore, more flow-sensi-  
tive than smaller fishes (Hanson 1977).  
With the exception of some threatened or  
endangered fishes, culturally important  
fishes are generally large enough to be val-  
ued 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 Wash-  
ington 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 in-  
corporate 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 en-  
sure reasonable availability of records of  
flows and fish production.

In order to achieve the goal of nondegra-  
dation, an appropriate protection statistic  
would be an infrequently exceeded amount  
of habitat. An example might be the 5%  
exceedence WUA. With this protection sta-  
tistic as part of the standard, extraordi-  
narily favorable conditions permitting  
unusually high production would not be  
precluded. Occasional high levels of pro-

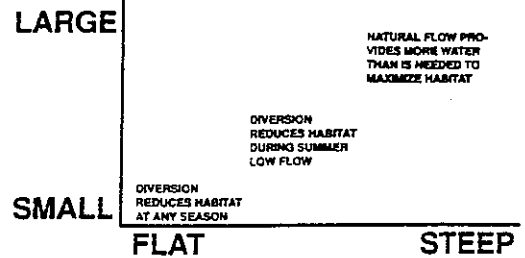


FIGURE 4. In single-channel streams, duration of availability of at least a given quantity of habitat is most limited in small, low-gradient streams.

duction contribute to maintenance of an  
average and significantly increase harvest  
of fish.

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 im-  
portant, flow-sensitive fishes; unit of mea-  
surement is WUA for those fishes; bench-  
mark is a recent 22-year period beginning  
after 1960; and protection statistic is 5%  
exceedence WUA. This recommendation  
illustrates how considering each of the ele-  
ments discussed will increase the chance  
that the choice is based upon a good un-  
derstanding of the options, their signifi-  
cance, 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 fre-  
quent 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 max-  
imize WUA in small, low-gradient streams  
(Figure 4). Thus, in large streams, a 5% ex-  
ceedence WUA may correspond to a fre-

quently 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 ve-  
locities into a usable range in these streams.  
In low-gradient streams, velocities are sel-  
dom unusably high except during infre-  
quent floods. Despite some published sal-

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

Species	Stream
cutthroat trout ( <i>Oncorhynchus clarki clarki</i> ) adult	Snoqualmie River above falls
steelhead ( <i>O. mykiss</i> ) parr	below falls
chinook salmon ( <i>O. tshawytscha</i> ) smolt	below falls
pink salmon ( <i>O. gorbuscha</i> ) adult	Skagit River
mountain whitefish ( <i>Prosopium williamsoni</i> ) 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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Contributions by author.

Stream
Columbia River above falls
Idaho Falls
Snake River
Yakima, Skagit, and Snohomish
Other rivers

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