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### Demonstration Flow Assessment: Judgment and Visual Observation in Instream Flow Studies

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## FEATURE: FISHERIES RESEARCH

Oak Grove Fork study site 3 at baseflow

### Demonstration Flow Assessment: Judgment and Visual Observation in Instream Flow Studies

**ABSTRACT:** The Demonstration Flow Assessment (DFA) method evaluates instream flow benefits using expert judgment and direct observation of habitat during several flows. Early DFA applications were low-effort, qualitative, and vulnerable to well-known biases. We describe a higher-effort, more quantitative DFA (or expert habitat mapping) approach that uses techniques from the judgment-based decision analysis literature to increase objectivity and reproducibility. Specific metrics—habitat types to be quantified visually during flow observations—are designed from appropriate conceptual models of how flow affects target resources. During field observations, patches of each habitat type are delineated by consensus and marked on maps for digital analysis. A case study illustrates these procedures applied to instream flows for salmon spawning and rearing.

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### Evaluación de Regímenes de Caudales: juicio y observación visual en Estudios de Caudal Ecológico.

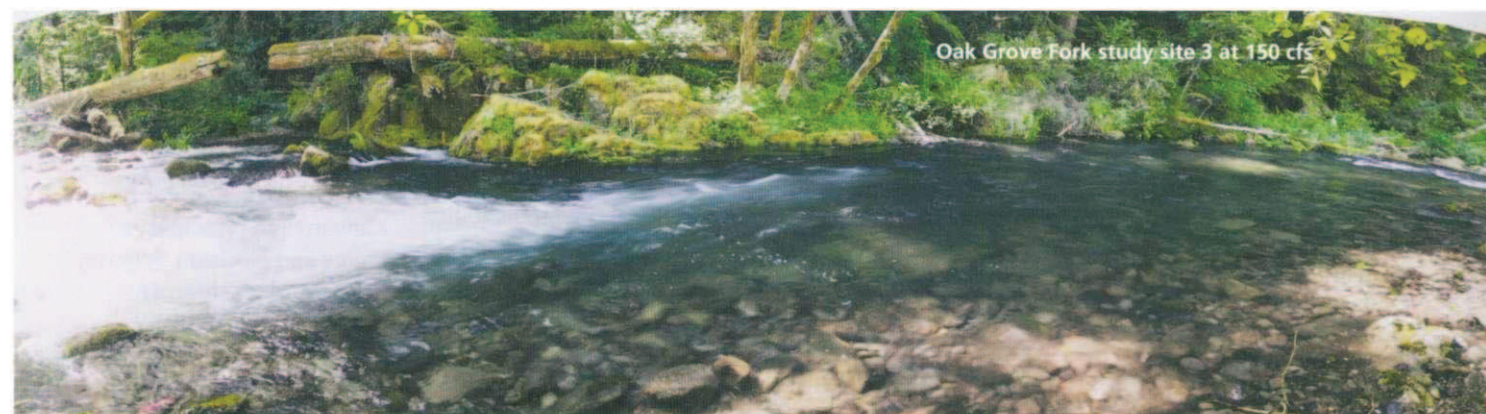
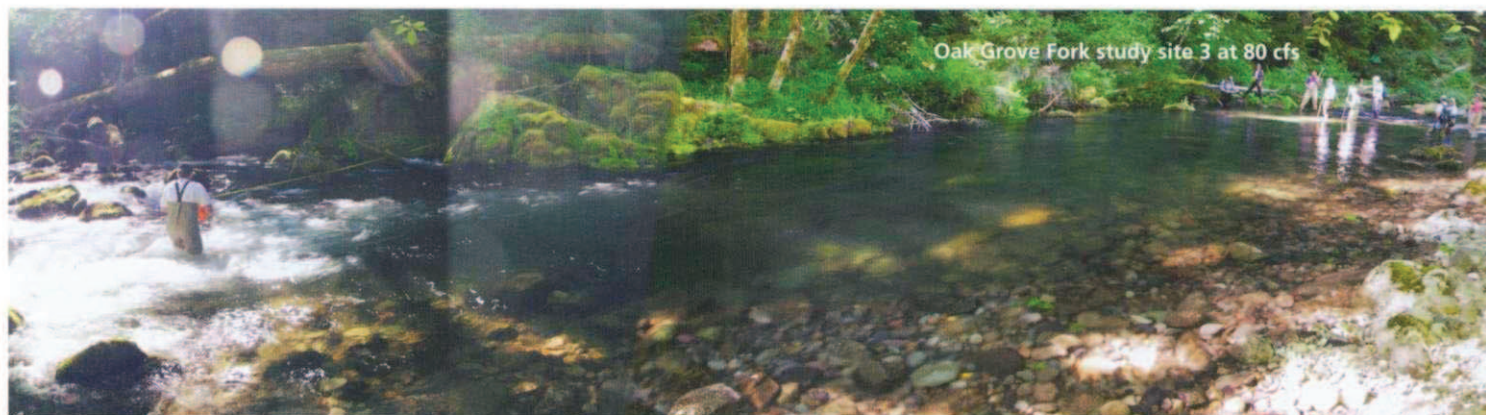
**RESUMEN:** El método de Evaluación de Regímenes de Caudales (ERC) examina los beneficios del caudal ecológico a través del juicio experto y observación directa del hábitat durante diferentes regímenes de caudal. Aplicaciones previas del ERC se caracterizaban por ser poco precisas, cualitativas y vulnerables a sesgos diversos. Con el fin de incrementar la objetividad y reproducibilidad de dichas evaluaciones, aquí se describe una ERC que implica un mayor esfuerzo que la anterior y enfoques de carácter más cuantitativo (Mapeo Experto de Hábitat) obtenidos de literatura sobre técnicas de análisis de decisión basados en juicio. Se diseñaron medidas específicas—tipos de hábitat a ser cuantificados visualmente durante la observación de los caudales—a partir de modelos conceptuales que describen cómo los caudales afectan las especies objetivo. Durante las observaciones en campo y por medio de un consenso, se delinean los parches de cada tipo de hábitat y se trasladan a un mapa para su análisis digital. Un caso de estudio ilustra la aplicación de estos procedimientos al caudal ecológico para el desove y cultivo del salmón.

### INTRODUCTION

Two recent reviews of instream flow methods (EPRI 2000; Annear et al. 2004) noted the increasing use of assessments conducted by observing the stream during several alternative flows, then recommending flows using professional judgment as the primary basis. The Instream Flow Council (Annear et al. 2004) referred to this approach as the "Demonstration Flow Assessment" (DFA) method. Unofficially, the method has

Oak Grove Fork study site 3 at 35 cfs







also been called BOGSAR—"bunch of guys standing along the river"—a name reflecting the method's reputation for subjectivity. The limitations of DFA noted by EPRI (2000; five DFA studies between 1995 and 2000 reviewed) and Annear et al. (2004) arise from its potential subjectivity: because DFA relies more on judgment and less on quantitative tools such as models and data analysis, it can appear unscientific, irreproducible, and susceptible to bias.

In practice, all decision models and analyses depend on professional judgment. Model-based approaches, for example, require judgment in selecting the processes or variables to include in the model, where to place study sites, what parameter values to use, and how to interpret results. Instead of describing alternative instream flow methods as subjective versus quantitative, it is more useful to see them as having different balances between the effort they require and the amount of useful information they provide. Good methods could provide either a modest amount of useful information at low effort, or more information (or more useful kinds of information) for greater effort. Whether low- or high-effort methods are best depends both on how much effort can be expended on a study (what resources—time, expertise, flow, etc.—are available) and on how much more useful information the high-effort methods provide. Early DFA applications tended to be at the low-effort, low information extreme of this balance, with observers using unstructured and holistic judgment to simply rank several alternative flows. Sometimes the choice of low effort appeared motivated not only by a lack of resources but by lack of confidence that higher-effort methods would provide more useful information (EPRI 2000).

The goal of this article is to improve the effort–usefulness balance for DFA studies by recommending procedures that improve credibility and reproducibility. DFA is a "grass roots" method largely lacking in published procedures. Professional judgment and visual observation have long been used for instream flow assessment (e.g., Tennant 1976; Tharme 2003), and several instream flow methods explicitly incorporate judgment (e.g., King and Louw 1998; Failing et al. 2004). There is extensive literature on judgment-based environmental decision-making (e.g., Keeney and von Winterfeldt 1989; Morgan and Henrion 1990; Kadvany 1995), and

balancing effort against usefulness is covered extensively in the judgment and decision-making literature (e.g., Payne et al. 1993). However, little from this literature has previously been applied explicitly to DFA.

Our approach is motivated by two basic principles of human judgment and decision-making. First is "bounded rationality" (Watson and Buede 1987; Payne et al. 1993), meaning that practical decision-making processes are subject to resource limitations; hence, estimation methods useful when resources are high are not necessarily useful when resources are low, and vice versa. Second is that judgments of complex quantities—the population of a large city, gross national product (GNP), etc.—can be improved by disaggregating the quantity into "smaller" or simpler quantities—population by neighborhoods, economic production by region and season—and then aggregating results. One application of this principle is the use of influence diagrams (Merkhofer 1990; Clemen 1996) or other conceptual models when using data and professional judgment to identify a small set of important variables or metrics to evaluate in the field. This kind of articulation and structuring of complex professional judgments also benefits communication by defining the problem more clearly and helps make more efficient use of resources (Merkhofer 1990; Morgan and Henrion 1990).

Judgment of quantities and probabilities is subject to several well-known kinds of bias because we often use a set of common heuristics to make mental estimates. For example, when making unconstrained judgments people tend to assume that an event results from a process when the event represents (i.e., fits a preconceived notion of) the process, to assume events are more likely when examples of them are easily brought to mind, and to estimate values by starting with a known value and adjusting from it, often inadequately (known as "anchoring"; Kahneman and Tversky 1982). No procedures guarantee the elimination of bias (Lichtenstein et al. 1982; Morgan and Henrion 1990), but our approach acknowledges and attempts to avoid these and several other types of error in expert judgment. Biases due to preconceived notions (e.g., the belief that more flow equates to more fish) or stakeholder preferences (e.g., water users benefit from lower instream flows) are reduced by using field evaluation of several

specific metrics developed by consensus from specific conceptual models rather than estimating a single holistic variable such as "overall suitability." Anchoring bias in estimating habitat area is reduced by delineating habitat patches on detailed maps instead of mentally estimating patch area. Susceptibility to group-think motivated by a shared set of desired outcomes (Budnitz et al. 1998) is reduced by including diverse stakeholders in the assessment. Other potential biases we consider include a tendency to underestimate uncertainty in subjective measurements (Morgan and Henrion 1990) and failure to eliminate incorrect observation "habits" developed early in field assessment.

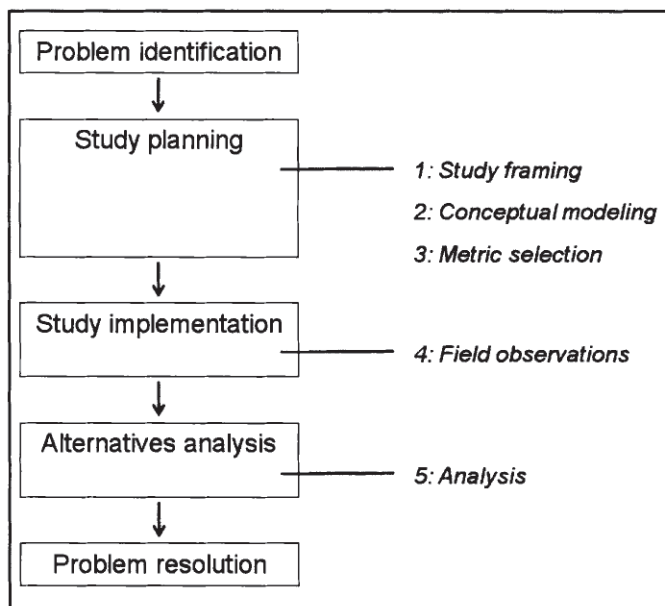
Here we focus on DFA studies in which observers use judgment to visually estimate the area of specific habitat types at several alternative flows. This kind of DFA (sometimes referred to as expert habitat mapping) requires more effort than the earliest DFA studies, but produces results that are more quantitative, reproducible, and therefore useful.

We limit our discussion to assessing instream flow releases for fish. Instream flow decisions typically require assessment of other resources such as recreation, aesthetics, channel maintenance, water quality, riparian vegetation and groundwater, etc. (Annear et al. 2004). DFA is potentially adaptable to some of these resources, but often other tools are required. Similarly, instream flows for fish often vary seasonally; separate DFA studies can be made to evaluate flow needs for different seasons, or other approaches can be used.

## DEMONSTRATION FLOW ASSESSMENT PROCEDURES

Like many other instream flow methods, DFA has the purpose of providing decision-makers with information on how aquatic ecological benefits vary with flow. The key difference between DFA as we describe it here and other popular methods is that DFA does not use mathematical models but it does provide quantitative information on how fish benefits change incrementally with flow. This information is gathered by directly observing and delineating usable habitat during several flows. We describe DFA as five steps that can fit within the Instream Flow Incremental Methodology (IFIM) decision-making process as described by Stalnaker et al. (1995; Figure 1).

**Figure 1.** The IFIM is described by Stalnaker et al. (1995) as having five phases (left column). Our five DFA steps (right column) fit within the IFIM's study planning, study implementation, and alternatives analysis phases.



For each step we describe its objectives, discuss key procedures and uncertainties, and illustrate the step through a case study. (EPRI 2004 provides additional detail.) The case study was conducted below a hydroelectric diversion on Oak Grove Fork of the Clackamas River, Oregon (CIFGS 2003). The Oak Grove Fork study preceded and was independent of our work on DFA procedures, but it illustrates many of our points.

### Step 1: Study Framing

“Framing” defines a study’s basic goals and resources and methods available to achieve them. This step settles issues such as:

1. Who participates in the study and what are their roles?
2. What resources are targeted, and what are their management objectives and priorities?
3. What study sites are to be used, and how will results from each be integrated?
4. Will different flows be recommended for different seasons, for wet versus dry years, etc.?
5. What range of flows are feasible, for either physical or legal and institution reasons? How many flows can be observed during the study (so how precisely must their effects be distinguished?)?

Fundamentally, this framing step should identify the larger decision-making con-

text for the study, and the role of the study in that context (as in Figure 1).

### Key procedures and uncertainties

Selecting how many and which flows to observe is a particularly critical framing issue for DFA. This decision is a judgment that strongly affects study cost and uncertainty, and subsequent study design decisions. Observing more flows increases the definition in the observed relation between habitat and flow (illustrated

at Step 5, below) but increases costs for field observations, analysis, and released water. It may be efficient to select flows adaptively, by first observing only a few flows over a wide range, possibly using coarse and less costly metrics (see Step 3), and then observing additional flows in the most promising range.

### The baseline flow

The flow existing before new flow requirements are instituted should be included in the observations, even if it is unlikely to be a preferred alternative. Habitat quantity at the baseline flow provides a basis for comparison. For example, three alternative flows might be determined by the study to provide 2,000, 2,200, and 2,500 m<sup>2</sup> of habitat. If the baseline flow provided 1,800 m<sup>2</sup>, these numbers would indicate that there is a steady but not spectacular increase in habitat with flow, but if the baseline flow provided 500 m<sup>2</sup> the interpretation would be that any of the new flows provides a major habitat increase.

## Case study

In the study framing step of the Oak Grove Fork case study, the assessment team identified representatives of the company operating the diversion, fisheries management agencies, and non-governmental

conservation organizations. A consulting firm (McBain and Trush, Inc., Arcata, California) was chosen to facilitate the study. The site supports spawning and juvenile rearing of coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*), and the clear objective of fisheries agencies was for instream flows to enhance the production of these anadromous species. The affected stream reach is 7,300 m long, bounded at the upper end by an impassible waterfall and at the lower end by the confluence with the mainstem Clackamas River. Gradient decreases as the mainstem is approached. The assessment team selected two study sites to represent higher and lower gradients. The lower and upper sites were 340 and 500 m in length, totalling 11% of the affected reach.

The range of feasible instream flow releases was established as 0 to 9.2 m<sup>3</sup>/s. The current release of 0 was the baseline; at 0 release, tributary and groundwater inflows produce 0.3-0.6 m<sup>3</sup>/s at the study sites. The upper limit of 9.2 m<sup>3</sup>/s was chosen because it approaches the range of flows that would exist with no diversion at all (the pre-dam median summer base flow is estimated to be 10.2 m<sup>3</sup>/s in average run-off years and 7.7 in dry years), and because observers could not wade safely at higher flows. The study team decided to observe seven flows over this range, including the baseline. This investment reflects a desire to avoid the uncertainties that result when only a few flows are observed and the flow-habitat area relationship is only coarsely defined. One consequence of this decision is that study methods then must be precise enough to distinguish among the seven observed flows.

### Step 2: Developing Conceptual Models of Flow Effects

This step establishes consensus on the most important ways that flow affects the target resources. Conceptual models can be thought of as shared assumptions and explanations for important processes, used to design assessment methods and interpret results.

### Key procedures and uncertainties

For DFA, conceptual modeling is when biological knowledge is most directly applied, as participants discuss and document assumptions for how flow affects the target resources. Conceptual model devel-



opment is a hypothesis-generating exercise, with participants discussing alternative models for how flow affects target resources and considering ways that these models can be quantified in the flow observations.

Many DFA studies depend mainly on the "habitat selection" conceptual model that is widely used in instream flow assessment (e.g., in the PHABSIM model; Bovee et al. 1998). Habitat selection analysis (a subset of "resource selection" analysis; Manly et al. 2002) identifies the kinds of habitat that fish select (or "prefer"), and assumes that alternatives providing more of the preferred habitat are better. The habitat selection concept has important limitations (EPRI 2000; Garshelis 2000; Manly et al. 2002; Railsback et al. 2003), but remains popular for instream flow assessment. Although its appropriateness remains debated, the conceptual model is simple to apply and habitat selection by fish is relatively easy to observe.

A strength of DFA is that studies can also use two other kinds of conceptual models. Mechanistic conceptual models explicitly consider ecological mechanisms by which flow affects fish, such as by scouring or drying redds or producing food. Theoretical conceptual models may be useful for complex resources and when mechanisms are too numerous or poorly understood. For example, if a study's target resource is a native warmwater community, the most useful conceptual model may be the theoretical assumption that biological diversity increases with habitat diversity (Schlosser 1982; Lobb and Orth 1991; Aadland 1993). (Example DFA methods for warmwater communities are in EPRI 2004.)

Each kind of conceptual model has limitations leading to uncertainty in assessment results. For habitat selection modeling, it may be only approximately correct (or even incorrect) that habitat types where fish are most often observed is high-value habitat or that population status varies directly with the area of selected habitat (Railsback et al. 2003). For mechanistic models, uncertainty is increased if key mechanisms are neglected or mischaracterized. For theoretical conceptual models, uncertainty arises from using a very coarse model of complicated aquatic communities.

### Case study

The Oak Grove Fork assessment team used the following sequence of assumptions to define two conceptual models of how flow affects the management goal of enhancing coho salmon and steelhead production. Each assumption was debated and judged by consensus to be a useful approximation.

1. Production of adult salmon and steelhead is enhanced by producing more and bigger smolts.
2. One important way flow affects smolt production is by affecting availability of spawning habitat.
3. Availability of foraging habitat for fry is not an important way flow affects smolt production because fry habitat was assumed sufficient at all flows.
4. Availability of foraging habitat for age-1 coho salmon and age-2 steelhead ("juveniles") is an important way flow affects smolt production. Flows sufficient for age-2 steelhead are also sufficient for age-1 steelhead.
5. The habitat selection approach is useful for defining spawning and juvenile foraging habitat, as highly selected habitat

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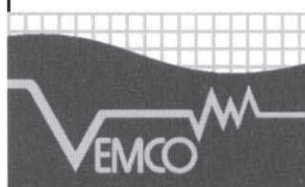


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(habitat types where fish are observed in high densities) is assumed highly productive.

Consequently, the first conceptual model addressed juvenile foraging. This model is that smolt abundance and size increase with the area of highly selected habitat for juvenile foraging. The second conceptual model is that spawning success increases with the area of highly selected spawning habitat.

The team's second conceptual model considers mechanistic effects of flow on spawning. Instream flow was judged to affect the risk of a redd being scoured out by high flows during incubation. Spawning in the deepest parts of the channel places redds at higher risk of scouring during uncontrolled high flows, so spawning habitat is more valuable if it is not in the deepest part of the channel. This conceptual model was based on a mechanism plausible at this site where redds are likely to be created during base flows but then exposed to spill flows.

The case study illustrates several important points. First, the number of conceptual models strongly affects both the study's effort and its uncertainty. More conceptual models, and more realistic models, may seem important for accuracy, and uncertainty will be high if important processes are ignored or misunderstood. Yet too many conceptual models could be too expensive to evaluate and too hard to integrate into meaningful conclusions. Second, while habitat selection is used widely in instream flow assessment, other kinds of conceptual models (here, mechanisms driving redd survival) can be important and easily incorporated.

### Step 3: Selecting Habitat Metrics

Now the specific metrics that will be quantified during the field observations of Step 4 are defined. Habitat metrics are the specific types of habitat that observers will quantify during the demonstration flows, and are defined from the conceptual models.

#### Key procedures and uncertainties

The habitat metrics are essentially models of ecological processes, so avoiding uncertainty requires consideration of three ecological modeling issues: repro-

ducibility, spatial resolution, and biological resolution.

Reproducibility is essential for any scientific study and especially important for overcoming DFA's reputation for subjectivity. Reproducibility can be provided by:

- Documenting assumptions about factors affecting habitat selection, such as the size of fish being evaluated, their activity (e.g., daytime foraging, nighttime foraging, spawning, winter sheltering), and site conditions that affect habitat selection.
- Using enough habitat types to represent the conceptual models but not so many that it is difficult to classify observations. (Think about organizing music at a record shop. Using more categories gives customers more information about the music in each bin, but also makes it harder to decide which bin a particular recording should be in.) Hierarchical habitat classification schemes (e.g., Vadas and Orth 1998) may allow more types to be used with less difficulty categorizing habitat.
- Documenting the characteristics of each habitat type, whether those characteristics are based on judgment, data, or other information.
- Ensuring that habitat types can actually be distinguished during observations. Depth and substrate type, for example, might be useful for defining habitat types in clear, wadeable streams but unobservable in deep, turbid rivers. In large and turbid streams, metrics could be based on such variables as the size and relative frequency of habitat unit and cover types (Lobb and Orth 1991; Aadland 1993).
- Ensuring that metrics do not change during an assessment. "Creep" in the definition of habitat types is likely as observers gain experience. Practice using the habitat metrics (e.g., during observation of the existing base flow) is essential for avoiding creep; ambiguous metrics or protocols can be identified and changed.

In some DFA studies, observers used published PHABSIM habitat suitability criteria to supplement their judgment. While supplementing judgment with "hard data" is attractive, PHABSIM criteria should be used judiciously. The traditional

PHABSIM "criteria curves" that assume effects of habitat variables (often, depth, velocity, and substrate type) are independent, range from 0.0 to 1.0, and are easy to use during DFA observations. However, this simplified approach to habitat criteria is outdated (Vadas and Orth 2001; Manly et al. 2002) and has been found less accurate than more sophisticated approaches (e.g., Ahmadi-Nedush et al. 2006). Experienced observers may have a more nuanced understanding of how habitat variables interact to affect fish. Because habitat preferences vary with factors including fish size, competition, temperature, and turbidity (Railsback et al. 2003), PHABSIM criteria should be avoided if they are not from clearly similar sites (or if it is not clear what kind of conditions they represent).

Spatial resolution is critical in any ecological study (e.g., Starfield and Bleloch 1986; Manly et al. 2002) because ecological relationships can change with scale. Using an inappropriate resolution or mixing resolutions is a common, major, yet poorly understood source of uncertainty in instream flow studies (Railsback 1999). Corsi et al. (2000) introduce scale issues in habitat modeling, Scott et al. (2002; Part 2) cover them extensively, and Railsback (1999) illustrates their relevance to instream flow assessment.

The spatial resolution of a habitat metric is the area over which habitat conditions are aggregated during observations. For territorial fish such as drift-feeding salmonids, the feeding territory size is an appropriate minimum observation area. Quantifying habitat at finer scales than a territory size is inappropriate because habitat value to the fish is determined by all the conditions throughout its territory, not just at any spot within the territory, and because a patch of otherwise good habitat is not useful if it is too small to support one fish. (An isolated 0.1 m<sup>2</sup> patch with perfect velocity and depth for adult trout feeding should not be counted as habitat because it is much smaller than a trout's territory.) Many warmwater fish use entire channel units (pools, riffles), so their habitat metrics should be at the channel unit scale (e.g., Vadas and Orth 1998). Spatial resolutions are often specified only approximately, and habitat can be quantified over areas greater than (but not less than) the chosen spatial resolution.

Biological resolution refers to how many metrics are used to represent how many resources. The Oak Grove team realized,



as have others (e.g., Loar et al. 1985; Studley et al. 1996), that habitat-based methods cannot predict how different fish groups respond to flow when those groups use the same habitat. If, for example, adults of two trout species both use the same foraging habitat, doubling the area of this habitat will probably not double the abundance of both species; instead, new habitat may be dominated by one species. The inability to resolve between fish groups with similar habitat requirements means that an instream flow study has limited biological resolution. If habitat metrics for two groups of fish cannot be clearly distinguished, then the groups must be combined in the assessment.

#### Case study

The Oak Grove team arrived at three habitat metrics: (1) coho salmon and steelhead spawning habitat—the area of habitat judged to be high quality for spawning, (2) coho salmon foraging habitat—the area of habitat judged to be highly selected by age one and older coho salmon for foraging, and (3) steelhead foraging habitat—the area of habitat judged to be highly selected for foraging by age two and older steelhead. Reproducibility, spatial resolution, and biological resolution were considered explicitly.

Concerning reproducibility, the team decided that their metrics should not include separate delineation of “marginal” and “good” habitat, but instead to delineate only clearly good habitat. This decision reduces the number of judgments and the opportunities for subjectivity, keeps field observations from being overly complex, and avoids, in the analysis step, the difficult problem of comparing marginal habitat to good habitat. Further, the team agreed that habitat metrics should be based on relatively well-defined and observable variables. Therefore, judgment of spawning habitat should be based mainly on availability of appropriate depths, velocities, and gravel sizes; and judgment of foraging habitat should consider proximity to velocities that provide drift food, availability of velocity shelters to reduce swimming speeds, and proximity to hiding cover.

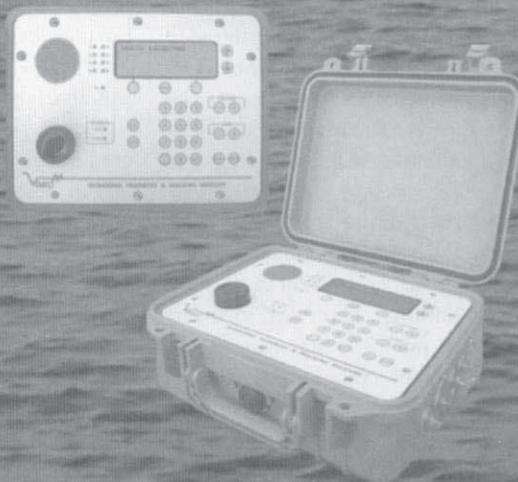
The assessment team explicitly discussed and selected a minimum size for delineated habitat areas, essentially the spatial resolution of field observations. They recognized that very small patches of habitat occur in complex habitats (e.g., small eddies in boulder gardens), but trying to identify such small patches would be impractical and uncertain, and very small patches are of less biological value (e.g., too small to support even one fish). Hence, they chose a minimum patch size of two square meters.

Concerning biological resolution, the team agreed that spawning habitat for coho salmon and steelhead could not be distinguished, so one spawning habitat metric applied to both species. However, they also agreed that coho salmon generally use lower velocities than steelhead, so separate foraging habitat metrics are needed.

#### Step 4: Designing and Conducting Field Observations

In Step 4 the habitat metrics are quantified at the different demonstration flows. Decisions include determining who participates in the observations, how to quantify the habitat metrics, and which types of uncertainty to address and how.

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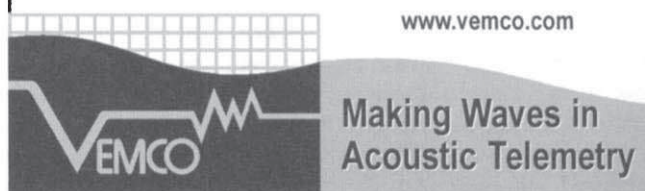
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## Key procedures and uncertainties

Delineating habitat metrics by marking patches of each type on a base map has been found (especially in the Oak Grove Fork study) to let field observers quantify the metrics rapidly and with a level of precision judged to be adequate, while avoiding anchoring biases associated with simply judging the size of each patch. Much of Step 4's effort and cost therefore is likely to be devoted to developing detailed and accurate base maps. Uncertainties and inaccuracies in field observations can be reduced by providing maps with an abundance of landmarks, e.g., boulders and trees.

Selecting the team of field observers is critical for both the study's scientific credibility and for its success as a decision-making process. Limiting observers to a few highly qualified scientists may cause some stakeholders to feel excluded and reduce their confidence in, and commitment to, the results. But including all stakeholders regardless of expertise could compromise the credibility of the results even if the team as a whole is well-qualified. Any stakeholders whose representatives in the overall decision process are not well-qualified for the field observations could choose to recruit field observers they believe to be both qualified and not biased against the stakeholder's values. Establishing expertise thresholds for observers early in the study (in Step 1, or early in Step 4) is recommended to reduce the potential for conflict over inclusion. Criteria for inclusion on the observer team should include familiarity with the target species and the biological processes of the conceptual models identified in Step 2, and field experience observing these species and processes. Finally, team members need to remember that they are collecting data, not making decisions.

During observations, it is desirable to encourage all members of the team to express their judgment instead of letting a single person or perspective dominate; a continual dialog provides checks and balances. One way to encourage participants to think independently is for each person to delineate an area's habitat on their own map, then develop a consensus delineation, all before moving on to the next area. When the group cannot arrive at a consensus in delineating a patch of habitat, separate delineations can be made for each opinion. If disagreements are few, they

may have no significant effect on results. If disagreements are many and consistent, then it may be necessary to analyze separate delineations produced by different participants; causes of disagreement (e.g., consistent differences in judgment of what constitutes highly selected habitat) should be documented for consideration in the Step 5 analysis. If disagreement in habitat delineation leads to different analysis results (e.g., different trends in how habitat metrics vary with flow; differences in which flow produces the highest metrics), the analysis can treat the differences as a source of uncertainty that must be considered in the instream flow decision.

An observation team needs a leader to draw the group's habitat delineation onto the map, mediate disagreements, forge consensus, and keep the team moving. It is typically best to explicitly select a leader that the participants feel is fair and able to address challenges reliably, instead of leaving this role to be filled by the most forceful personality. Consensus formation will depend both on leadership and a team goal of developing the best possible analysis.

Concern about uncertainty in DFA usually focuses on the visual observations, because these are the key difference from model-based approaches. Several sources of uncertainty could affect the field observation step, though they may not be the most important uncertainties overall. (1) Observers can be biased by preconceived notions or desired outcomes, although the use of specific shared metrics should reduce this uncertainty. (2) Habitat metrics can be inconsistent, changing over time or varying among observers. (3) There is error and variability in habitat quantification, e.g., uncertainty in visual observations due to habitat varying too gradually to delineate habitat types sharply. (4) There can be error in measuring and controlling the flow rates during observations (a challenge at Oak Grove Fork because of groundwater inflows and a lack of good gaging sites).

Some DFA studies may choose to quantify uncertainty in the habitat area estimates. Whether and how to do so must be decided in advance of field observations because the decision affects how data are collected. There are several potential approaches. (1) Uncertainty in the area of each habitat patch can be quantified, e.g., by estimating the minimum and maximum extent of each patch. (2) Uncertainty in the entire study can be estimated by quantifying habitat several times. (3) Bias and

uncertainty among observers can be evaluated by having each participant delineate habitat separately (which can also help calibrate individual or group judgments).

## Case study

The case study delineated habitat metrics by drawing patch boundaries on highly detailed base maps. Available aerial photographs were unusable as base maps because overhanging trees obscured the channel. (Reflected sunlight is another common problem.) McBain and Trush, Inc. used a balloon-mounted photography system (Floatograph Technologies, Napa, California); three technicians photographed the study reach from an elevation of about 15 m, during a low flow. The photographs were digitally rectified and assembled into composites (Figure 2). Developing the maps required several person-weeks of research, field time, and computer processing, especially to rectify and combine approximately 200 photos.

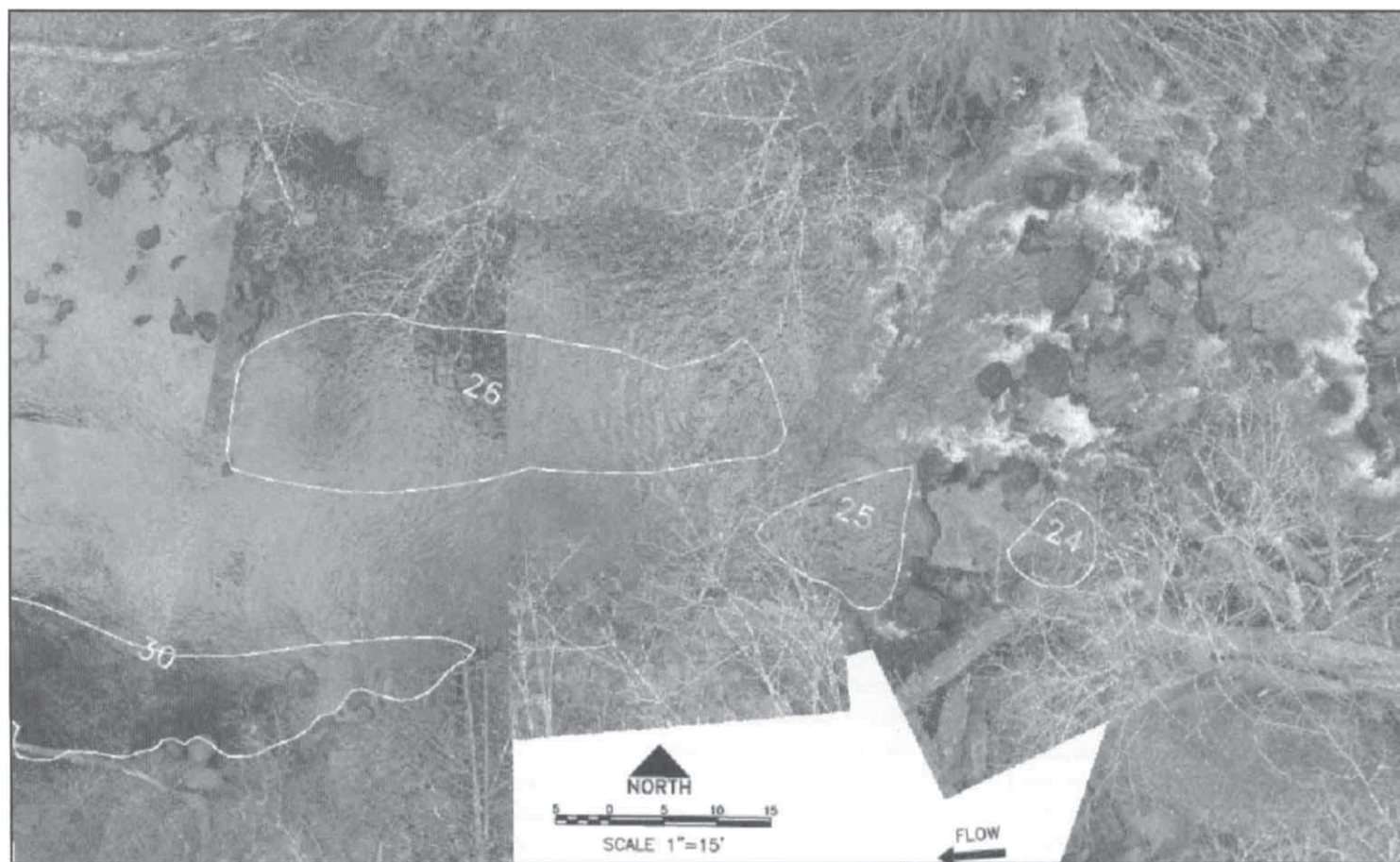
The assessment team considered which among its members had sufficient experience observing the target fish to participate in the habitat delineation, and determined (using unreported criteria) that all members were qualified. The habitat delineations were carried out by separate teams for each site. Two demonstration flows could be evaluated each day (including the time for changing and measuring the dam release) and the seven flows were observed within four consecutive days. The group discussed each patch that contained habitat as defined by the three metrics, and the facilitator drew the patch on the base map after its boundaries were agreed upon. Field assistants measured depth and velocity as requested, allowing team members to re-calibrate their mental estimates of these variables and their judgments based on them.

## Step 5: Analysis

The final step analyzes field data with the objective of producing the assessment results, a summary of how well each alternative instream flow meets aquatic resource management objectives identified in the study framing step. If field data on uncertainty in habitat quantification were collected, they are also analyzed at this point.



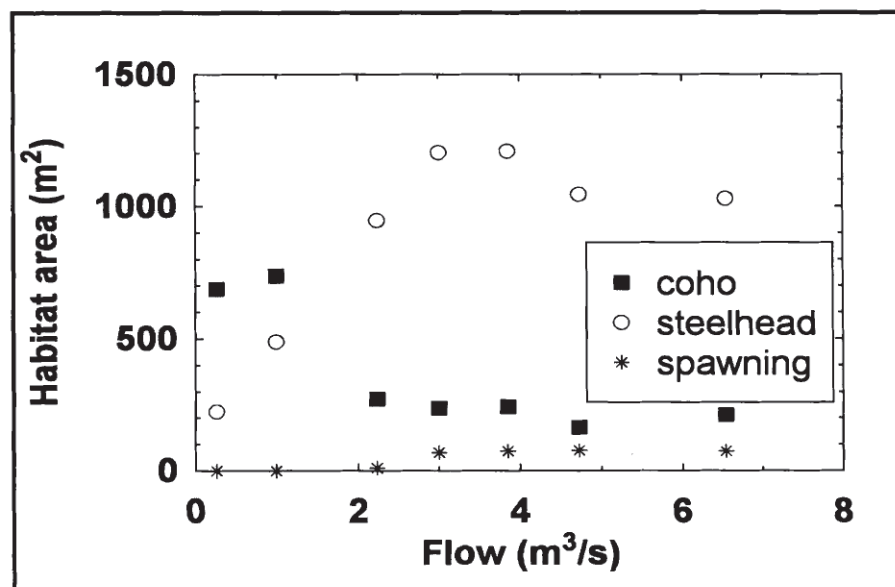
**Figure 2.** Example base map and field habitat delineation from the Oak Grove Fork study. The white curve is a digitization of patches of coho salmon foraging habitat delineated by observers at a demonstration flow of 2.3 m<sup>3</sup>/s, in a small portion of the study site. (Figure reproduced from CIFGS 2003.)



### Key procedures and uncertainties

The analysis of DFA results to recommend instream flows is much like analysis of PHABSIM results. Relations between flow and habitat may differ strongly among target species and life stages (e.g., between coho salmon and steelhead in the case study, below) and these differences must be resolved. In all habitat-based studies, the relation between habitat area and population response is a fundamental uncertainty. This approach cannot predict population responses so its use implies an assumption that trends in habitat area produce similar trends in population. The assessment team can use a mixture of quantitative analysis, qualitative judgment, and consensus formation to make final flow comparisons. The team's judgment should be guided by the conceptual models developed in Step 2 and thoroughly documented. Final instream flow recommendations, of course, consider all the resources affected by flow.

**Figure 3.** Example results of the Oak Grove Fork DFA study, for one study site. The graph shows the total area of habitat for the three metrics (foraging habitat for coho salmon and steelhead; spawning habitat) at each of the seven demonstration flows.





## Case study

For analysis, McBain and Trush, Inc. digitized the habitat patches delineated in field observations so patch areas could be computed and summed. Then results from each study site (e.g., Figure 3) were weighted by the river length represented by the site, and combined into total metrics for entire reach.

The case study analysis found that some habitat metrics varied sharply and inconsistently as flow increased (Figure 3). For example, coho salmon habitat increased as flow increased from 0.3 to 1.0 m<sup>3</sup>/s, then decreased sharply as flow further increased above 2 m<sup>3</sup>/s, and then increased again between 4.7 and 6.5 m<sup>3</sup>/s. Interpolating a "best" flow for each species and life stage would have been quite uncertain if fewer flows had been observed.

## CONCLUSIONS

In deciding whether DFA is an appropriate method for an instream flow assessment, its following characteristics deserve consideration.

1. Because DFA does not require hydraulic simulation, assessment of habitat with complex hydraulics is more feasible. However, high depth, velocity, or turbidity can limit how observations are made (e.g., by limiting how much of a site can be waded, or how accurately habitat metrics can be estimated).
2. A DFA study can assess long reaches fairly quickly, whereas approaches requiring hydraulic modeling are often constrained to a small number of transects.
3. Being explicitly judgment-based, DFA can encourage open consideration and revision of the many assumptions and judgments that are involved in any instream flow study.
4. Uncertainty in field observations of habitat metrics is often of special interest in DFA studies. There are several ways this uncertainty can be quantified.
5. DFA facilitates use of mechanistic and theoretical conceptual models in addition to, or instead of, habitat selection.
6. A DFA study can quantify habitat at only a few discrete flows, so assessment

of other flows requires interpolation between, or extrapolation from, results from the observed flows.

7. DFA requires extensive field time by a number of people, in addition to the effort of developing maps and analyzing results.
8. DFA could be difficult to apply where flows are not controlled by a dam.

Dependence on judgment in environmental decision support studies is unavoidable and does not necessarily reduce the quality of decisions; judgment is necessary because data and models are inherently uncertain and decisions inherently involve values (Gregory et al. 2006). The DFA procedure we describe is intended to control subjectivity and uncertainty by using established ecological and decision analysis frameworks. Biological knowledge and judgment are applied and documented, especially in the conceptual modeling and metric development steps. Explicitly defining, delineating, and quantifying habitat metrics helps make results quantitative and defensible.

Our case study was high-effort and produced extensive data and analysis. However, lower-effort (but carefully designed) DFA studies may be as appropriate as any other method for target resources so complex or poorly understood that higher effort produces little more useful information. If we lack reliable mathematical models of how instream flow affects a resource (e.g., the biodiversity of an unstudied warmwater community), then a low-resolution DFA—perhaps based on theoretical conceptual models—might be appropriate, especially if it frees resources for purposes such as monitoring and watershed restoration.

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