Uncertainty and Instream Flow Standards

By Daniel T. Castleberry, Joseph J. Cech Jr., Don C. Erman, David Hankin, Michael Healey, G. Mathias Kondolf, Marc Mangel, Michael Mohr, Peter B. Moyle, Jennifer Nielsen, Terence P. Speed, and John G. Williams

Several years ago, *Science* published an important essay (Ludwig et al. 1993) on the need to confront the scientific uncertainty associated with managing natural resources. The essay did not discuss instream flow standards explicitly, but its arguments apply. At an April 1995 workshop in Davis, California, all 12 participants agreed that currently no scientifically defensible method exists for defining the instream flows needed to protect particular species of fish or aquatic ecosystems (Williams, in press). We also agreed that acknowledging this fact is an essential step in dealing rationally and effectively with the problem.

Practical necessity and the protection of fishery resources require that new instream flow standards be established and that existing standards be revised. However, if standards cannot be defined scientifically, how can this be done? We join others in recommending the approach of *adaptive management*. Applied to instream flow standards, this approach involves at least three elements.

First, conservative (i.e., protective) interim standards should be set based on whatever information is available but with explicit recognition of its deficiencies. The standards should prescribe a reasonable annual hydrograph as well as minimum flows. Such standards should try to satisfy the objective of conserving the fishery resource, the first principle of adaptive management (Lee and Lawrence 1986).

Second, a monitoring program should be established and should be of adequate quality to permit the interim standards to serve as experiments. Active manipulation of flows, including temporary imposition of flows expected to be harmful, may be necessary for the same purpose. This element embodies the adaptive management principles that management programs should be experiments and that information should both motivate and result from management action. Often, it also will be necessary to fund ancillary scientific work to allow more robust interpretation of the monitoring results.

Third, an effective procedure must be established whereby the interim standards can be revised in light of new information. Interim commitments of water that are in practice irrevocable must be avoided.

The details of the monitoring program should vary from case to case. Where protection of particular populations is emphasized, the monitoring program should produce estimates of population size. However, population estimates by themselves often will not provide useful guides to action. This is particularly likely with anadromous fishes such as salmon, where populations of adults depend on harvest, ocean conditions, and other factors not related to instream flows, and populations of juveniles are hard to estimate accurately. Managers will learn more if the monitoring program also includes a suite of indices of the growth, condition, and development of the target species. These indices need to be interpreted with awareness of the complications arising from variations in life history patterns within and among populations. However, the indices and population estimates together will offer the best evidence of the mechanisms by which flows affect the survival and reproduction of individuals and thus the persistence of populations.

Daniel T. Castleberry *is a fishery biologist with the U.S. Fish and Wildlife Service, Stockton, California.* ***Joseph J. Cech Jr.*** *and* ***Don C. Erman*** *are professors in the Department of Wildlife, Fish, and Conservation Biology, University of California-Davis.* ***David Hankin*** *is a professor in the Department of Fisheries, Humboldt State University, Arcata, California.* ***Michael Healey*** *is a professor at the Institute for Resource and Environmental Studies, University of British, Columbia, Vancouver.* ***G. Mathias Kondolf*** *is an associate professor of environmental planning, Department of Landscape Architecture, University of California-Berkeley.* ***Marc Mangel*** *is a professor with the Environmental Studies Board, University of California-Santa Cruz.* ***Michael Mohr*** *is a statistician for the National Marine Fisheries Service, Tiburon Laboratory, Tiburon, California.* ***Peter B. Moyle*** *is a professor in the Department of Wildlife, Fish, and Conservation Biology, University of California-Davis.* ***Jennifer Nielsen*** *is a research fisheries biologist for the U.S. Forest Service, Pacific South, and visiting scientist, Hopkins Marine Station, Department of Biology, Stanford University, Pacific Grove, California.* ***Terence P. Speed*** *is a professor in the Department of Statistics, University of California-Berkeley.* ***John G. Williams*** *is a consultant at 875 Linden Lane, Davis, CA 95616; jgwill@wheel.dcn.davis.ca.us.*

The 1990 "Hodge Decision" in the case of *Environmental Defense Fund v East Bay Municipal Utility District* [Superior Court of Alameda County (California) No. 425955], with which several of us have been involved, exemplifies this approach. Judge Richard Hodge set flow standards for the American River, a major tributary to the Sacramento, that are intended to protect chinook salmon and other public trust resources from diversions by the East Bay Municipal Utility District. However, Hodge recognized the "fundamental inadequacy" of existing information regarding flow needs, so he retained jurisdiction and ordered parties to the litigation to cooperate in studies intended to clarify what the flow standards should be. Experience with these studies motivated the April 1995 workshop.

Our claim that there is now no scientifically defensible method for defining flow standards implies that the Physical Habitat Simulation Model (PHABSIM), the heart of the Instream Flow Incremental Methodology (IFIM), is not such a method. We have divergent views on PHABSIM. Some of us think that, with modification and careful use, it might produce useful information. Others think it should simply be abandoned. However, we agree that those who would use PHABSIM, or some modification of it, must take into account the following problems: (1) sampling and measurement problems associated with representing a river reach with selected transects and with the hydraulic and substrate data collected at the transects; (2) sampling and measurement problems associated with developing the suitability curves; and (3) problems with assigning biological meaning to weighted usable area (WUA), the statistic estimated by PHABSIM. Estimates of WUA should not be presented without confidence intervals, which can be developed by bootstrap methods (Efron and Tibshirani 1991; Williams 1996). Nor should any analytic method become a substitute for common sense, critical thinking about stream ecology, or careful evaluation of the consequences of flow modification, as has sometimes happened with the implementation of the IFIM.

Establishing instream flows involves both policy and science, and scientists and resource managers have challenging roles in the process. Managers need to accept the existing uncertainty regarding instream flow needs and make decisions that will both protect instream resources and allow development of knowledge that will reduce the uncertainty. Scientists need to develop and implement monitoring methods that will realize the potential of adaptive management, and develop the basic biological knowledge that will provide a more secure foundation for decisions that must balance instream and consumptive uses of water.

References

Efron, B., and **R. Tibshirani.** 1991. Statistical data analysis in the computer age. Science 253:390–395.

Lee, K. N., and **J. Lawrence.** 1986. Adaptive management: learning from the Columbia River basin fish and wildlife program. Environmental Law 16:431–460.

Ludwig, D., **R. Hilborn**, and **C. Walters.** 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17, 36. (See also the "Forum on Science and Sustainability," Ecol. Appl. 3:4 [1993]).

Williams, J. G., ed. In press. Workshop on instream flow standards, University of California-Davis, April 7, 1995. Water Resources Center Report 89, Centers for Water and Wildlands Resources, University of California, Davis, CA 95616.

———. 1996. Lost in space: minimum confidence intervals for idealized PHABSIM studies. Trans. Am. Fish. Soc. 125:458–465.