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Hydrology and Water Resources Planning

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John Chaffrey, Chair
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95821-0100

Dear Mr. Caffrey:

Here are some comments on the draft Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The comments focus on the proposed biological monitoring, and particularly on matters related to the "cold freshwater habitat" and "fish migration" beneficial uses. The comments are based primarily on my experience with efforts to monitor the effects of various levels of flow on the public trust resources of the Lower American River, under the *EDF v. EBMUD* continuing jurisdiction, and my thoughts about how that could be better done. The comments begin with a list of general principles, with some commentary, and then provide some specific suggestions about the application of the principles. Please note that in making these comments I am speaking only for myself, and not the *EDF v. EBMUD* parties.

1. Monitoring should evaluate the condition of organisms as well as populations. Studies of oil field monitoring in the Santa Barbara Channel have demonstrated that variables describing attributes of individuals, such as growth rates, are more useful than variables describing attributes of populations or chemical-physical variables (Osenberg et al. 1994). I found this to be true on the American River, and the same presumably applies to the Bay/Delta. The several advantages of studying individual organisms as well as populations are well summarized in the concluding paragraph of Osenberg et al.'s paper:

> The observation that individual-based parameters may yield more powerful assessments is troubling given the rarity with which they are measured in field assessments. Care must be taken to guard against only considering parameters that yield low probabilities of demonstrable results (e.g., chemical-physical and population attributes), and inclusion of individual-based parameters could greatly increase the sensitivity of assessment studies (citations omitted). However, the need to investigate individual-based parameters goes far beyond power considerations; it is the individual based (and demographic) parameters that provide the mechanisms that underlie changes at the population (and therefore community) level. Furthermore, these individual-based parameters provide an explicit connection with detailed laboratory studies that focus on individuals and mechanisms of toxicity. What is needed are more realistic studies of individual-based effects under field conditions combined with both mechanistic laboratory studies and field assessments of population-level consequences. Recent advances with individual-based models (citation omitted) provide an explicit framework for making these fundamental linkages among environmental chemistry, physiology, and population ecology (citation omitted). Such models

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provide a powerful, mechanistic approach to assessing impacts on natural populations and complement the traditional approach of monitoring environmental impacts.

2. Monitoring should clarify the effects of water temperature on salmon smolts.
When the EPA declined approval of the 1991 Bay/Delta Plan, one of the shortcomings noted was the absence of scientifically supportable temperature standards on the San Joaquin and Sacramento Rivers, to protect emigrating salmon smolts. Participants in the technical workshops that discussed the proposed EPA standards agreed that high water temperatures do decrease smolt survival in the Delta, but noted the lack of good information on the matter (Kimmerer 1994). Similarly, the effects of elevated water temperature on the growth and smolting of juvenile chinook was identified as an area of major uncertainty in the trial of *EDF v. EBMUD*. Appropriate monitoring of the condition of emigrating chinook can shed significant light on these questions, although complementary laboratory experiments, to establish cause-and-effect relationships that would allow more robust interpretation of the monitoring results, would still be needed.

3. Monitoring should incorporate up-to-date statistical methods.
The statistical methods used by the USFWS in past coded-wire tag studies have been authoritatively criticized (Speed 1993, Kimmerer 1994); Baker et al. (in press) present a more sophisticated analysis. Generally, the computational power of modern computers has permitted the development of new statistical methods that allow more useful information to be developed from the monitoring program (Jongman et al. 1987; Efron and Tibshirani 1991), and approaches specifically designed to detect environmental impacts of human activity are under development and debate (Osenberg and Schmitt 1993). Hilborn and Ludwig (1993) urge that Bayesian statistics provide a more useful guide to management of natural resources than do the more traditional frequentist methods. Because these methods are new, they are not familiar to most working biologists or hydrologists outside of research institutions, so specialists should be consulted.

4. Monitoring should try to answer multiple questions.
Just as a good move in chess attacks and defends at the same time, so a good monitoring program should develop new knowledge, at the same time that it checks the performance of management measures in light of existing knowledge. In addition, by addressing multiple scientific questions, a monitoring program can develop data that can allow management questions to be addressed from several different points of view. This is important, because field observations of single variables will almost never provide unambiguous answers.

5. Monitoring methods should be evaluated by simulations.
Experience with ecological studies shows the wisdom of simulating measurement programs. Analysis of simulated data that include realistic amounts of uncertainty can help determine whether a proposed monitoring program will provide useful answers to the questions it is designed to address, and is much less expensive than a trial-and-error approach (Hilborn and Mangel, in prep.).

6. Monitoring should be complemented by modeling.
To be useful, monitoring data must be converted into information, and one of the best ways to do this is to model the underlying biological processes that are thought to underlie the

variables being monitored. In an important sense, modeling is simply a formal way of thinking about the data, and many different kinds of models can be used. As with statistics, ecological modeling is a rapidly developing field that has been stimulated by the decreasing cost of computer computations (Mangel and Clark 1988), and experts at research institutions should be consulted.

7. Monitoring programs should have close supervision.
In my experience, monitoring produces better and more useful data if the person responsible for interpreting the data is closely associated with the data collection. This gives the interpreter a better understanding of the strengths and weaknesses of the data, and promotes careful work by the crews.

8. The monitoring program should provide for contingencies.
Extra sampling during unusual events can sometimes produce particularly valuable information. By their nature, unusual events are hard to plan for, but funding for contingency sampling can be made part of the modeling program. The utility of contingency sampling probably depends upon close supervision of the monitoring.

9. The monitoring program should take advantage of the intellectual resources of California's universities.
The State of California already has on its payroll some of the best statisticians and biologists in the world, and it is simply poor public policy not to involve them with the very difficult problems that the monitoring program needs to clarify. This can be done in a variety of ways, and which is appropriate will vary from issue to issue. Generally, the best results will come from work focused on areas of overlap between scientific and management interests; hiring graduate students simply as cheap labor is a poor idea. The University of California Water Resources Research Center is now headed by an aquatic biologist, Don Erman, and is well situated to arrange and oversee academic participation in the program.

10. Monitoring conducted under the Delta Agreement should be coordinated with monitoring mandated by the CVPIA.

Let me try to describe a monitoring program that would embody the ideas suggested above.

Chinook smolts would be sampled, by trawls or by traps, at various locations in the Delta and lower Sacramento and San Joaquin rivers. Releases and recoveries of tagged smolts would continue. However, subsamples of tagged and untagged fish would also be subjected to various analyses to evaluate their condition and extract other useful information.

Both the CVPIA and the proposed Delta standards call for doubling the natural production of chinook salmon. To tell whether this goal is being realized, the monitoring program must be able to distinguish between naturally produced and hatchery produced fish, which will require marking hatchery fish in some way. Clipping the adipose fin from all or a constant fraction of hatchery produced fish would be a simple way to do this; however, the information gained would be limited. Much more information could be gained from a program that depends on examination of the growth increments in otoliths (ear stones).

The otoliths are made of alternating layers of protein and calcium carbonate that in cross section look like tree rings, when properly prepared and viewed through a microscope. The otoliths start to form in embryonic chinook, and almost invariably, there is a band of narrow rings associated with hatching. Typically, there is another band of narrow rings associated with emergence from the gravel, or first feeding. Volk et al. (1990, 1994) describe an economical method for "bar-coding" the otoliths of juvenile chinook salmon with short-term variations in water temperature, by which the hatchery of origin and other information can be encoded. Then, examining the otoliths of smolts sampled in the Delta would not only distinguish hatchery and naturally produced fish, but would also produce information about the hatching dates and growth rates of naturally produced smolts, and about the relative performance of various hatchery programs. Even without special treatment, Zhang et al. (1994) found that they could distinguish wild chinook salmon from hatchery salmon released as smolts with reasonable accuracy, based on the greater variance in the widths of otolith increments in wild fish, and an extra "growth-check" associated with the release of hatchery fish. Zhang et al. also describe a method for preparing the otoliths of adult chinook, so that examination of otoliths could also be used to distinguish wild and hatchery fish from spawning runs. The age and other life-history information about the fish could also be determined using this approach, so that more could be learned about the conditions that lead promote survival to spawning. Life history models (Mangel 1994) can provide a framework for the interpretation of such data.

In juvenile chinook salmon in field conditions, one "ring" is laid down every day (Castleberry et al. 1994), so the otoliths can be used to determine the age of the fish. Accordingly, length at age can be used as a measure of long-term growth rate, and with some additional assumptions an absolute long-term growth rate can also be estimated. Simulations indicate that the importance of the assumptions decrease rapidly with the length of the fish. [Unfortunately, otoliths seem not to produce reliable estimates of short-term growth rates. There is a general relation between growth rate and the width of otolith increments, but the width of the increments apparently depends on metabolic rates, rather than growth *per se*. Stressfully high water temperatures disrupt the relationship between metabolic rates and growth, so the recent otolith increments of a fish sampled in the Delta in late spring might be wide, even though the fish was temporarily not growing.]

The effect of water temperature on smolt survival through the lower rivers and the Delta is recognized as an important issue. Previously, this has been approached by comparing the recoveries of tagged smolts that were released under varying conditions. However, because of sampling problems and other complications, this approach has not produced good answers. Laboratory analyses can provide better information, in effect by interrogating the sampled fish about their level of thermal stress.

One way that high temperatures affect organisms is by damage to proteins. The functioning of many proteins depends upon the protein molecules being folded in particular ways, with particular three-dimensional geometries. Heat, which makes the molecules vibrate more rapidly, can simply shake proteins out of shape. Like other organisms, fish respond to stressfully warm conditions by increased production of "heat shock" or "stress" proteins, that are involved in the processes by which proteins are folded into their functional shapes in the cells. The higher levels of stress proteins allow organisms to survive temperatures that would otherwise be lethal, and is at least one mechanism behind the well-known effect of "acclimation" on the lethal water temperature for juvenile salmon (Mosser and Bols, 1988; for a general introduction to stress proteins, see Welch, 1993).

In the monitoring program, assaying the level of stress proteins in tissues from the sampled smolts would provide a measure of the heat stress to which they have been exposed. Apparently, reliable assays can be done; Jennifer Nielsen and Paul Levine at the Stanford University Hopkins Marine Station are starting to apply this approach to juvenile steelhead, and could provide details. [Note that various toxins can also cause proteins to lose their functional shape, and also promote high levels of stress proteins; however, the presence of such toxins should also be a concern of the monitoring program.]

High temperatures also affect organisms by increasing metabolic rates. For a given caloric intake, this decreases the amount of energy that fish can store as lipids, or else forces the fish to draw on stored lipids to make up an energy deficit. This effect of temperature on fish can be assayed by measuring total non-polar lipid contents, as was done on the American River by Castleberry et al. (1991, 1993), or by measuring blood triglyceride levels, as was done on the Trinity and Klamath rivers by Foott (1994). [Liver glycogen levels can also be measured by histological techniques (e.g. Okihiro et al. 1992) but because of the expense of preparing histological samples this approach is less attractive, unless concerns about toxins otherwise justify histological studies.]

Lipid levels are also useful as a measure of "smolt quality." Presumably, the transition from fresh to salt water is a challenging experience for juvenile chinook, and smolts with more stored energy have a better chance of survival. Studies of hatchery fish support this assumption (see references in Castleberry et al. 1993). Use of the smolt survival index (SSI) in monitoring is based largely on the assumption that the survival of tagged hatchery smolts is similar to the survival of wild fish. The various measures of condition suggested above provide a check to that assumption. If the condition of the tagged smolts tended to differ from that of other smolts, the assumption would be challenged, and *vice versa.*

As another measure of smolt condition, sampled smolts should be evaluated by field autopsy methods, as described by Foott (1990), to check for evidence of diseases that also could cause poor growth or low lipid levels. Similarly, stomach contents should be analyzed to determine whether lack of food may be compromising the condition of the sampled fish. Shackley et al. (1993) propose analysis of sodium, potassium, and calcium ratios as indicators on undernourishment, which could be assayed if lack of food appears to be a problem.

In my opinion, this kind of multi-faceted approach offers the best hope for rapid development of the information needed to balance the competing demands on water from the Sacramento and San Joaquin rivers. The appropriate level of effort for the various monitoring methods suggested above should be determined by experience, based for example on amount of variability in the results. The draft plan notes that monitoring may be limited by the available funding. This is unfortunate, and in my opinion short-sighted. There is no doubt that a good monitoring program will be expensive, but it will be much less expensive than continued controversy, which is the alternative.

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