DESIGN OF LONG-TERM ENVIRONMENTAL MONITORING PROGRAMS: APPROACHES TAKEN AND LESSONS LEARNED IN THE CHESAPEAKE BAY PROGRAM

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Long-term environmental monitoring programs are established for a number of reasons: *e.g.* to determine the relative status of environmental conditions in various regions of a study area; to determine whether management goals are being achieved in these regions; and to determine whether there are any long-term trends in key indicators of environmental quality. The initial design of the monitoring program should be made with specific program goals in mind, but the effectiveness of the program should be re-evaluated and optimized once a sufficient empirical data base has been accumulated. The power and robustness of the program should be assessed in the context of the monitoring regime, the characteristics of the data being collected, and the statistical models employed in order to determine whether scientific and management goals can be achieved.

A long-term environmental monitoring program was initiated in 1984 to track water quality and the condition of living resources in the extensive watershed of Chesapeake Bay, USA. Following six years of data collection, the monitoring program was re-evaluated for sensitivity and effectiveness in achieving programatic goals, as well as for cost-effectiveness. Empirically based simulation models were employed to assess a number of monitoring data sets. The initial focus was upon the capacity of the monitoring effort to detect true trends (power assessments) without excessive probability for producing Type I errors or "false alarms" (robustness assessments). Additional analyses were conducted to determine the power to detect attainment of water quality goals on an annual basis, as well as to determine the optimal program design needed to address both the "status" and "trends" questions for biological monitoring efforts with specific management goals.

Assessments were conducted for thousands of water quality and biological parameter-region combinations. An asymptotic relationship between sensitivity in trend detection and program duration was observed to occur for most data sets after approximately 6-8 years. The power of various sampling regimes was also assessed and, for most parameters, monthly sampling provided nearly as much sensitivity as twice a month collections: a 10-20% change occurring over a time of at least six years would have a high probability of being detected by either regime. Likewise, the reduction of collections from semimonthly to monthly still allowed adequate sensitivity in annually tracking regions of the Bay for attainment of water quality goals. Since differences in sensitivity between the two regimes were negligible and both would allow management oriented data quality objectives to be achieved, the monitoring regime was changed to monthly and the resources that were saved were reallocated to enhance other aspects of the program.

Design issues related to the balance between status and trend assessments were evaluated in a similar manner for certain biological monitoring efforts. The benthic biological monitoring program involved a seasonal sampling regime involving fixed stations located throughout the Bay and its major tributaries. However, power simulations and other assessments indicated that the optimal regime would involve approximately equal sampling efforts allocated towards stratified random sampling (for characterizing the status of a region) and fixed station sampling (for detecting long-term trends). The assessments indicated that this optimal regime could be approached without additional resources by reallocating half of the seasonal fixed-station sampling effort to the randomized design, providing that the collections were made during spring and summer, the seasons shown to be most sensitive both for trend detection and for biological discrimination between stressed and nonstressed conditions of environmental quality. The loss in power for long-term trend detection was negligible.

The overall approach to monitoring program design, re-evaluation, and refinement employed in the Chesapeake Bay Program will be discussed. Also to be presented are ancillary data analysis approaches such as techniques to separate the impacts of natural factors (e.g. seasonality, river flow, stratification, etc.) from anthropogenic effects on long-term trends in water quality, methods for presenting "status" estimates of environmental quality, and indices developed to summarize the relative environmental health of biological communities.